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Land cover change and its social driving forces in the upper Min River basin, China

Yonghua Zhao*, Xiaojing Liu

College of Earth Science & Resources, Chang'an University, Xi'an 710054, China
Email: yonghuaz@chd.edu.cn

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ABSTRACT

land use and land cover change (LUCC) and the forces that drive it are important subjects in global change research. Spatiotemporal characteristics and social forces behind LUCC in the upper Min River basin, in Sichuan Province, China, were analyzed using questionnaire data and the Landsat TM and ETM + data from 1986 to 2000. The results showed that LULC changed remarkably from 1986 to 2000, especially from 1995 to 2000. The conversion between LULC types mostly occurred among cropland, woodland, and grassland. Woodland area decreased by 3.526%, and cropland and grassland area increased by 0.352 and 1.575% respectively from 1986 to 2000. Water bodies and unused land increased by 0.380 and 0.161% from 1995 to 2000. Changes in built-up land area were negligible over the study period. However, Principal component analysis (PCA) revealed that social policy and population factors were the principal drivers of land cover changes from 1986 to 2000 in the upper Min River basin. PCA was suitable for performing quantitative analysis driving factors behind LUCC.

Keywords: Dynamic change; Land cover; Min River; Driving forces

1. Introduction

Land use and land cover (LULC) is of vital importance in the study of human alteration of the Earth's land surface [1,2]. Research on land use and land cover change (LUCC) is a prominent subject in the study of global change and has been designated as a core field of study by the International Geosphere-Biosphere Program and the International Human Dimensions of Global Environmental Change Program [3–5]. The goal of LUCC Program is two-fold: firstly, to gain a clear understanding of the current state and the processes of LUCC at local, regional, and global; and second to understand the natural and anthropogenic forces underlying LUCC [6,7]. The driving forces behind LUCC have received attention from many researchers worldwide. Qualitative descriptions have frequently been used to analyze the drivers of LUCC; however, quantitative analyses based on social factors at the household level have rarely been performed [8,9].

Remote sensing is a powerful tool for monitoring land use dynamics [10,11], and can provide detailed

*Corresponding author.

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information about large-scale deforestation and the spatial distribution and extent of land use changes [7,12]. Geographic Information System (GIS) techniques also provide a widely accepted tool for examining spatially referenced objects over time by comparing time-series maps prepared from satellite data [13]. The used of overlaying change-detection techniques in GIS has been especially effective for understanding land cover transformations [7,14–15].

The Min River is a first-order branch of the Yangtze River. In addition to its economic and ecological significance in southwestern China, the Min River is the primary water resource in Sichuan Province, especially in the Aba area, where it influences agricultural and industrial production. Rapid environmental changes have taken place in the watershed surrounding the upper Min River basin, in northwestern Sichuan Province. This area is considered to be representative of typical LUCC at the regional level in China. LUCC in the upper Min River basin has played a significant role in the stability and economic development of this semiarid region. However, anthropogenic alterations of the landscape have resulted in a shift in the structure and composition of LULC types over the recent decades. In the present study, Landsat TM and ETM + data were used to study the patterns in land cover dynamics in the upper Min River basin from 1986 to 2000. The results of this analysis will be helpful in determining reasonable uses of the water resource and effective strategies for protection of land resources in the region.

2. Materials and methods

2.1. Study area

The study area included five counties (Wenchuan, Maoxian, Lixian, Heishui, and Songpan) in Sichuan Province, China, occupying an area of approximately 24 740.51 km^2 area (lat 102° 59′ to 104° 14′ N, long 31° 26′ to 33° 16′ E) (Fig. 1). The landscape is highly dissected with irregular, heterogeneous topography, and supports a variety of flora and fauna because of its unique geographic and climatic conditions. Annual rainfall is low (avg. 490.7–835.8 $mm\,y^{-1}$) with low inter annual variation, and annual transpiration is high (avg. 1,100–1,600 $mm\,y^{-1}$), relative humidity ranges from 62 to 72%. Most of the region's precipitation falls between June and August, and a pronounced dry season occurs between October and March. The altitude ranges from 870 to 6,251 m with the highest elevation (the Siguniang peak) located in Wenchuan County.

