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Catena 72 (2008) 56–66
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Land use change and its driving forces on the Tibetan Plateau during 1990–2000

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Received 28 July 2006; received in revised form 24 March 2007; accepted 8 April 2007

Abstract

Rapid economic development has spurred land use change in China since the Chinese government initiated its economic reform in 1978. Although many papers have analyzed the characteristics of land use change, especially cropland conversion to non-agricultural use affected by economic development in the developed regions of China, relatively less attention has been paid to studying the characteristics of land use change affected by both economic development and environmental changes in its undeveloped regions. This paper analyzes the land use change and its driving forces in Dulan County, Qinghai Province on the Tibetan Plateau during 1990–2000. The land use change was studied based on the landscape metrics change and transition matrix of land use types, while its driving forces were analyzed according to climatic changes and socioeconomic development. The study indicates that the increase of land use benefits was given great attention; however, the protection of arid environment did not attracted much attention. The study suggests that the land use should be based on the sustainable protection of arid environment on the Tibetan Plateau.

Keywords: Land use change; Landscape metrics; Fragmentation; Arid zone; Tibetan Plateau; China

1. Introduction

Land use change is closely related to socioeconomic development and environmental changes; therefore, land use change has become a major area of research, especially since the International Geosphere and Biosphere Programme (IGBP) and the International Human Dimensions Programme on Global Environmental Change (IHDP) initiated their core project on land use and cover change in the mid-1990s (Turner et al., 1995; Lambin et al., 1999; Li and Wang, 2003). Since 1978, when China initiated economic reform and an open-door policy, rapid land use and land cover change has taken place in most of its territory (Weng, 2002). It has been well documented that obvious land use change, especially cropland conversion to non-agricultural use, has occurred in the processes of environmental changes, industrialization and urbanization in the whole country (Li, 1997, 1999; Tan, 1999; Bi, 2000; Li, 2000). Regional land use changes in the eastern developed regions of China have received great attention (Weng, 2002; Chen et al., 2003; Lu et al., 2003; Jia et al., 2004; Zhao et al., 2005). Comparatively, land use changes in its western undeveloped regions have attracted little attention, especially on the frigid and arid Tibetan Plateau, where both economic development and arid environmental changes strongly affect land use change.

As the roof of the world, the Tibetan Plateau is a gigantic tectonic geomorphologic region on the earth (Zheng, 2003). As a result of the typical climatic changes and human activities, the land use change on the plateau is quite different from that in lowlands at almost the same latitudes as well as in high latitudinal regions. According to the recent study of the environmental changes on the plateau during 1971–2000, the climatic changes were mainly characterized by increase of temperature and precipitation and decrease of potential evaporation capacity (Wu et al., 2005), which was apparently beneficial to the improvement of the frigid and arid environment on the plateau. Based on China statistical yearbook, GDP (Gross Domestic

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doi:10.1016/j.catena.2007.04.003

Product) in the Tibetan Autonomous Region and Qinghai Province has clearly increased following the 1978 reforms, especially in 1990s (NBSC, 1991–2003a). However, rapid population growth had occurred on the plateau in the same period. The aforesaid climatic and human factors greatly affect the land use change on the plateau. Better understanding of the processes that resulted in changing land use in the past may enable the improvement of future planning strategies (Shoshany and Goldshleger, 2002). Thus, a study of land use change and its driving forces on the Tibetan Plateau is much needed.

The objective of this paper is to analyze land use change pattern using a geographical information system (GIS) and patch analysis methods and to discuss its driving forces based on the climatic changes and socioeconomic development, which will benefit the process study of land use change and land-use planning on the Tibetan Plateau.

2. Study area

Located between 95°34′–99°40′ E and 35°20′–37°22′ N and situated on a transitional belt between the frigid Tibetan Plateau and the arid Northwest China, Dulan County of Qinghai Province covers an area of approximately 54,269 km^2 (Fig. 1). It is mainly characterized by arid climate and basin landscape. Air temperature spatially increases from southeast to northwest with a mean annual value of 2.7 °C–4.4 °C. The coldest month (January) generally has a mean air temperature ranging from −10.6 °C to −10.1 °C, while the warmest month (July) usually has a mean air temperature ranging from 14.9 °C to 17.2 °C. Sunshine and solar radiation are quite high, which partly compensate for the disadvantageous low temperature. Precipitation increases from northwest to southeast with a mean annual precipitation of 37–296 mm. Evaporation is quite strong with a mean annual evaporation capacity of 2088–2716 mm. Frequent strong wind is another climatic feature directly affecting agricultural development and arid environment, which becomes stronger from east to west with a mean annual speed of 3.5 m s^{-1}. After autumn harvest, strong soil erosion usually occurs on cropland. Located in the eastern part of the Qaidam Basin, Dulan County has a plain area with an elevation between 2675 m and 3300 m, and a mountain area with an elevation between 3300 m and 5536 m (MCA, 1993; Wang, 1995; Zhao, 1998). Many alpine and desert soils can be found, which have very coarse soil texture. These physical conditions result in the fact that most of the area of Dulan County is covered by unused land (56%) and grassland (41%).

As a Mongolian place name, “Dulan” means warm. It historically indicates that the physical conditions for agricultural production in Dulan County are relatively satisfactory compared with that in other parts of the frigid plateau. Holding the highest record for spring wheat yield of 15,195 kg ha^{-1} (1978) in China and having large grassland, Dulan County is a famous agricultural county in China.

