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THE DRIVING FORCES OF LAND USE/COVER CHANGE IN THE UPSTREAM AREA OF THE NENJIANG RIVER

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ABSTRACT: Based on the Landsat 5 and Landsat 7 TM images, the land use/cover change was detected in the upstream area of the Nenjiang River between 1995 and 2000. With the spatial analysis techniques of GIS, the maps of land use degree and its change within this period were produced. To identify the causes of changes, elevation and slope were regarded as the main natural influencing factors and were transformed from coverage format to grid format within GIS. The Thiesson polygon method was used to the spatial allocation of socio-economic factors including human population, livestock numbers, mechanizing power of farming and the nearest distance from the changed pixel to the trunk stream and to main settlements, thereby the spatial relationship between land use degree change and socio-economic factor variation was analyzed. According to results of the spatial correlation, the determinants of changes in land use/cover, i. e. elevation, slope, population density change, livestock increase were extracted quantitatively in this area. At last, the spatial multi-linear regression model of land use degree change was developed as follows: $\triangle La = 11.037 - 4.512 \star$ elevation $- 0.298 \star$ slope $+ 0.292 \star \triangle$population $+ 2.596 \star \triangle$livestock.

KEY WORDS: the upstream area of the Nenjiang River; land use degree change; Thiesson polygon method; driving forces

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1 INTRODUCTION

Since the early 1990s, the acceleration of land use/cover change(LUCC) has spurred renewed concerns about the role of land use change in driving many environmental problems. Research on the causes and consequences of regional LUCC has been the important part of global environmental change studies. Some previous reports sought to explain the determining factors of land use and its spatial dependency through mathematical statistics method or multi-scale GIS techniques in China (ZHANG *et al.*, 1999; CHEN *et al.*, 2000b).

With its abundant forest, land and water resources, the area of the Nenjiang River valley is one of the important lumber products and commodity grain bases in China. Land use/cover change in forest and agriculture in this area over the last few decades was considerable and fast-paced development, which resulted in environmental degradation issues. The studied area covers an area of 80 820km^2 of the middle and upper reaches of the Nenjiang River, including the

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Nenjiang County of Heilongjiang Province, Oroqen Autonomous Banner and Daur Autonomous Banner of Morin Dawa of Hulun Buir League in Inner Mogolia. The Gan River, the Nuomin River and the Duobukuer River are the main branches of the Nenjiang River. The average altitude is between 400m and 500m. The landscape is topographically heterogeneous. The north part of this area consists of low hills, while the plain are the dominant landform types in the south. Before 1949, most area was covered with the forest and grassland. However, under the pressure of population growth and excessive land exploitation, large area of forest land were destroyed or reclaimed. With the rapid development of economy in recent years, the acceleration of deforestation has resulted in a reduction in forest coverage from 61.11% to 58.12% during the period of 1995 - 2000. Because the amount of natural vegetation has been continually dropped, the capacities of flood peak reduction and runoff adjustment weaken; thereby the regional eco-environmental status has been exacerbated severely. In the summer of 1998, there was a cataclysm over the whole drainage area of the Nenjiang River. The long duration and expansive area of the flood are rare in its history and was closely related to the intensity of land use/cover change (ZHANG, 2000). Based on the techniques of remote sensing and GIS, not only the dynamic monitoring of the LUCC can be performed rapidly but also its main driving forces can be analyzed effectively, which is very significant to the ecological management of this watershed.

2 DATA AND THEIR PROCESSING

The available satellite imageries were the Landsat 5 TM (or Landsat 7 ETM +) images covered the studied area in the corresponding seasons of 1995 and 2000. To analyze the remote-sensing data, MGE (Modular GIS Environment) software was used to process the images. Visual interpretation, followed by screen digitizing was applied to obtain vector data of land use in 1995 and 2000. The methods are as follows (The General Technique Group, 1998; ARC/INFO 8.0 documentation online, 1982 - 2000):

1) Referring to the latest edition of administrative maps, the county boundaries of the topographic maps on 1: 100 000 scales were marked and corrected. After the errors check being finished, the control points were selected from the topographic maps and the administration boundaries were manually digitized. The software MGE was used to produce the false color composite and strengthened the images. Then, geographic reference was carried out so that the county boundaries and images were matched perfectly.

