

Land Use Change and Anthropogenic Driving Forces: A Case Study in Yanhe River Basin

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Abstract: Human activities alter land use patterns and affect landscape sustainability. It is therefore very important to investigate the relationship between land use change and human activities. This study focuses on the detection of changing land use patterns in the Yanhe River Basin in northern Loess Plateau of China between 1995 and 2008. Landscape metrics were used to analyze the changing land use patterns and to explore the related anthropogenic driving forces. Results show that: 1) Totally, 186 590 ha of croplands were converted into alternate land-use types (equivalent to 61.7% of the original cropland area). The majority of cropland areas were found to be converted into grassland and woodland areas (accounting for 55.9% and 4.9% respectively of the original cropland areas). 2) Both cropland and woodland demonstrated an increasing fragmentation tendency while grasslands showed a decreasing fragmentation tendency. 3) Multiple driving forces of land use change were thought to act together to changes in landscape metrics in the Yanhe River Basin. The anthropogenic driving forces were analyzed from four perspectives: ecological conservation policy, labor force transfer, industrial development, and rural settlement. The policy of the GfG (Grain for Green) project was the main driving factor which expedited the conversion from cropland to woodland and grassland. Industrial development was also found to affect land use change through the direct impact of economic activities such as oil exploration and agricultural production, or through indirect impacts such as the industrial structures readjustment. Labor force transfer from rural to urban areas was found to follow the industrial structure readjustment and further drove land use change from cropland to off-farm land use. Establishment of new tile-roofed houses instead of cave-type dwellings in rural settlements has helped to aggregate the original scattered land-use type of construction.

Keywords: land use; landscape metrics; anthropogenic driving force; Grain for Green (GfG) policy; Yanhe River Basin

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1 Introduction

Humans rely on ecosystems for welfare and survival (Feng *et al.*, 2010). Human activity and regional development profoundly influence ecosystems and land use patterns (Nagashima *et al.*, 2002). Effects of human activity include high natural resource extraction, food web simplification, habitat and landscape homogeneity and high inputs of nutrient and energy (Western, 2001). Ac-

celerating social and industrial development exacerbates the conflict between the high requirements of land resources and the limited and irreversible land reserves. Land resources are natural complex and are typified by high spatial heterogeneity. Spatial statistics and landscape metrics are two popular methods used to quantify land use changes (Wu, 2000). Spatial statistics has effectively solved the problem of spatial autocorrelation in geographical research, which the traditional statistics

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has not been able to accomplish. Landscape metrics has gone a step further to depict the landscape properties by quantifying the spatial patterns based on landscape geometry and spatial arrangement of patches (Herzog *et al.*, 2001). As landscape ecology has been progressively increasing, landscape metrics has gradually played a leading role in landscape pattern monitoring, assessment and planning (Gustafson, 1998; O'Neil *et al.*, 1998; Lausch and Herzog, 2002; Li and Wu, 2004; Gardner and Urban, 2007; Schindler *et al.*, 2007; Cushman *et al.*, 2008; Chen *et al.*, 2009). However, a sound technical and ecological understanding of landscape metrics is still lacking. Wu and Hobbs (2002) argued that the major questions concerning landscape metrics are: 1) How can links be built between ecological processes and landscape metrics? 2) How can landscape metrics reflect the scaling function? 3) What is the standard for selection of landscape metrics? 4) How can synthetic or holistic metrics that combines social, cultural, and ecological diversity and heterogeneity be developed?

Land use change is driven by forces differing in origin (Klijn, 2004), nature (Lambin *et al.*, 2003; Liu *et al.*, 2007a; 2007b), geographical extent (Verburg and Veldkamp, 2001), duration and intensity (Goodale and Aber, 2001). These forces can be broadly divided into two categories; physical driving forces such as climate (Viglizzo *et al.*, 1997; Solecki and Oliveri, 2004; Cui *et al.*, 2006; Ostwald and Chen, 2006; Delucchi, 2010), hydrology (O'callaghan, 1996; Carlson and Arthur, 2000), and soil (Fu *et al.*, 2000; Haygarth and Ritz, 2009; Marzaioli *et al.*, 2010), and anthropogenic driving forces such as population (Verburg *et al.*, 1999; Kok, 2004; Hamandawana *et al.*, 2005; Currit and Easterling, 2009), technology (Koukios, 1987; Burgess and Morris, 2009), political and economical systems (Long *et al.*, 2007; Lee *et al.*, 2010; Kuskova *et al.*, 2008), culture and religions (Fu *et al.*, 2001; Dalle *et al.*, 2006; McGregor *et al.*, 2009). Most of these researches were based on case studies. Based on the analysis of land uses and their driving factors supported by remote sensing and GIS technology (Long *et al.*, 2007; Lee, 2010), various empirical or mechanism models were developed for simulation of land use pattern (Verburg *et al.*, 1999; Solecki and Oliveri, 2004; Lee *et al.*, 2010). Generally, physical driving factors are limited, static and easily quantified (Fu *et al.*, 2006). Anthropogenic factors are diverse and reflect landscape change accurately, however, it is hard

to analyse them quantitatively. In a short term, socioeconomic processes play a decisive role in shaping land use change (Wu and Hobbs, 2002; Serra *et al.*, 2008). Optimization of composition and configuration of patches and matrices plays a significant role in biodiversity conservation, ecosystem management, and landscape sustainability (Wu and Hobbs, 2002). Exploring the socioeconomic metabolisms underlying land use change is of paramount importance in addressing the issue of landscape pattern optimization (Fischer-Kowalski, 1997; Wu and Hobbs, 2002). In addition, land use change exerts a profound influence on the environment and provides abundant information on changes in human activities. It is gradually becoming an integral component of global environmental change research and key item for the IGBP (International Geosphere-Biosphere Program). The most direct effect of investigating the socioeconomic driving forces of land use change can help to develop sound and effective land use management strategies (Fu *et al.*, 2006). The key to the question is the selection of appropriate socioeconomic indices to link socioeconomic driving forces and the changing land use patterns.