Following the 1978 economic reforms, grain production and animal husbandry have still played an important role in the local economic development, since the county’s economy is still dominated by agriculture. The formation of cropland needs special conditions, regarding elevation, soil texture, water resources and infrastructure. As temperature decreases with increasing elevation, the areas with an elevation less than 3250 m generally

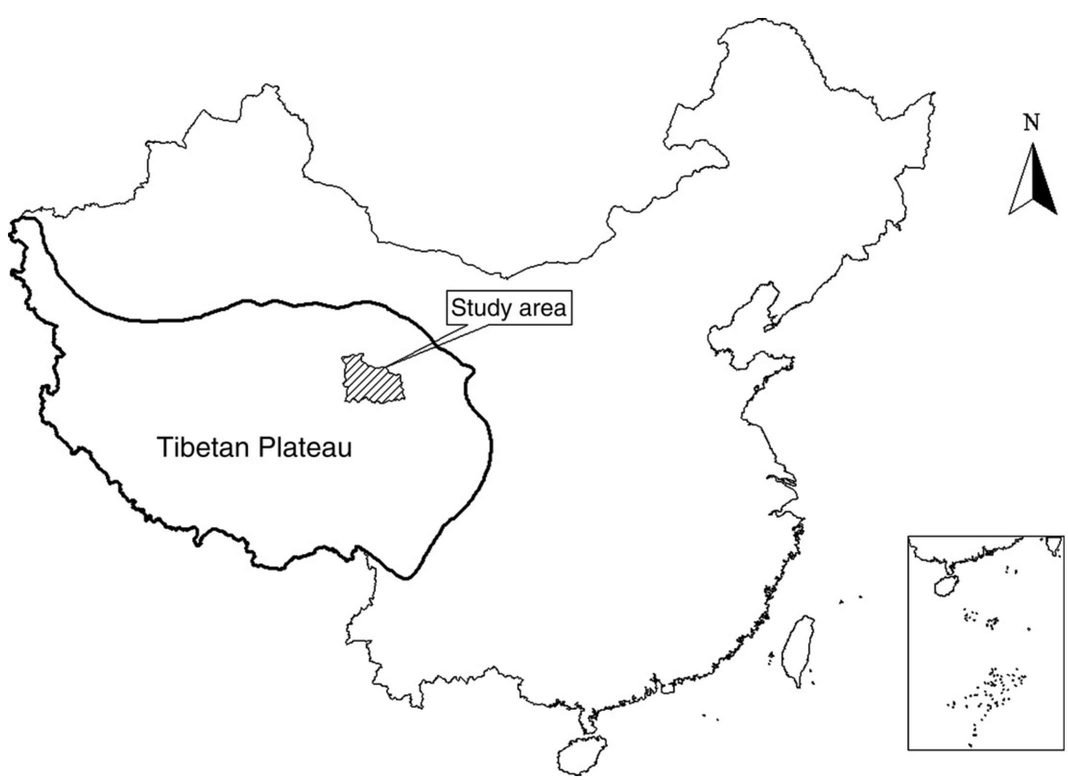

Fig. 1. Study area and location of Dulan County on the Tibetan Plateau, China.

have higher temperature favorable to the growth of some crops (one crop a year), such as spring wheat, horsebean, potato, cole and many kinds of vegetables. From the upper part to the lower part of alluvial fans, soil texture becomes fine, fine soil depth increases, soil fertility enhances, but soil salt content also increases. Therefore, it is only the middle part of alluvial fans that possess soils favorable to crop growth. Without irrigation, farming is impossible. Although some rivers seep into the ground after running out the mountain areas, many rivers overflow near the edge of alluvial fans. Moreover, some larger rivers directly reach the fine earth belts. Gainable water resources make irrigation and cultivation possible. Apart from the aforesaid conditions, better economic conditions, especially transportation, are also favorable to cropland expansion. The above-mentioned four conditions affect each other and work together. Thus, cropland is mainly distributed on the fine earth belts with an elevation ranging from 2800 m to 3000 m. It is horizontally along the sides of roads and vertical to the flow directions of rivers (Wang and Hu, 1998). However, irrational expansion of cropland usually accelerates wind erosion and soil secondary salinization.

Widely distributed in the study area, grassland can be divided into many types based on vegetation types and landform characteristics. It includes plain meadow, montane meadow, alpine meadow, swamping meadow, shrub meadow, sparse forest meadow, montane steppe, alpine steppe, plain desert, and montane desert. Many vegetation types can be found on the grasslands in Dulan County, such as xerophyte, mesophyte, hygrophyte and halophyte on different landforms. Vegetations usually have a mean height of 5–80 cm (some reaching about 200 cm) and a mean coverage of 5–70% (Ma, 1995).

3. Data and methods

3.1. Database

The use of satellite remote sensing has been proven to be a good choice for detecting and monitoring land use transformation (Longley, 2002). In this study, we used the digital land use dataset (vector) at a scale of 1:100 000 in 1990 and 2000 developed by the Resources and Environment Data Center, Chinese Academy of Sciences (CAS) (Liu et al., 2003, 2005a,b,c).