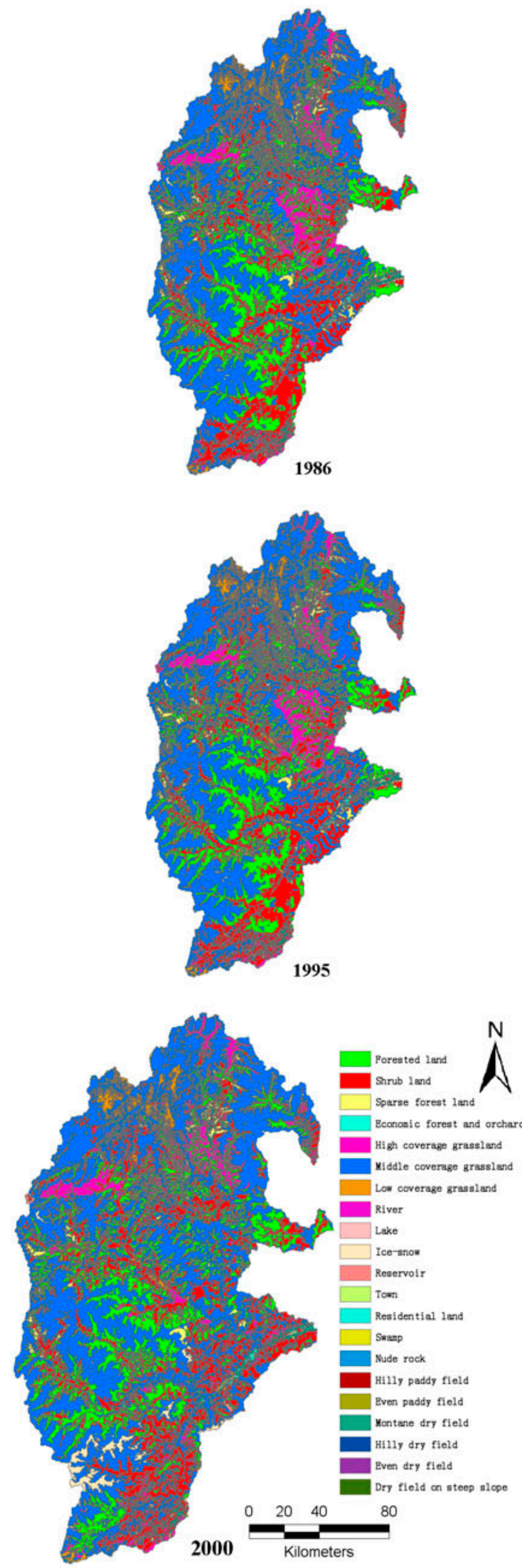

Fig. 1. LULC types in the upper Min River basin.

2.2. Data processing

In order to describe the modern processes in Earth's surface and to predict further trends of land use change, a database of spatial and temporal characteristics must be built [3]. Seasonal Landsat TM and ETM + images covering the study area in 1986, 1995, and 2000 were used to extract the LULC type and topographic maps and regional thematic land use data were consulted. The integration of remote sensing and GIS has been widely used to monitor the changes in LULC, and that method was used in the present study [16].

The first step was to classify the LULC types. A three-level classification system was adopted according to the Chinese National Technical Standard for Land-Use Survey [17], statistical data, attributes of land resources and land utilization, and field investigation data. The first level consisted of six land use types, cropland, woodland, grassland, water bodies, built-up land, and unused land. The second level contained 17 land use types, classified primarily according to natural attributes of landscape. The third level was subdivided into eight categories according to geomorphic landscape features. Twenty-one LULC classes were defined from the Landsat images and aggregated into six main categories (Table 1).