The Loess Plateau in China has long been plagued by soil erosion due to severe human disturbances (Fu, 1989; Fu and Gulinck, 1994). Since the 1950s, the policy of 'taking grain as the key link' has been practiced to increase grain yield to feed the mass population in starvation. The high stress caused by intensive agriculture resulted in serious vegetation degradation and soil and water loss. In the 1970s, the Chinese central government launched a number of ecological projects which failed to achieve satisfactory results. In 1999, an ambitious project termed as 'Grain for Green' (GfG project) was launched to curb the continually deteriorating ecological situation. The project stipulated that slope cropland and cropland unsuitable for farm production should be gradually converted to woodland and grassland. As an area severely damaged by long-time water loss and soil erosion, the Loess Plateau was identified as one of the priority areas for GfG project (Zhang *et al.*, 2004). Under the GfG project land use patterns in the Loess Plateau have changed significantly with woodland and grassland areas greatly increased while slope cropland areas greatly decreased (Zhou *et al.*, 2009).

The dramatic landscape change in the Loess Plateau calls for an investigation into the underlying driving

mechanism, in particular, their association with socio-economic factors. In this study, the Yanhe River Basin in the Loess Plateau was chosen as a study area to explore: 1) the variation of land use from 1995 to 2008 through landscape metrics analysis; 2) the underlying anthropogenic driving forces of land use change.

2 Material and Methods

2.1 Study area

The Yanhe River Basin ($36^{\circ}21' - 37^{\circ}19'N$, $108^{\circ}38' - 110^{\circ}29'E$) is situated in the northern part of Loess Plateau of China (Fig. 1). In total there are 35 towns in this region which are governed under the administration of three counties (Ansai, Yanchang, and Zhidan) and one district (Baota) of Yan'an City. The whole area was under the administration of Yan'an City. The Yanhe River

Basin has a typical warm temperate continental monsoonal climate. The long-term annual mean precipitation is approximately 500 mm, of which over 60% falls during the period from July to September (Wang *et al.*, 2010). The annual mean temperature varies between $8.8^{\circ}C$ to $10.2^{\circ}C$. The study area is covered by thick erosion-prone loess, a type of fine silt soil (Fu and Gulinck, 1994). The Yanhe River Basin loses approximately 45.4 t/ha of soil each year, causing enormous sedimentation and high flood risks in areas downstream of the Yellow River (Stolte *et al.*, 2003). The annual runoff in the area is $2.89 \times 10^8 m^3$, with runoff modulus and sediment transportation modulus of 364.25 $m^3/ha \cdot yr$ and 780 t/ha·yr respectively (Ran *et al.*, 2010). Long term incision by soil erosion resulted in the fact that 90% of the territory of the Yanhe River Basin was covered with ridges and gullies, with an elevation ranging from 495 m