The dataset is based on the Landsat Thematic Mapper (TM) remotely sensed data for the whole country with a maximal spatial resolution of 30 m. The Landsat images were enhanced using the linear contrast stretching and histogram equalization to help identify ground control points in the rectification to a common ALBERS coordinate system based on 1: 100 000 topographic maps of China. The land use classification was conducted through visual interpretation to guarantee the consistency and accuracy of data processing. After geometric correction and georeferencing, the average location errors in the Landsat images are less than 50 m (about 2 pixels). Field survey and random sample check show that the overall interpretation accuracy for land use classification is 92.92% for 1990 and 97.45% for 2000 (Liu et al., 2005c).

A hierarchical classification system of 25 land-cover subclasses was applied to the Landsat TM/ETM (Enhanced Thematic Mapper) data. The 25 subclasses of land cover were further grouped into 6 aggregated classes of land cover: croplands, woodlands, grasslands, water bodies, unused land and built-up areas including urban areas. Croplands include paddy and dry farming land. Woodlands include forest, shrub and others. Grasslands include three density-dependent types: dense, moderate and sparse grass. Water bodies include stream and rivers, lakes, reservoir and ponds, glacier and firn, beach and shore, and bottomland (overflow land). Unused land includes sandy land, Gobi, salinized land, wetland, bare soil, bare rock and others such as alpine desert and tundra. Built-up land includes urban area, rural settlements and others such as roads and airports (Liu et al., 2005a,b,c). In this study, we selected some related subclasses and class as land use patch types according to our field investigation (Table 1). Land use maps of Dulan County in 1990 and 2000 were displayed by using a GIS software ArcView 3.2 (Fig. 2).

To explain the reasons for land use change, the authors selected some related data reflecting climatic changes and human activities. The climatic data was obtained from the Meteorological Information Center, China Meteorological Administration, while the socioeconomic data was from the Qinghai Statistical Yearbook (NBSC, 1991–2003b).

3.2. Methods

The Patch Analyst module was used to calculate the landscape metrics, which is an extension to the ArcView GIS

Table 1
Land use patch types and their definitions in Dulan County

Patch ID	Patch type	Definition
11	Irrigated cropland	Irrigated crops can ripen once a year.
21	Dense forest	Woodland with a crown density >30%
22	Scrubland	Scrubland with a crown density >40% and height less than 2 m
23	Sparse forest	Woodland with a crown density of 10%–30%
31	Higher coverage grassland	Grassland with a coverage >50%
32	Medium coverage grassland	Grassland with a coverage between 20% and 50%
33	Lower coverage grassland	Natural grassland with a coverage of 5%–20%
41	River and channel	Natural river and artificial channel
42	Lake	Natural lake
43	Reservoir and pond	Artificial water area
44	Glacier and firn	Land covered with glacier and firn
45	Overflow land	Flood-affected land on riverside or lakeside
50	Built-up land	Residential area and land for stand alone industrial and mining sites
61	Sandy land	Land covered with sand, vegetation coverage <5%
62	Marsh	Land with accumulated water and hygrocolous plants
63	Salinized land	Land with more salt gathered on top soil
64	Desert land	Stony and alpine deserts with a vegetation coverage <5%

system that facilitates the spatial analysis of landscape patches, and modeling of attributes associated with patches (Rempel and Carr, 2003). Two levels of metrics were computed, i.e., class level, which means each land use type (patch type) in the landscape mosaic, and landscape level, which means the landscape mosaic as a whole (Lu et al., 2003). The various patch metrics follow the definitions in FRAGSTATS (McGarigal and Marks, 1994). Patch Analyst is capable of calculating a lot of landscape metrics. However, many of them can be highly correlated. In this analysis of the change of landscape metrics at the class