Landsat TM and ETM + images from 1986, 1995, and 2000 were classified using a supervised classification method with ERDAS software. The classification was performed on decorrelated images by combining three spectral bands based on principal components. The image enhancement facilitated the identification of several types of land use, particularly in agricultural areas, and the maximum likelihood algorithm based on training zones was used for the classification [18]. Repetitive land-cover maps make it possible to observe the transitions between LULC types [19]. Successful overlay of the images not only displays LUCC at the macro scale (i.e. regional) but also enables analysis of changes at the microscale (i.e. town). The 1995 image was the benchmark, and the maps (images) were overlaid to clarify the LULC history; the 1986 map was overlaid on the 1995 map and the 1995 map on the 2000 map). Finally, a transition probability matrix was adopted to conduct a trend analysis of LULC dynamics [20]. A survey of the study area was made to correlate the image characteristics and ground features, and an interpretive key was developed based on the relationships between the image properties and survey information. The image elements including tone, texture, size, shape, pattern, shadow, association, and physiography were considered in the supervised classification. The redundant ground data on different land cover types were used to check the interpretation. These interpreted maps were digitized and stored in a GIS domain using ArcGIS software. The LULC type maps for the three periods were converted into grid format. For all maps, the smallest interpretable resolution was 30×30 m.

2.3. Interview investigating

A series of hypotheses were developed about the causes of land cover change in the upper Min River basin in a questionnaire, and many preliminary group interviews were conducted with long-term residents to develop and refine these hypotheses. The objective of these interviews was to elicit farmers' perceptions of the causes of land cover change between 1949 and 2000. Land cover change maps were used to select residential areas in which to conduct interviews, and 105 participants were interviewed at different villages. The participants included 100 elders ($\geqslant$50 years old), and five individuals in their 40s; 95 were men and 10 were women; 71 were Tibetan, 20 were Chiang Chinese, and 14 were Han Chinese. All interviewees had lived in the upper Min River basin for at least 40 years. The interview focused on specific changes in the land cover change maps. Participants were queried on their livelihood system, major changes in human populations, livestock populations, their land

Table 1
Vegetation type map simplified for change detection

No.	Vegetation types mapped	Vegetation types grouped for change detection
1	Hilly paddy field, Even paddy field, Montane dry field, Hilly dry field, Even dry field, Steep slope dry field	Cropland
2	Forested land, Shrub land, Sparse forest land, Forest plantation and Orchard	Woodland
3	High coverage grassland, Middle coverage grassland, Low coverage grassland	Grassland
4	River, Lake, Reservoir, Ice-snow	Water bodies
5	Town, Residential land	Built-up land
6	Swamp, Nude rock	Unused land

use patterns, and forest/grassland/cultivated land area from 1949 to 2000. For each change, interviewees were asked to explain why the changes had occurred and what types of land cover were affected. The 105 valid questionnaires were collected and analyzed using principal component analysis (PCA) in SPSS V.16.0.2 software (SPSS, 2008).

3. Results and discussion

3.1. Changes in land cover

LULC class maps were created for 1986, 1995, and 2000 (Fig. 1). The results indicated that areas of the first level types of LULC were altered to different degrees. Areas of cropland and grassland increased from 1986 to 2000, and the increase from 1995 to 2000 was more pronounced than that from 1986 to 1995. Woodland area decreased from 1986 to 2000, especially from 1995 to 2000; water, built-up land and unused land areas increased primarily from 1995 to 2000 (Table 2). Among the increasing land cover types, grassland area increased by 38,000 ha, a proportional change in area of approximately 0.394% from 1986 to 1995 and 1.181% from 1995 to 2000 (Table 2).