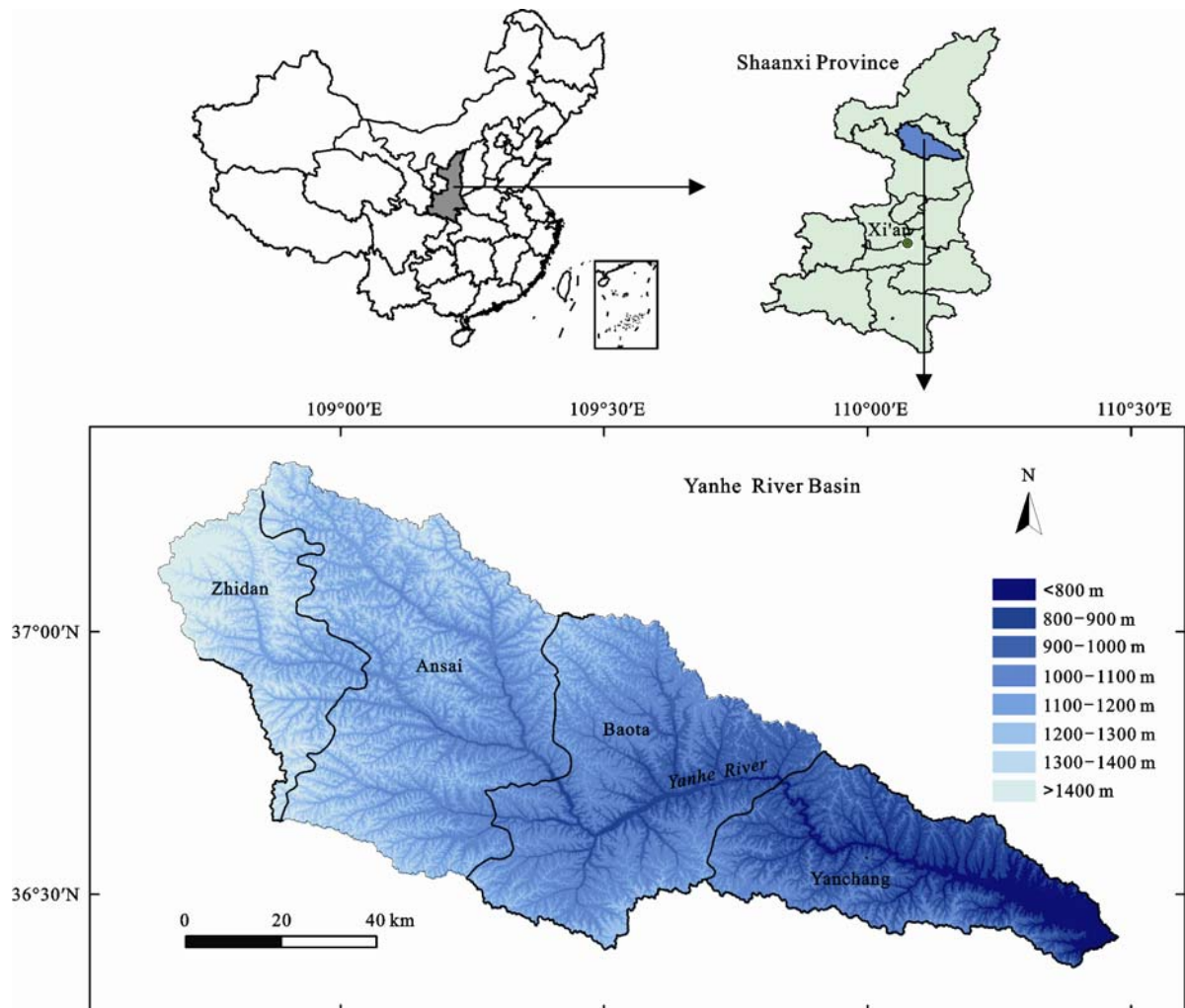


Fig. 1 Location of study area

to 1795 m a.s.l. (average 1218 m) (Fu *et al.*, 2005). The major land-use types in the study area include cropland, woodland, grassland, construction land, water bodies, and wasteland.

2.2 Data sources

Three sets of images were collected for the study, which were Landsat TM images of 30 m resolution for 1995 and 2000, and Cbers-2B image of 19.5 m resolution for 2008. Socio-economic data including population, cropland area, and GDP were obtained from statistic yearbooks issued by statistic departments of concerned counties and districts in the Yanhe River Basin (ASB, 1996; 2001; 2009; BSB, 1996; 2001; 2009; YSB, 1996; 2001; 2009; ZSB, 1996; 2001; 2009).

2.3 Selection for landscape metrics

Landscape metrics can be broadly categorised into eight groups, i.e., area/density/edge metrics, shape metrics, core metrics, isolation/proximity metrics, contrast metrics, contagion/interspersion metrics, connectivity metrics, and diversity metrics. The development of software in landscape metrics has enabled ecologists to calculate multiple indices. However, high correlations between some indices lower the information they can produce. In these cases, ‘parsimony’ in selection of landscape metrics indices with full consideration of correlation is prudent and advisable (Cushman *et al.*, 2008). In this study, we selected four categories including 14 landscape metrics: 1) area/density/edge metrics: class area (CA), number of patches (NP), patch density (PD), edge density (ED), landscape shape index (LSI), and largest patch index (LPI); 2) shape metrics: perimeter-area ratio (PARA), shape index (SHAPE), continuity index (CONTIG), and fractal dimension index (FRAC); 3) contagion/interspersion metrics: aggregation index (AI) and splitting index (SPLIT); and 4) diversity metrics: Shannon’s diversity index (SHDI), and Shannon’s evenness index (SHEI) (see Help Content of Fragstats).

2.4 Data analysis

Three sets of satellite images from 1995, 2000, and 2008 were visually interpolated and calibrated with field survey information. Probability sampling and error matrix analysis indicate that the accuracy of classification is up to 85%. The data were classified with six domains: 1) cropland, including dry cropland of various slope and

irrigated cropland; 2) woodland, including evergreen coniferous woodland, deciduous broad-leaf woodland and mixed broadleaf-conifer woodland; 3) grassland, including typical grassland and shrub land; 4) construction land, including urban construction land, rural settlement, and transportation facility areas; 5) water body, including swamp, lake, river and wetland; 6) wasteland, including naked rocks, bare land, and sand land. Interpolated polygon-type images from 1995, 2000, and 2008 were further converted into a grid format of 30 m resolution for calculation of landscape metrics through use of the FRAGSTAT 3.3 program. The intersection module of ArcGIS was used to compute the geometric intersection between land use maps from 1995, 2000, and 2008. Cross-tabulation tables of transition matrixes were then calculated by applying the PivotTable Wizard in Microsoft Excel.

3 Results

3.1 Changes of different land use types

Areas of different land use types remained relatively stable from 1995 to 2000 and then changed drastically from 2000 to 2008, which was characterized by grassland expansion and cropland shrinkage (Table 1, Fig. 2).

Table 2 shows that between 1995 and 2000, 7116 ha (2.35%) and 6535 ha (2.16%) of cropland were turned into grassland and woodland, respectively. Between 2000 and 2008, 165 800 ha (56.6%) and 8477 ha (2.9%) of cropland was further converted to grassland and woodland, respectively. During this same period, 2586 ha of wasteland was transformed to water bodies. During the entire period between 1995 and 2008, 186 590 ha of cropland was converted into off-farm land use types (61.7% of the original cropland area), within which 168 900 ha (55.9% of the original cropland) and 14 840 ha (4.9% of the original cropland) of cropland were converted to grassland and woodland respectively.