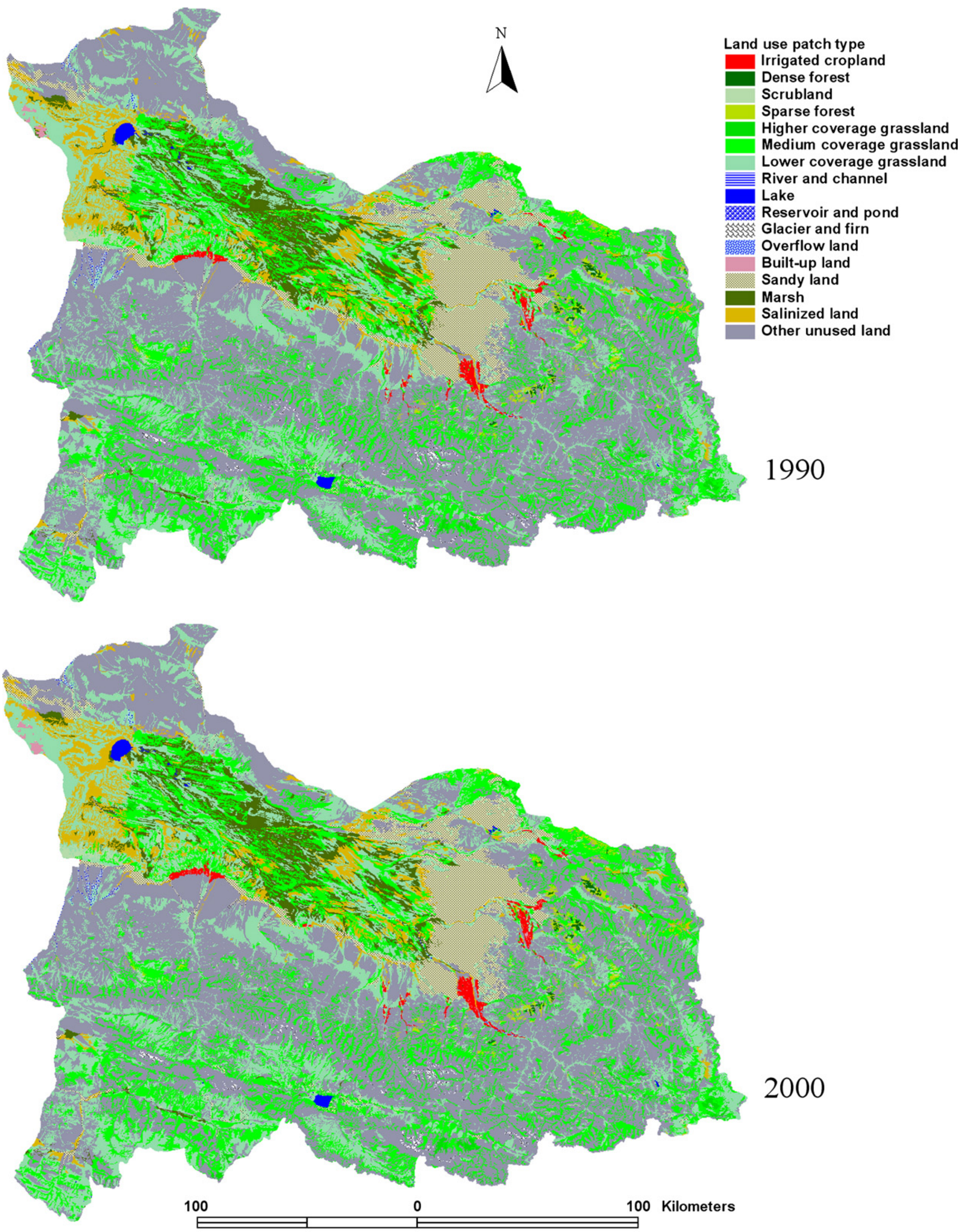

Fig. 2. Land use maps of Dulan County in 1990 and 2000.

level, five indices were selected: percent of landscape (PL), number of patches (NP), mean patch size (MPS), patch size coefficient of variance (PSCV), and area-weighted mean patch fractal dimension (AWMPFD). AWMPFD reflects shape complexity weighted by the area of patches. Land use patches with simple or regular shape usually have a low AWMPFD. Human activities usually make the shape of land use patches simple or regular. To make the phenomena of land use change easier to understand, cluster analysis was used to regroup land use types based on changing ratios of landscape metrics during 1990–2000. For the analysis of the change of landscape metrics at the landscape level, Shannon's diversity index (SDI) was selected (Table 2).

The magnitude and direction of changes in landscape are the most important factors relating to landscape evolution (Antrop, 2000). To define the transition of land use types in Dulan County during 1990–2000, the authors used Overlay Tool in the GIS software Arc/Info 8.3 to compute the geometric intersection of two periods of land use maps. The output coverage file was converted into shape file. The cross-tabulation table was calculated by using the PivotTable Wizard in Microsoft Excel, which was output as a transition matrix. The magnitude and direction of land use change was determined based on the transition matrix.

4. Results

4.1. Comparison of landscape metrics

Table 3 lists landscape metrics at class level and landscape level in 1990 and 2000. It is clear that land use patch types directly affected by human activities usually have a lower AWMPFD($\leq$1.30) (except for two types of natural water area of lake and glacier and firn). This is because that more human influence makes the shape of land use patches simpler or more regular. Geomorphology or flow direction of river mainly affects patterns of the patches in land use map. The plain area usually has patches elongating in northwest direction; whereas the mountain area usually has patches elongating in northeast direction (Fig. 2). Cluster analysis of landscape metrics (variables) at class level indicated that percent of landscape, patch size coefficient of variance, and area-weighted mean patch fractal dimension are relatively independent variables. Based on the changing ratios of three mentioned landscape

Table 2
Definitions of landscape metrics

Landscape metrics	Short description
Percent of landscape (PL)	Percentage of the landscape comprised of the corresponding patch type
Number of patches (NP)	Total number of patches in the landscape
Mean patch size (MPS)	Average patch size
Patch size coefficient of variance (PSCV)	Variability in patch size relative to the mean patch size
Area-weighted mean patch fractal dimension (AWMPFD)	Shape complexity weighted by the area of patches
Shannon diversity index (SDI)	Measure of relative patch richness