2) Under the environment of Coreldraw 7.0 software , according to the characteristics of the images and field investigation, the interpretation key was defined, thereafter visual interpretation, followed by screen digitizing were adopted to obtain the vector land use/cover maps in 1995 for each county and stored in ARC/INFO coverage format. After being transformed to the Albers Equal Area Conic Projection, the coverages were edited and merged into a single coverage.

3) The images received in 2000 were rectified to the basic images in 1995. Comparing the images in 1995 and 2000 within ArcView GIS 3.2, the conversions among land use types were detected and changed polygons were positioned and sketched. Then, the outcome data were written to ARC/INFO coverage and corrected. Therefore, the land cover change map was produced over the period of 1995 - 2000.

3 DATA MINING

3.1 The Calculation of Land Use Degree

The land use degree is a comprehensive index, which reflects quantitatively not only the natural characteristics of land but also the interaction between human and environmental elements (LIU, 1996). In this paper, the land use maps (coverage format) in 1995 and 2000 were transformed to land use degree map (GRID format) by calculating the land use degree of each cell (1km × 1km, the same below) within ARC/INFO 8.0 (TANG, 2000) . With the support of map algebra, the distribution of land use degree variation was also produced. The land use degree index is a value ranging between 1 and 4, which represents the land use intensity at regional scale. Considering the convenience of data processing within GIS, the index was multiple by 100 after being evaluated according to corresponding grades. The index model was calculated with the formula as follows:

$$L_a = 100 \times \sum_{i=1}^{n} A_i \times C_i$$

$$L_a \in [100, 400]$$

where L_a indicates the comprehensive index of land use degree; A_i is the grade of land use type i, C_i represents the area percentage of land use type i, then the change of land use degree ΔL_a between two points of time can also be calculated from the following equation, in which L_{at0} and L_{at1} is land use degree at the moment of t_0 and t_1 respectively:

$$\Delta L_a = L_{at1} - L_{at0}$$

3.2 The Generation of Natural Factor Maps

Based on the available contour data at the scale of 1: 25 0000, the TIN data layer was generated by using the ARCTIN command in the ARC/INFO 8.0 environment. Then, TINLATTICE was applied to transfer TIN to the elevation and slope in GRID format. The input value of elevation GRID and slope GRID were reclassified so that the calculation was easier to be carried out. The remap-table is shown in Table 1.

Table 1 The remap table of elevation and slope GRID

Elevation(m)	Reclassified-code	Slope (degree)	Reclassified-code
0 - 200	1	0 - 3	1
200 - 300	2	3 - 5	2
300 - 500	3	5 - 8	3
500 - 800	4	8 - 15	4
800 - 1500	5	15 - 25	5
> 1500	6	25 - 90	6

3.3 The Methods of Spatial Allocation of Socio-Economic Data

3.3.1 The population distribution estimation

Assuming that the area of a settlement is positively related to the number of its population under certain natural and socio-economic condition, the population of the studied area was reallocated. First, the location of the settlements including all the villages and towns was extracted from the vector land use map in 1995 and 2000 respectively. Second, the Thiesson polygon method was adopted to create the boundary of village (CHEN *et al.*, 2000a; HUANG *et al.*, 1989; MARAIN, 1999); thereby the total population of the district was allocated to each settlement based on the area of the settlement. The following equation was developed to simulate the population of each settlement:

$$P_i = P_t / A_t \times A_i$$

where P_i is the population of settlement i; P_t represents the total population of the district; A_t is the total area of the district; A_i is the area of settlement i.

On the basis of above formula, the vector coverage of population was obtained and spatialized into GRID Modular with the support of ARC/INFO8.0. After that, the simulation of the change of population(Δ poppulation) was conducted with the map algebra rules for 1995 - 2000 period.

3.3.2 The allocation of livestock and mechanizing power of farming

In a similar way, the spatial distribution of livestock and that of the mechanizing power of farming were fulfilled. According to the interpreted land use/cover map, the area of grassland was obtained. After the number of livestock for each grassland parcel being calculated, the livestock change grid layer (Δ livestock) was produced within the period. Δ force, the change layer of the mechanizing power of farming grid, was created in the same way too.