In conclusion, the Yanhe River Basin underwent a conversion of land use change from cropland to woodland and grassland. And most of land use change happened within the period between 2000 and 2008. The conversion of cropland to grassland occurred across the whole study area except the fringe area, while the conversion of cropland to woodland was very scattered in the southwestern, southern, southeastern, and northeastern edges of the study area. The conversion of woodland

Table 1 Land use areas in Yanhe River Basin in 1995, 2000 and 2008

	1995		2000		2008	
	Area (ha)	Percentage (%)	Area (ha)	Percentage (%)	Area (ha)	Percentage (%)
Cropland	302396	43.8	292908	42.5	118500	17.2
Grassland	308239	44.7	308990	44.8	474600	68.8
Woodland	73600	10.7	80090	11.6	88557	12.8
Construction land	2679	0.38	2452	0.36	2626	0.38
Water body	2773	0.40	2713	0.39	5347	0.78
Wasteland	259	0.04	2792	0.40	206	0.03

Source: Data extracted from lab for agriculture and environment under Institute of Remote Sensing Applications, Chinese Academy of Sciences

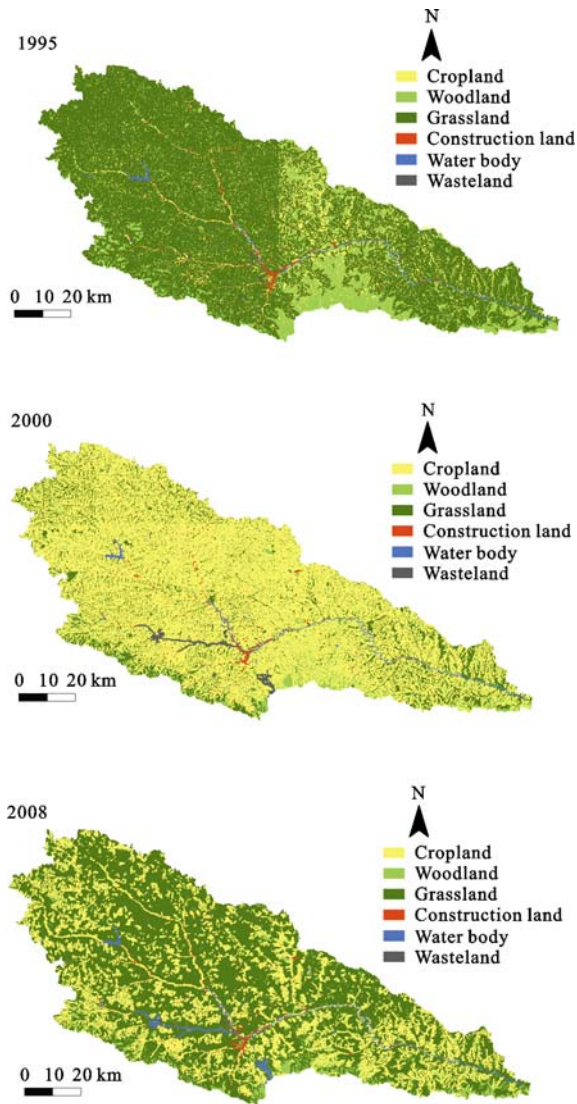


Fig. 2 Land use in Yanhe River Basin in 1995, 2000 and 2008

to grassland occurred minimally in the southern edge.

3.2 Changes of landscape metrics at landscape level

At the landscape level, NP and PD demonstrated an in-

creasing tendency between 1995 and 2008 (Fig. 3), indicating intense landscape fragmentation during this period. ED showed a slight increase between 1995 and 2000 and then decreased sharply between 2000 and 2008 (Fig. 3). This result implied that the shapes of the patches were becoming simpler or more regular after 2000. LSI and PARA remained relatively stable from 1995 to 2000 and then decreased after 2000, which matched the simplification tendency of the patch shapes. CONTIG decreased slightly between 1995 and 2000 and then jumped drastically between 2000 and 2008, indicating that patch contiguity was enhanced over the whole period. AI displayed a decrease-and-jumping curve between 1995 and 2008; in contrast, SPLIT increased between 1995 and 2000 and then decreased after 2000, which suggested that patches were becoming more aggregated. Both SHDI and SHEI increased slightly between 1995 and 2000 and quickly decreased after 2000. This indicated that land-use types were becoming more diversified and more evenly distributed. In contrast, FRAC decreased linearly between 1995 and 2008, indicating that patch shapes were becoming simpler and thus signaling the increase in human disturbance. LPI decreased slightly between 1995 and 2000 and then jumped after 2000, which indicating that large patches were getting more frequent (Fig. 3).

In conclusion, land use in the Yanhe River Basin roughly assumed a fragmentation tendency between 1995 and 2008, which caused habitat fragmentation and resulted in possible species loss. Patches' shapes had a tendency towards regularization and simplification, which was possibly caused by the increase in human disturbance. The regularity and simplicity of patches are likely to have hindered species diversity. However, the enhanced connection between patches may have provided more routes for species migration.

Table 2 Change of land use types in Yanhe River Basin in different periods (ha)

1995	2000					
	Cropland	Grassland	Woodland	Construction land	Water body	Wasteland
Cropland	286000	7116	6535	131	82	2532
Grassland	4570	299600	3835	49	59	26
Woodland	1803	2091	69660	0	16	31
Construction land	321	37	39	2266	0	16
Water body	139	46	22	5	2556	4
Wasteland	75	0	0	0	0	183

2000	2008					
	Cropland	Grassland	Woodland	Construction land	Water body	Wasteland
Cropland	118500	165800	8477	102	0	0
Grassland	0	308800	0	57	48	0
Woodland	0	0	80080	16	0	0
Construction land	0	0	0	2452	0	0
Water body	0	0	0	0	2713	0
Wasteland	0	0	0	0	2586	206

1995	2008					
	Cropland	Grassland	Woodland	Construction land	Water body	Wasteland
Cropland	115800	168900	14840	233	2594	23
Grassland	1412	302600	3917	107	129	0
Woodland	804	3003	69730	16	47	0
Construction land	313	46	39	2266	16	0
Water body	134	51	22	5	2560	0
Wasteland	2	74	0	0	0	183

Source: Data extracted from lab for agriculture and environment under Institute of Remote Sensing Applications, Chinese Academy of Sciences

3.3 Changes of landscape metrics at class level

3.3.1 Cropland

The area of cropland (CA) showed a decreasing tendency between 1995 and 2008. ED, LSI, and SHAPE also decreased during the same period. However, NP, PD and SPLIT were detected to have increased, particularly between 2000 and 2008 (Fig. 4). The decreasing tendency of CA versus the increasing tendency of NP and PD implied a fragmentation tendency of cropland, which was confirmed by the increase of SPLIT. The decreasing LPI and PARA suggested that the shape of cropland patches had a tendency towards further uniformity and simplicity, while the increasing CONTIG suggested that cropland patches were becoming more connected. Fragmentation and regularity of cropland patches exert detrimental influence on biodiversity whereas it is beneficial to farm production as agricultural produces are confined to limited species.