Table 3
Landscape metrics in Dulan County in 1990 and 2000

Patch type	CA	PL	NP	MPS	PSCV	AWMPFD	SDI
1990							
Irrigated cropland	28,091	0.52	125	225	335	1.29	
Dense forest	7140	0.13	45	159	155	1.28	
Scrubland	32,707	0.60	787	42	843	1.32	
Sparse forest	33,108	0.61	476	70	255	1.31	
Higher coverage grassland	30,406	0.56	147	207	174	1.30	
Medium coverage grassland	1,071,115	19.74	2866	374	488	1.35	
Lower coverage grassland	1,130,668	20.83	2786	406	661	1.34	
River and channel	1138	0.02	1	1138	0	1.43	
Lake	12,180	0.22	93	131	576	1.20	
Reservoir and pond	108	0.00	4	27	103	1.22	
Glacier and firn	10,215	0.19	276	37	208	1.27	
Overflow land	7590	0.14	34	223	180	1.41	
Built-up land	4973	0.09	161	31	529	1.26	
Sandy land	324,798	5.98	246	1320	638	1.31	
Marsh	223,438	4.12	500	447	742	1.36	
Salinized land	232,598	4.29	561	415	313	1.32	
Desert land	2,276,665	41.95	1331	1710	2101	1.43	
landscape	5,426,937	100.00	10439	520	2509	1.38	1.726
2000							
Irrigated cropland	33,979	0.63	103	330	305	1.28	
Dense forest	7141	0.13	45	159	155	1.28	
Scrubland	32,486	0.60	778	42	843	1.32	
Sparse forest	32,900	0.61	458	72	253	1.31	
Higher coverage grassland	31,357	0.58	137	229	194	1.30	
Medium coverage grassland	1,066,956	19.66	2834	376	485	1.35	
Lower coverage grassland	1,129,013	20.80	2740	412	662	1.34	
River and channel	1138	0.02	1	1138	0	1.43	
Lake	12,187	0.22	90	135	557	1.19	
Reservoir and pond	115	0.00	5	23	122	1.22	
Glacier and firn	10,215	0.19	276	37	208	1.27	
Overflow land	7520	0.14	32	235	175	1.41	
Built-up land	5921	0.11	161	37	540	1.24	
Sandy land	325,787	6.00	243	1341	635	1.31	
Marsh	220,765	4.07	457	483	712	1.36	
Salinized land	232,944	4.29	550	424	313	1.32	
Desert land	2,276,513	41.95	1329	1713	2100	1.43	
landscape	5,426,937	100.00	10239	530	2485	1.38	1.724

ID: ID of land use type; CA: class area (ha); PL: percent of landscape (%); NP: number of patches; MPS: mean patch size (ha); PSCV: patch size coefficient of variance; AWMSI: area-weighted mean shape index; AWMPFD: area-weighted mean patch fractal dimension; SDI: Shannon's diversity index.

metrics, cluster analysis of land use path types (cases) was used to regroup land use types (Fig. 3). The analysis indicated that there is obvious difference in landscape metrics change between land use types with higher land use benefits and land use types with lower land use benefits.

4.1.1. Landscape metrics change of land use types with higher land use benefits

Cropland occupied only about 0.52% of the total land area in 1990, but it was the most highly variable land use type. Its NP decreased from 125 to 103, while its MPS increased from 225 ha to 330 ha. Both its PSCV and AWMPFD decreased. Built-up land was only about 0.1% of the total land area, however it was also variable. Its NP did not change, yet, its MPS expanded from 31 ha to 37 ha. Its PSCV slightly increased, but its AWMPFD decreased. Higher coverage grassland is commonly affected by animal husbandry. Its NP decreased from 147 to 137, whereas its MPS, PSCV and AWMPFD increased. Reservoir and pond is very important to irrigation. Its NP increased from 4 to 5, but its MPS shrank from 27 ha to 23 ha. Both its PSCV and AWMPFD increased.

4.1.2. Landscape metrics change of land use types with lower land use benefits

Overflow land and marsh are essential to environmental protection. Overflow land had an NP decreasing from 34 to 32, and an MPS increasing from 223 ha to 235 ha. Both its PSCV and AWMPFD decreased. Marsh had an NP decreasing from 500 to 457, and an MPS expanding from 447 ha to 483 ha. Its PSCV decreased, however, its AWMPFD slightly increased. Other land use types usually had a decreasing NP, increasing MPS, decreasing PSCV and decreasing or stable AWMPFD.

Comparison of the changes of landscape metrics at landscape level showed that the study area had an NP decreasing from 10,439 to 10,239, an MPS expanding from 520 ha to 530 ha, a PSCV decreasing from 2509 to 2485, and an SDI decreasing from 1.726 to 1.724.

4.2. Magnitude and direction of land use change

Indicated by AWMPFD and based on our field investigation, land use types with higher land use benefits (cropland, dense forest, higher coverage grassland, reservoir and pond, and built-up land) belonged to artificial landscapes; while land use types with higher environmental value but lower land use benefits (scrubland, sparse forest, medium coverage grassland, lower coverage grassland, river, lake, glacier and firn, overflow land, and marsh) were usually close to natural landscapes. The expansion of some artificial landscapes were usually forced by socioeconomic development and aided by climatic conditions, while the changes among natural landscapes were usually forced by natural factors. The magnitude and direction of land use change in Dulan County during 1990–2000 were summarized concerning economic development and environmental protection.

4.2.1. Land use change driven by economic development

As shown in Table 4, cropland and built-up land remarkably increased by 20.96% and 19.08%, reservoir and pond and higher coverage grassland moderately increased by 5.92% and 3.13% from 1990 to 2000, respectively. Cropland expansion mainly resulted from shrinkage of lower coverage grassland (8.87%), medium coverage grassland (7.10%), salinized land (1.41%) and sparse forest (1.05%). Built-up land expanded mainly because some marsh (7.51%), salinized land (4.00%), cropland (2.72%) and lower coverage grassland (1.68%) were converted into built-up land. Reservoir and pond expanded mainly by occupying some cropland (2.76%) and lake (2.82%); whereas higher coverage grassland expanded mainly by occupying some medium coverage grassland (3.93%).