3.4 The Nearest Distance from Changed Pixel to the River and to Main Settlements

Based on the TM images, the trunk stream of the Nenjiang River was sketched. The label points of the changed polygons were extracted and a point layer was produced. We conducted the NEAR command to estimate the nearest distance from changed points to the trunk stream or the main settlement. Then, value of the distance was assigned to each changed polygon and transferred to data layers, Distance-to-river and Distance-to-settlement, in GRID format. Table 2 lists the economic statistical data between 1995 - 2000.

Table 2 The economic statistical data between 1995 - 1999

County and Banner	Population of town (10^4)		Population of village (10^4)		Mechanizing power of farming (10^4kw)		Number of livestock (10^4)	
	1995	1999	1995	1999	1995	1999	1995	1999
Morin Dawa	7.08	4.97	20.90	23.84	19.00	25.31	6.49	3.84
Oroqen	28.58	25.83	5.76	5.87	15.00	16.03	2.06	1.56
Nenjiang	17.20	17.90	30.80	31.40	40.70	55.30	11.88	7.09
Total area	52.86	48.70	57.46	61.11	74.70	94.64	20.43	12.49

Source: Statistical Yearbook (1996 - 2000), The Statistic Bureau of Heilongjiang Province and Inner Mongolia.

4 THE SPATIAL CORRELATION ANALYSIS OF DRIVING FORCES

The spatial correlation function was applied to calculate the correlation coefficient among different factors (ARC/INFO 8.0 documentation online, 1982 - 2000). The matrix of coefficient was shown in Table 3. Most of coefficients were small, which indicated that the relationships between the independent variables were weak. $\triangle L_a$ was negatively related to elevation and slope, while as there existed some certain positive relationship between $\triangle L_a$ and $\triangle$population or $\triangle$livestock. According to the result, the coefficients between $\triangle L_a$ and Distance-to-settlement, Distance-to-river were lower and there was no direct relationship between $\triangle L_a$ and $\triangle$ force. Therefore, the variance of elevation, slope, population and livestock were the leading driving forces influencing the spatial change of land use degree.

5 THE ESTABLISHMENT OF SPATIAL REGRESSION MODEL OF CHANGE OF LAND USE DEGREE

On the basis of above correlation analysis, $\triangle$ force, Distance-to-river and Distance-to-settlement showed slight impact on the change of land use degree ($\triangle L_a$), while the GRID elevation, GRID slope, GRID $\triangle$population and GRID $\triangle$livestock were chosen as the independent variables, owing to their higher correlation coefficients, GRID $\triangle L_a$ was regarded as the dependent variable. Then, using the SAMPLE and REGRESSION functions, the following multi-linear regression model was developed to explore the possible natural and human impacts on land use change.

$$\triangle L_a = 11.037 - 4.512 * \text{elevation} - 0.298 * \text{slope} + 0.292 * \triangle\text{population} + 2.596 * \triangle\text{livestock}$$

From the model, there was linear relationship among the spatial variation of land use degree with the change of elevation, slope, population density and the numbers of livestock during the period of 1995 - 2000. The future land use could be estimated if the growing tendency of population and the level and scale of livestock were to know.

6 DISCUSSION

The spatial allocation of socio-economic data was a hot-spot problem. In this paper, the Thiesson polygon method was used to the spatial reallocation of so-

Table 3 The matrix of correlation coefficient among driving forces

	Elevation	Slope	ΔPopulation	ΔLivestock	ΔForce	Distance-to-settlement	Distance-to-river	ΔL_a
Elevation	1							
Slope	0.40212	1						
ΔPopulation	-0.40274	-0.18312	1					
ΔLivestock	-0.06119	-0.03443	-0.00619	1				
ΔForce	-0.00931	-0.00112	-0.00753	0.00081	1			
Distance-to-settlement	0.02184	-0.00484	-0.01609	0.01501	0.00031	1		
Distance-to-river	0.02078	0.00198	-0.02329	0.00050	0.00005	0.49200	1	
ΔL_a	-0.19214	-0.10436	0.07856	0.04674	-0.00087	0.02235	0.02567	1

cial-economy, thereby the spatial relationship between land use degree change and socio-economic factor variation was detected within GIS. According to the results, it is an effective method for the settlements whose graphs are regular and distributes evenly in space. As for the analysis of relationship between the grassland and livestock, the yields of grass were various and the shape of each plot of grassland was irregular, so the precision of the model was limited. To some extent, the method proposed in the paper was appropriate for estimating the change of land use degree at mesoscale while lacking of enough statistical data.

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