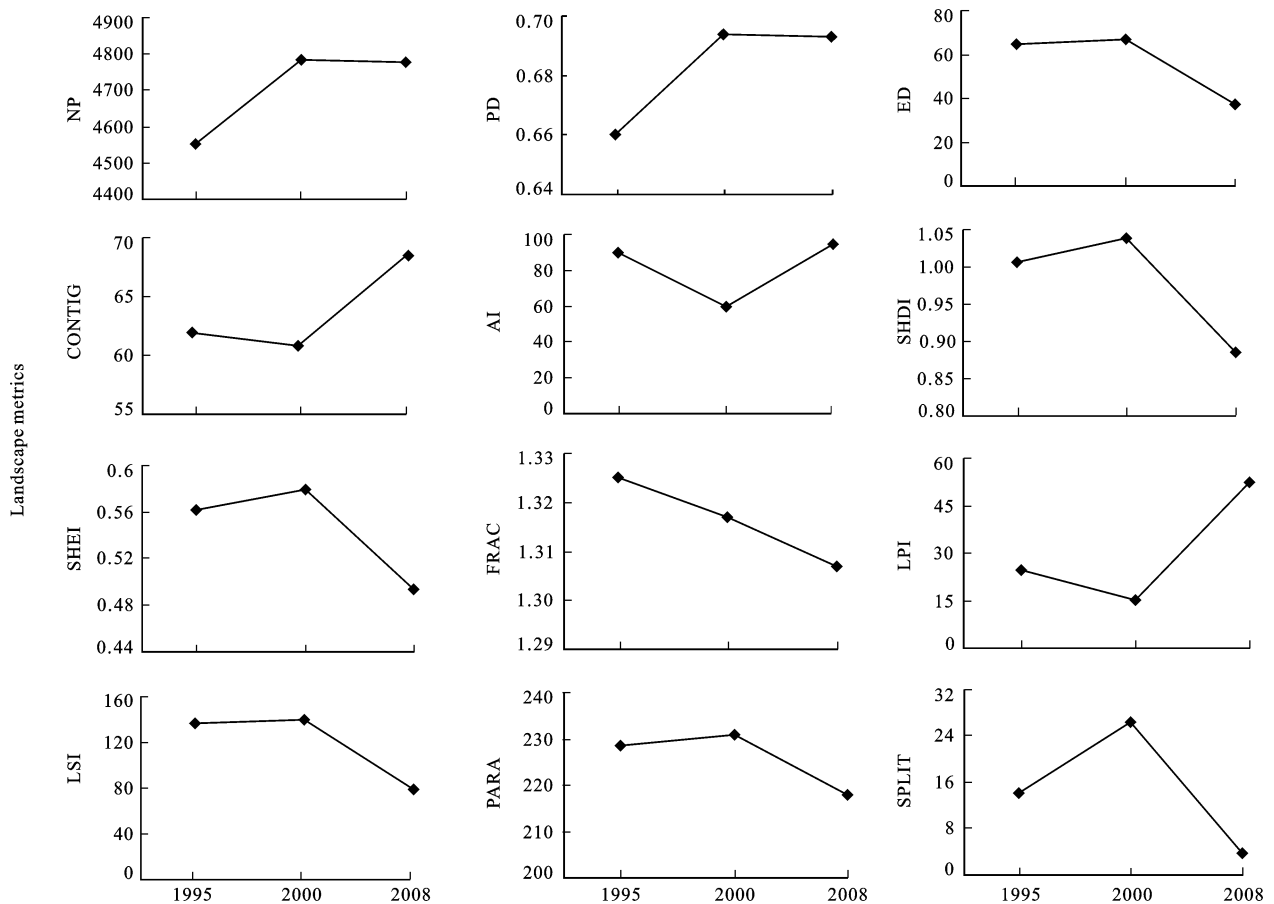
3.3.2 Woodland

In comparison with cropland, the landscape metrics of

woodland fluctuated moderately. CA, NP, PD, ED, and LSI for woodland increased progressively between 1995 and 2008 (Fig. 4). FRAC and SPLIT remained stable, possibly due to the joint effects of increasing CA and increasing NP. The low and stable LPI for woodland indicated that large woodland patches were not frequent. The moderate change in landscape metrics possibly reflected the difficulties of afforestation as forest has a higher requirement for rainfall and site conditions.

3.3.3 Grassland

In contrast to cropland, the CA of grassland remained relatively stable between 1995 and 2000, and then jumped after 2000. PD, NP, ED, and LSI also remained relatively stable during the period between 1995 and 2000 and then plummeted after 2000 (Fig. 4). It may be deduced from the increase in CA and the decrease in NP that there was a decreasing fragmentation tendency for grassland. The decreasing FRAC indicated that the grassland patches became more uniform between 1995 and 2008. Overall, the steep increase in LPI indicated



NP: number of patches; PD: patch density; ED: edge density; CONTIG: continuity index; AI: aggregation index; SHDI: Shannon's diversity index; SHEI: Shannon's evenness index; FRAC: fractal dimension index; LPI: largest patch index; LSI: landscape shape index; PARA: perimeter-area ratio; SPLIT: splitting index

Fig. 3 Changes of landscape metrics at landscape level

that large patches of grassland were more frequent. The increase in PARA and AI implied that grassland patches had a high tendency of aggregation and complication, whereas the decreasing CONTIG indicated a moderate decreasing continuity tendency.