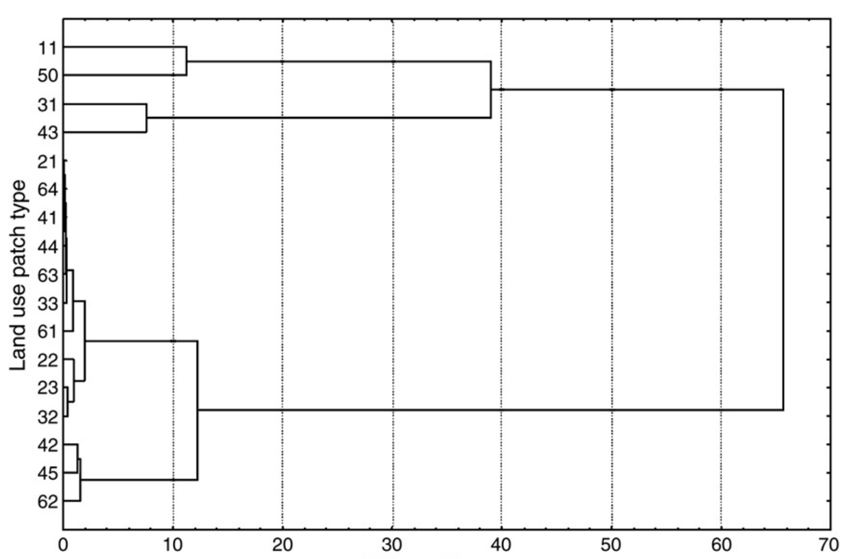

Fig. 3. Cluster analysis of land use types based on landscape metrics change.

Table 4
Magnitude and direction of land use change in Dulan County during 1990–2000 (%)

Patch type	Change	Land loss (mainly converted to)	Land expansion (mainly converted from)
Irrigated cropland	20.96	63(0.96), 51(0.57), 33(0.44), 61(0.19), 32(0.15)	33(8.87), 32(7.10), 63(1.41), 23(1.05), 61(0.16)
Dense forest	0.01	23(0.52)	32(0.53)
Scrubland	−0.68	11(0.65)	33(0.03)
Sparse forest	−0.63	11(1.08)	32(0.41), 21(0.11)
Higher coverage grassland	3.13	33(0.46), 62(0.21), 31(0.15), 64(0.10)	32(3.93)
Medium coverage grassland	−0.39	11(0.23), 33(0.13), 31(0.12)	33(0.11)
Lower coverage grassland	−0.15	11(0.27), 32(0.11)	32(0.12), 63(0.11)
River and channel	0.00		
Lake	0.06	33(1.28), 62(0.29), 63(0.27), 32(0.11)	45(0.85), 32(0.51), 33(0.36), 62(0.30)
Reservoir and pond	5.92		11(2.79), 42(2.79)
Glacier and firn	0.00		
Overflow land	−0.92	42(1.36), 33(0.17), 11(0.13)	33(0.42), 32(0.18)
Built-up land	19.08		62(7.51), 63(4.00), 11 (2.72), 33(1.68)
Sandy land	0.30	11(0.02)	33(0.17)
Marsh	−1.20	63(0.79), 33(0.41), 32(0.27), 50(0.20)	33(0.27), 32(0.25)
Salinized land	0.15	33(0.52), 11(0.21), 32(0.12), 51(0.10)	62(0.75), 32(0.20), 11(0.12)
Desert land	−0.01	61(0.01)	

Change $=(S_{2000}-S_{1990})/S_{1990}$ (%), S_{2000} and S_{1990}: land use areas in 1990 and 2000.
Number in front of the parenthesis is ID of land use patch type.
Number in the parenthesis is the percent of land conversion of the corresponding type.

4.2.2. Land use change detrimental to environmental protection

During 1990–2000, marsh and overflow land decreased by 1.20% and 0.92%; whereas scrubland, sparse forest, medium coverage grassland and lower coverage grassland slightly decreased by 0.68%, 0.63%, 0.39% and 0.15%, respectively. Marsh shrank mainly because it changed into salinized land (0.79%); while overflow land decreased mainly because it changed into lake. The shrinkage of scrubland, sparse forest, medium coverage grassland and lower coverage grassland was mainly caused by cropland expansion. Sandy land and salinized land slightly increased by 0.30% and 0.15%, respectively. Conversion of some lower coverage grassland into sandy land mainly resulted in the slight increase of sandy land; while salinization of some marsh, medium coverage grassland and cropland led to the slight increase of salinized land.

5. Discussion

5.1. Climatic changes affected land use change

According to the climatic changes in Dulan County during the period 1970–2002, climatic conditions were generally favorable to agricultural development in the study area. The mean annual air temperature increased with a rate of 0.39 °C per decade, and obviously increased with a higher rate in the 1990s. The annual precipitation increased with a rate of 10.6 mm per decade (Fig. 4). According to the relative study during 1960–2000 by Chen and Wu (2002), although the precipitation in autumn decreased, the precipitation in the other three seasons and the mean annual precipitation increased; the precipitation during crop growing period (from April to September) clearly increased with a rate of 10.8 mm per decade. The wind speed generally decreased with a rate of 0.4 m s^{-1} per decade during 1960–2000; however, it slightly increased in the end of 1990s. The evaporation capacity decreased with a rate of 124.3 mm per decade. Evaporation capacity is non-linearly correlated to many geographic elements, such as air temperature, air pressure, wind speed, relative humidity and characteristic of underlaying surface. It decreased partly because precipitation increased and wind speed decreased on the plateau.