At the subclassification level of grassland areas, area with a middle level of coverage increased by 80,000 ha, but areas with high and low coverage decreased by nearly 45,000 ha. Large areas with high coverage of grassland were converted into middle levels of coverage, which demonstrated that there were some issues such as excessive pasturage, inefficient grass management, etc. Cropland increased by 8,500 ha, and approximately 8,000 ha of dry montane field were present between 1995 and 2000. Town land and residential land increased slightly by 10 and 50 ha, respectively, which probably was related to some small patches not being extracted and counted. This result also showed that there was a low population density in the region. Changes in water bodies and unused land area occurred mainly from 1995 to 2000, increasing by 0.38 and 0.161%, respectively. One reason for the change in area of water bodies was that local governments constructed a large number of hydroelectric plants, most of which were built by diverting river water through artificial channels to new areas where the topographic fall was very large. Another reason for the change in water surface area was that the Landsat TM and ETM + images were captured in the summer, which was the rainy season in the upper Min River basin, and many floodplains were inundated; these areas were displayed as lakes in the Landsat TM and ETM + images. Unused land area increased because local governments developed tourism resources and some natural disasters occurred. Woodland area decreased by more than 80,000 ha from 1986 to 2000, especially from 1995 to 2000, a proportional decline of 0.411 and 3.115% during the two respective time periods (Table 2). Changes in land use occurred mainly among cropland, woodland, and grassland. Compared to the period between 1986 and 1995, the alterations that occurred from 1995 to 2000 were more significant.

Table 2
Area change of LULC in two time stages (%)

	1986–1995	1995–2000
Cropland	0.016	0.336
Woodland	−0.411	−3.115
Grassland	0.394	1.181
Water		0.38
Built-up land	0.002	0.001
Unused land		0.161

The probability matrix of LUCC revealed the direction and sources of different changes in land use type. Land use change in the study area occurred in both positive and negative directions (increases and decreases in area) among cropland, forest land, shrub land, forest plantation land, grassland, and built-up land. Table 3 shows the increases and decreases in land use areas; the ultimate direction of LUCC did not alter.

3.2. The dynamic change of LULC

The change in quantities of land resources could be described by a land use dynamic index (LUDI), which could quantitatively explain the rate of LUCC and help to predict trends in LUCC. The objective of time series analysis was to study the change of the amount, structure, mode, and intensity of LUCC with time. The LUDI was selected to explain the changes of land use type in some study areas during defined time range. This LUDI was calculated from the following equation [3,21]:

$$\mathrm{LUDI} = \frac{U_{\mathrm{b}} - U_{\mathrm{a}}}{U_{\mathrm{a}}} \times \frac{1}{T} \times 100 \tag{1}$$

where T represents time range (year), U_{a} and U_{b} are the original area of a given land use type at the beginning and end of the research period, respectively. When T is counted by year, the LUDI represents the annual change rate for a given land use type in the study area.

The results of LUDI (Table 4), which were calculated for the first-level LULC types, showed greater

Table 3
Transfer matrix of LUCC (ha)

Land-cover type	Cropland	Woodland	Grassland	Water	Built-up land	Unused land
1986–1995						
Cropland		157.9	331.8		1.1	
Woodland	111.2		4061.2	0.2	2.1	
Grassland	3.9	14189.7		0.1		0.1
Water						
Built-up land	1.4	12.0	31.4			
Unused land						
1995–2000						
Cropland		2570.4	4851.5	0.1	33.1	
Woodland	5546.3		133855.6	3478.5	29.2	1622.8
Grassland	10252.6	65056.1		21,451	5.2	2354.4
Water	0.3	1.5	81.2			
Built-up land	12.6	22.9	5.6			
Unused land		0.1	1.3			

Table 4
Dynamic change of LUCC in two time steps (%)

	1986–1995	1995–2000
Cropland	0.07	2.21
Woodland	−0.10	−1.13
Grassland	0.09	0.38
Water		22.87
Built-up land	0.43	0.34
Unused land		46.71

LUDI values for all land use types from 1995 to 2000 than from 1986 to 1995, except for built-up land. The explanation behind the large LUDI values for cropland, water bodies, and unused land was that the total area of these land uses was less than that of other types. Table 4 also shows that changes in LULC were adversely influenced by human activity and occurred primarily from 1995 to 2000.