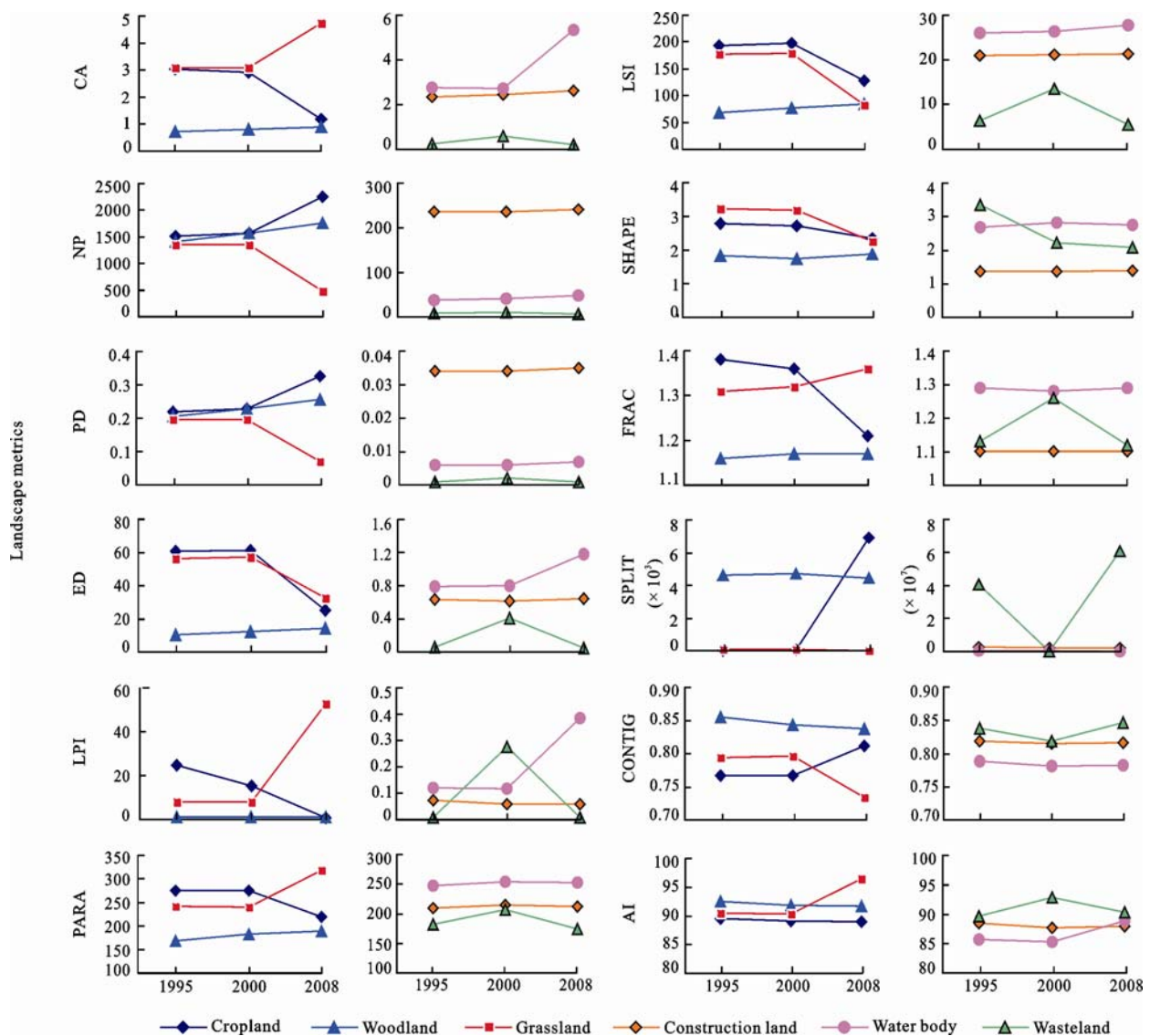
3.3.4 Construction land, water body and wasteland

In comparison with cropland, woodland, and grassland, the landscape metrics change in construction land was found to be very mild (Fig. 4). SPLIT of construction land decreased minimally between 1995 and 2008, indicating an aggregation tendency. CA of water body doubled between the same periods. The decrease in SHAPE for these three land-use types suggested that their shapes were becoming more regular due to concentrated human disturbance. LPI of water body increased significantly from 1995 to 2008, indicating water body was gradually dominated by large patches. SHAPE of wasteland decreased gradually, implying that wasteland patches have a regularization tendency, while the increasing of SPLIT of wasteland imply that waste-

land patches are more separated.

4 Discussion

Between 1995 and 2008 the Yanhe River Basin experienced a sharp decrease in cropland area and an increase in grassland and woodland area. Cropland had a strong tendency towards fragmentation. Grassland area increased by a great margin due to the 'Mountain Closure' measure under the GfG project (Xu *et al.*, 2006; Liu *et al.*, 2008). In contrast to cropland, grassland showed a decreasing fragmenting tendency, reflecting the mitigating human disturbance on grassland. Woodland increased but by only a small margin and this was attributed to the conflict between the high requirement for site conditions of woodlands and complex topography/low water availability of the Yanhe River Basin (Cao *et al.*, 2007; Cao *et al.*, 2011). Geist and Lambin (2002) distinguished and ranked five underlying social economic driving factors according to their frequencies



CA: class area; NP: number of patches; PD: patch density; ED: edge density; LPI: largest patch index; PARA: perimeter-area ratio; LSI: landscape shape index; SHAPE: shape index; FRAC: fractal dimension index; SPLIT: splitting index; CONTIG: continuity index; AI: aggregation index
Every two neighboring subplots in one row share the same y-axis

Fig. 4 Changes in landscape metrics at class level

in published papers: institutional and policy factors, technological factors, cultural socio-political factors, economic factors and demographic factors. Based on Geist and Lambin's results and the endemic characteristic of the Yanhe River Basin, the driving forces were analysed from the perspective of policy, labor force transfer, industrial development and rural settlement evolution.