Low temperature, scarce precipitation and high evaporation capacity are usually limiting factors affecting agricultural development on the frigid and arid plateau. Thus, the above-mentioned climatic changes were generally favorable to expansion of cropland and high coverage grassland and increase in area and patch number of reservoir and pond in the study area. Similar to the highlands of Chiapas in Mexico, the increase of agricultural lands also depends on other factors such as slope angle, soil depth and the availability of water sources (Ochoa-Gaona and Gonzalez-Espinosa, 2000).

However, the increase of the mean annual temperature and wind speed in the end of 1990s likely contributed to the expansion of sandy land and salinized land and shrinkage of marsh. Distributed on relatively high or sunny places with low soil moisture, some lower coverage grassland easily converted into sandy land. Comparatively, distributed on relatively low places, some marsh, medium coverage grassland and cropland easily changed into salinized land. Continuous expansion of sandy land and salinized land and shrinkage of marsh are harmful to environmental protection and sustainable agricultural development.

5.2. Economic development spurred land use change

Apart from climatic factors, economic development obviously spurred land use change. During 1990–2002, the average annual growth rate of GDP in the study area was about 23.5% (NBSC, 1991–2003b). Contributions to the growth rate from primary, secondary and tertiary industry were 8.2%, 6.9% and 8.3%, respectively (Fig. 5).

Just like other parts of West China (Li and Wang, 2003), crop production and animal husbandry have still played the most important role in the local people's life. For increasing their income and supporting growing rural population, the local people tried to expand cropland, higher coverage grassland, and reservoir and pond with higher economic benefits. Development of secondary and tertiary industry, as well as primary industry, also spurred built-up land expansion. In 1990, urban land, rural residential area and other built-up land (factory, industrious area,

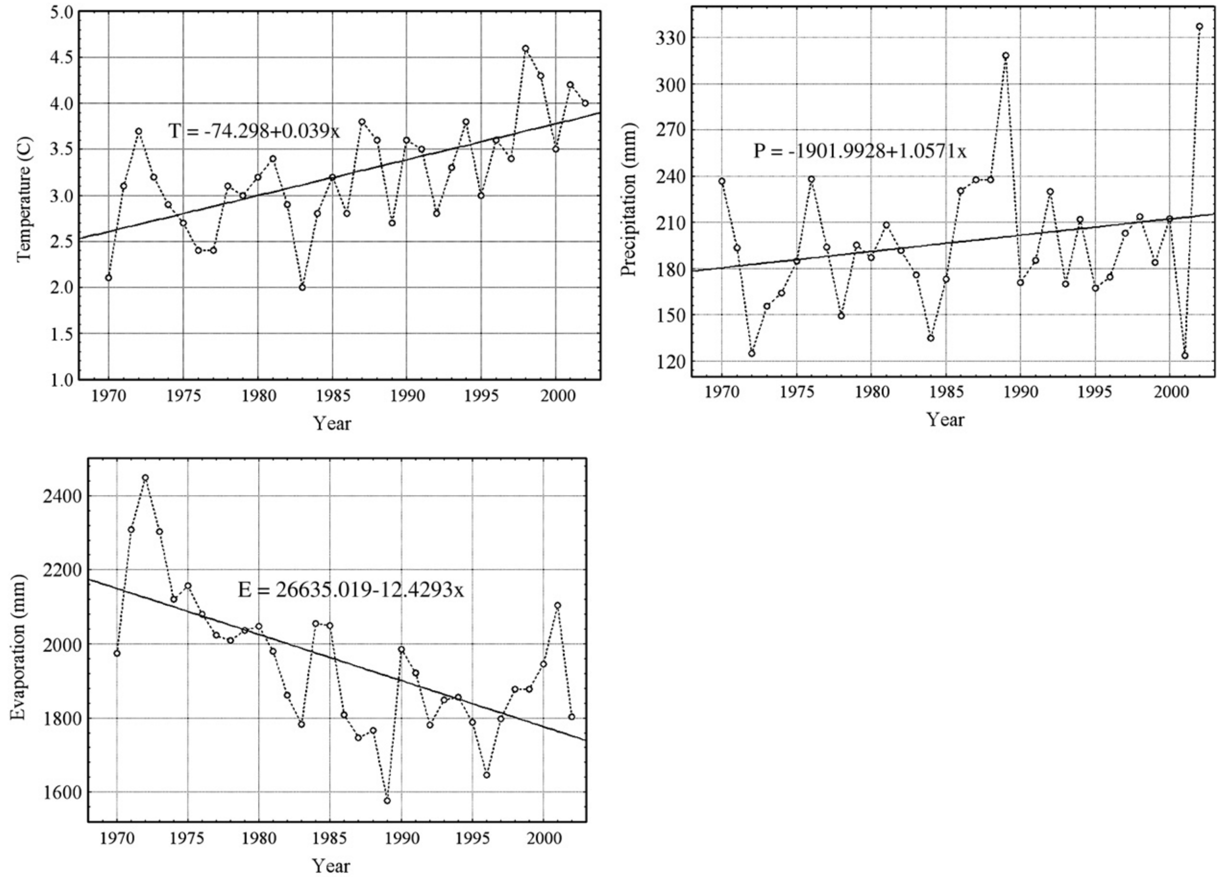

Fig. 4. Climatic changes in Dulan County during 1970–2002.

road, salt field, stone pit and so on) occupied 3.2%, 25.7% and 71.2% of the total built-up land area, respectively. From 1990 to 2000, they increased by 42.5%, 11.3%, and 20.9%, respectively. Thus, remarkable expansion of built-up land and cropland, moderate expansion of higher coverage grassland, and slightly shrinking of natural vegetation with lower economic benefits but higher environmental value are the characteristics of land use change in the agricultural counties on the plateau.