3.3. The driving factors of land cover change

At present, the study of causes, processes, and consequences of LUCC is one of the main research topics in landscape ecology [22–23]. There are many driving factors behind LUCC; this study primarily analyzed social factors. Seven social factors from 105 questionnaires were analyzed with correlation analysis and the correlation coefficients were all $\geqslant 0.3$, or the Kaiser-Meyer-Olkin value was over 0.7 [24]. Therefore, it was appropriate to use the data for analysis of land cover changes by PCA. In general, when the cumulative contribution rate from PCA is $>75\%$, the statistical results are considered to provide good representation [25]. The first principal component resulted in a cumulative contribution rate of 83.2%. The results of the PCA (Table 5) showed that a series of policies related to land use in the upper Min River basin was the most important driving factor behind LUCC, and total population size was the second. In this light, policy and population factors are the main focus of discussion here.

Many local and national policies were established from 1949 to 2000, including the commune period, the Cultural Revolution, the Great Leap Forward, the deforestation, the agriculture and stockbreeding, the family-contract responsibility system, the reformation and opening up, and the Natural Forest Conservation Program. During the commune period, some off-farm works (such as planting of fruit tree and bunge prickly ash) were not encouraged, even

Table 5
The cumulative contribution rate of different social factors by PCA

Social factors	Cumulative contribution rate
Policy	0.968
Total population	0.932
Total crop production	0.578
Education	0.838
Economy	0.915
Income and expense	0.523
Natural disaster	0.786

though they were helpful to raising income. The community leaders organized the village (or community) labor-force for large-scale agricultural activities. Most land was used to plant crops. Because there was not enough cultivatable cropland and much of the land in the study area was infertile; people expanded cropping into areas around their original cropland, which resulted in LUCC on a small scale. However, after the Great Leap Forward movement in 1958 and the Cultural Revolution during the late 1960s and 1970s, forest was destroyed and its area decreased significantly. In addition, there were four large departments of deforestation engineering (Chuanxi, Songpan, Heishui, and Maoergai) that took charge of timber production in the study area in the early 1960s, which also caused a rapid decrease in forest area until the early 1990s. After the introduction of the family-contract responsibility system and reform and opening up, most lands were contracted by individual farmers and used according to their choices, and most agricultural activities were undertaken in small units (e.g. farmer, group). Peasants changed their thinking due to the land reform, and began to accept new planting methods and technologies. However, the most important concern for farmers was economic gain. Land was changed into cropland and forest plantation land because farmers could increase their income by planting economic crops (e.g. bunge prickly ash, cabbage). Cabbage and forest plantation were developed as important industries from the 1980s. These factors shaped the rent-seeking behavior of individuals, leading to further land use change. Institutional factors, such as policies on land use and economic development related to transportation, or subsidies for land-based activities were also causes of land cover change. For example, the departments of deforestation engineering had different deforestation assignments every year prior to 1998. At the same time, in carrying out their tasks, these departments often exceeded the amount of deforestation stipulated. Land-tenure arrangements and policy failures (such as corruption, legal deforestation, or mismanagement in the forestry sector) were also important drivers of land use change. The combination of these activities explained a large part of the land cover change in the upper Min River basin.

The human population in the study region increased by 192,000 from 1950 to 2000, and as it grew the need for resources (e.g. foodstuffs, cropland, firewood, houses, roads) increased [9]. However, the availability of resources and cultivatable land was inadequate, and the resulting imbalance between land and inhabitants increased with time. People's activities continuously altered land use structure and patterns, and finally resulted in shifts between the different land cover types.

4. Conclusions

In this study, a database of dynamic changes in LULC from 1986 to 2000 was developed using remote sensing and GIS techniques. The statistical data indicated that LULC in the upper Min River basin changed remarkably from 1986 to 2000, especially from 1995 to 2000. The conversion of LULC types mainly occurred among cropland, woodland, and grassland areas. Changes of LULC types were different. Woodland area decreased, while cropland, grassland, and built-up land increased from 1986 to 2000. Water bodies and unused land also increased from 1995 to 2000, there were no changes from 1986 to 1995. LUDI of all types of land cover excluding built-up land were greater from 1995 to 2000 than from 1986 to 1995. According to the questionnaire result, the primary driving factors for land cover change in the upper Min River basin were a collection of land use policies, followed by the total population size. PCA was shown to be a suitable method for calculating and analyzing driving factors behind land cover changes.

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