4.1 Policy

The famous 'Great Development of Western China' program began in 1999 and included a series of ecological

preservation projects such as the Natural Forest Protection Project, GfG Project, and the Northwest-North-Northeast Shelterbelts Project (three-North) (Xu *et al.*, 2006). In addition, Yan'an City also launched local projects including the Non-wood Forest Base Construction Project, the Infrastructure Consolidation for Forest Seedling Project and the Foreign Capital Funded Projects. After ten years of practice, approximately 109 000 ha of cultivated land was converted to woodland. And 79 000 ha of waste mountains and un-reclaimed lands suitable for woodland was afforested (Fig. 5) (Xu, 2010). The ecological state and environment of the Yanhe

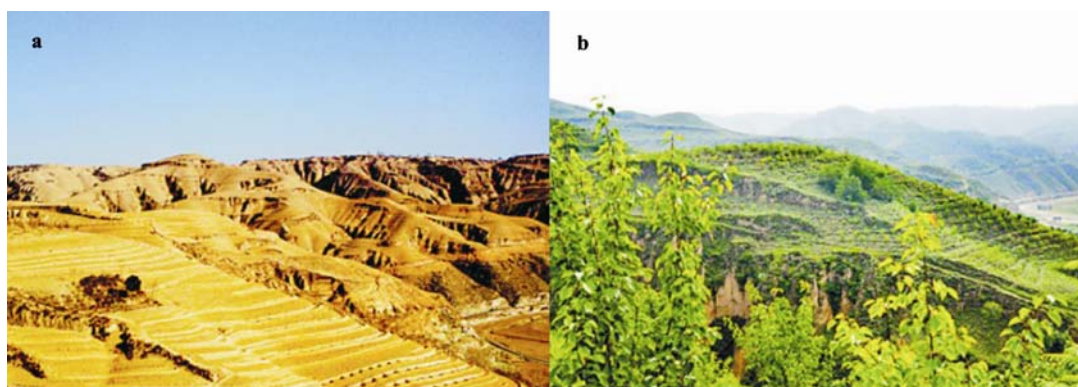


Fig. 5 Contrasting views of same site before (a) and after GfG Project (b) (1998–2007)

River Basin was thus greatly improved. The incidences of runoff, flood peak flow, and soil loss decreased by 50%, 64% and 72%, respectively (Qi *et al.*, 2008). The complexity of topography caused cropland to shrink with a fragmentation tendency. Grassland is highly adaptable to harsh geographical conditions and can therefore be easily established by mere measure of ‘mountain closure’. This high adaptability of grassland partially explains its decreasing fragmentation tendency. In contrast to grassland, woodlands have high requirements for water and site. This means that woodland expansion can only be mild and gradual in the study area.

4.2 Labor force transfer

Population in the Yanhe River Basin steadily increased from 388 578 in 1995 to 434 268 in 2000 and to 501 480 in 2008. In the ‘New Countryside Construction’ from 2004 to 2008, there were 138 new resettlement villages established in Yan’an City with improved infrastructure facilities. This included improved water and power supply, transportation and education facilities. Totally 27 000 households and 120 000 farmers were relocated from areas of scattered dwellings to towns or newly built rural settlements (Feng, 2008). Many farmers were required to switch to off-farm activities, which was well reflected by the decreasing proportions of agricultural population and farming labor force. The proportion of agricultural population decreased from 93.2% through 87.4% to 82.4% and the proportion of farming labor force decreased from 96.1% through 92.9% to 90.0% during the period from 1995 to 2008. Such tendencies exert significant influence on land use transition from cropland to woodland or grassland. The shrinking of population for farm production helps to vacate large

area of cropland, which is conducive for the GfG project.

4.3 Industrial development

The economy of the Yanhe River Basin developed very rapidly during the period of GfG project. The GDP increased from 1.67×10^9 yuan (RMB) in 1995 to 1.71×10^{10} yuan in 2008. Different sectors of the economy developed unevenly, which was characterized by soaring secondary industry and plummeting primary industry (Fig. 6). Such economic pattern significantly influenced land use change, particularly the change in cropland, woodland and grassland areas. The strong momentum of industrial development in the Yanhe River Basin is a result of three pivotal industrial activities: burgeoning oil exploration, shrinking but intensified green agriculture and a booming tourism industry.

4.3.1 Oil industry

Oil exploration is the major industry of the Yanhe River Basin and has exerted a profound influence on the general local economic pattern. Yan’an City obtained $4.28 \times$

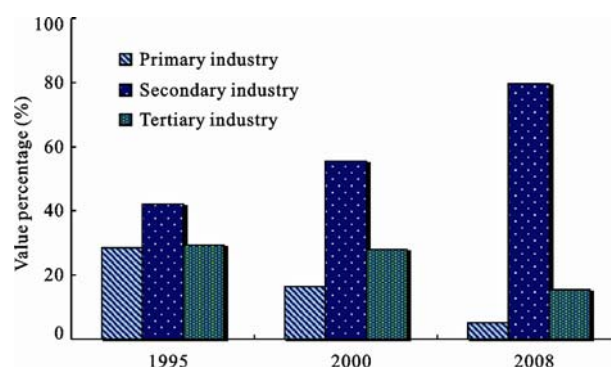


Fig. 6 Value percentage of different sectors of industry in Yanhe River Basin

10^{10} yuan RMB of added values from the oil industry in 2008, accounting for 89.2% of the total industrial value and 72.1% of the GDP respectively (Xu, 2010). The direct influence of oil exploration on the landscape pattern is the presence of infrastructure construction, i.e. roads and refineries. In addition, the absorption of a large redundant rural labor force by the oil industry has also exerted potential impacts on land use pattern change.

4.3.2 Green agriculture

Yan'an is an agricultural city with an agricultural population over 82.4% of the total. In order to improve farmers' incomes, Yan'an City developed three major agricultural products: fruits, greenhouse vegetables, and strawberries. Taking apple production as an example, there were 173 000 ha of apple trees planted with an income of 4×10^9 yuan annually (Xu, 2010). Such green agriculture practices altered the land use pattern directly by converting cropland to orchards or to construction land (such as the processing and storing factories and roads connecting orchards and factories). In addition, rapid industrial development led farmers to improve their farming technology, such as the ever increasing farm mechanisation. Improved production capacity liberated farmers from excessive dependence on farm work and expedited diversification of land use patterns to off-farm practices.

4.3.3 Tourism

As one of the 24 historical and cultural cities in China, Yan'an City has many advantages in tourism industry. It has numerous educational bases for patriotism and revolutionary tradition. Yan'an built its reputation as a revolutionary base for its contribution to the founding of the P. R. China. Totally, 5808 historic relic sites are in

the city and among 350 are of the revolutionary category (Xu, 2010). Yan'an also provides the ideal place for travelers to experience the splendid expanse of loess and enjoy the coziness of cave dwelling. Benefited from such advantageous historical and natural conditions, Yan'an City earns tourism revenue of 4.3×10^9 yuan in 2008, accounting for 50.3% of the tertiary industry and 6% of the total GDP (Xu, 2010). In the Yanhe River Basin, tourism affected the landscape primarily through: 1) directly altering land use patterns through the construction of greenbelts, road networks, and reservoirs; 2) the output of tourist revenue that could be further used as funds for betterment of woodland and grassland; and 3) absorption of farmers into the tourism sector lowering the pressure on the limited cropland area and pushing forward land use change.

4.4 Rural settlements

Historically, cave dwelling is popular for rural population in the Yanhe River Basin (Fig. 7) for its good insulation of temperature, appropriateness for dense loess, suitability for complex topography, and sparing of expensive construction material (Yoon, 1990). Cave dwelling has special requirements for site, such as steep slopes, well compacted, dry and dense loess, and specific requirements by geomancy (Chinese *Fengshui*). The strict requirements for site condition have resulted in a specifically scattered and dispersed pattern of rural settlement in the Yanhe River Basin. Thanks to the policy of 'New Countryside Construction', rural settlements have been gradually liberated from the traditional cave dwellings to artificial standing free caves, or tile-roofed houses (Fig. 7). The easing of requirements for dwelling sites has enabled farmers to build houses more freely.



Fig. 7 Cave dwelling (a) and tile-roofed house (b) in Yanhe River Basin

The originally dispersed rural settlements have gradually aggregated into large and connected settlements, which are mirrored by the decreasing SPLIT of construction land from 2 510 786 in 1995 to 2 113 072 in 2008 (Fig. 4).

5 Conclusions

Between 1995 and 2008, the Yanhe River Basin underwent great land use change characterised by shrinking cropland and expanding grassland and woodland. Totally, 186 590 ha of cropland were converted into off-farm land-use types (61.7% of the original cropland area), within which approximately 55.9% and 4.9% of cropland were transferred to grassland and woodland respectively. The whole study area demonstrated a tendency towards fragmentation. Patch shapes became more uniform whereas the continuity and aggregation between patches were enhanced. Cropland showed a strong tendency towards fragmentation as reflected by decreasing CA and increasing NP, which was confirmed by the increasing SPLIT. In contrast to cropland, grassland demonstrated a decreasing fragmentation tendency reflected by the increasing CA and decreasing NP, which was mirrored by decreasing SPLIT. In comparison with cropland and grassland, woodland demonstrated a 'moderate' land use change pattern. The CA, NP, and ED of woodland demonstrated a mild increasing tendency, which jointly functioned to keep FRAC and SPLIT nearly constant. The construction land showed a mild aggregation tendency.

Multiple socioeconomic factors combined to jointly cause land use change in the Yanhe River Basin, of which the GfG project was the leading driving force. In addition, industrial development, labor force transfer and rural settlement evolution directly or indirectly consolidated the land use change. In the research, ecological conservation policies directly shape land use patterns with foreseeable and tangible effects. Other indirect driving factors (such as labor force transfer and rural settlement) are caused or coordinated by land-use policy. There exist feedbacks within the joint driving factors and land use pattern. For example, the grassland expansion and cropland shrinking also guide farmers to adjust their production and life style towards off-farm production. Despite its robustness in spatial analysis of landscape pattern, satellite images cannot reflect some

cultural landscapes, e.g. cave dwelling settlements in Loess Plateau cannot be interpreted due to their earth-submerge characteristics. Simply interpreting historic relics as construction sites does not reflect their tourism value. Besides, the incompatibility of spatio-temporal scales between land use and anthropogenic factors is out of the reach of pure satellite image-based methodology for land-use analysis, which limits its application in cultural landscape management and policy-making processes. In addition, the ecological significance of landscape metrics in land use change research still needs further exploration. Based on these facts, future orientations for land use change and its underlying anthropogenic driving mechanism research lie in: 1) improving the implication of landscape function based on the traditional category scheme; and 2) blending the traditional land use research methods with cultural landscape methodology systematically.

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