Rapid expansion of cropland and built-up land and evident shrinkage of native vegetation resulting from improvement of socioeconomic conditions and population growth also occurred in other arid areas (Xinjiang, Gansu and Shanxi) in Northwest China (Zhang et al., 2003; Zhou et al., 2003; Li and Wang, 2004). Driven largely by farmers' tendency for maximization of income, agricultural expansion was also found in the ecologically fragile and economically underdeveloped Himalayas in

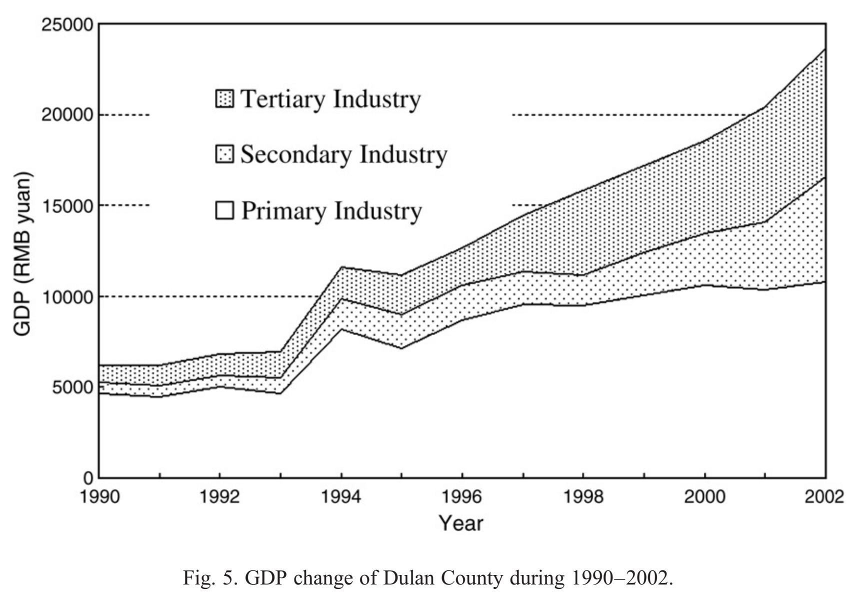

Fig. 5. GDP change of Dulan County during 1990–2002.

the absence of other means of livelihood (Tiwari, 2000; Semwal et al., 2004). Conversion of native grasslands into croplands also occurred in the temperate South America in the last century due to the aptitude of their soils and the adequate climatic conditions; however, the rate of agricultural expansion rises considerably due to technological changes and market circumstances at present (Baldi et al., 2006). In the eastern highlands of Madagascar, intensive cultivation of slopes increased during 1972–2001, a significant part of which came from cultivation of grassland savanna (Vagen, 2006).

However, agricultural expansion usually caused irrational water use and salinization, especially in arid and semi-arid regions wherever irrigation is practiced. Based on our filed investigation, problems of water shortage, waterlogging and salinization were common in the study area. In some parts of the world, like Pakistan, the population is growing very fast, and therefore, attempts are made to increase the agricultural production, in many cases by land reclamation, but facing limited water resources, waterlogging and salinization (Khan et al., 2005).

In South Asia with main climatic zones of arid/semi-arid, population growth, urbanization and real income growth also lead to greater demands for food and higher pressure on environment. In India and Pakistan, there has been a significant degradation of arid/semi-arid grasslands due to overgrazing. In India, there has been a marked reduction over the years in common property resources as a result of increased cropping. In Bangladesh, as a result of intensive cropping, negligible areas of native grasslands are now available for grazing. In Nepal, increasing animal populations and uncontrolled utilization have resulted in overgrazing, soil erosion and forest degradation (Devendra and Thomas, 2002). Because of the quick expansion of agricultural activities during the 1990s, the imbalanced provision of economic and ecological services has also become an issue of increasing concern in Del Plata Basin in South America (Viglizzo and Frank, 2006).

The shrinkage of scrubland and sparse forest were also due to that the local people prepare their meals and warm their houses with fuelwood. Especially in areas surrounding permanent settlements, scrubland loss was common in the study area, resulting in serious soil erosion. This situation also occurred in Mexico. It has been estimated that in Mexico around 19 million people prepare their meals with fuelwood. In the highlands of Chiapas, Mexico, a higher and increasing rate of deforestation occurred in areas surrounding permanent settlements (Ochoa-Gaona and Gonzalez-Espinosa, 2000).

The changes of landscape metrics were usually characterized by decreasing NP, increasing MPS and slightly decreasing AWMPFD, indicating that the landscape heterogeneity slightly declined with more larger and simpler-shaped patches mainly affected by human influence. This result is similar to that done in the middle Heihe River Basin of arid northwest China (Lu et al., 2003), which is near the study area.

5.3. Land use and land suitability

Although the recent climatic changes and socioeconomic development are favorable to the expansion of cropland and higher coverage grassland, the original natural landscapes such as scrubland, sparse forest, medium coverage grassland, lower coverage grassland, water area and marsh should be protected by special land use policy or an effective Tibetan Plateau Protection Law (Wang and Fu, 2004). The positive economic and environmental changes for land use were also found in the Central Plateau of Burkina Faso; however, the battle against land degradation on the plateau has not yet been won (Reij et al., 2005). It is clear that the environmental conditions are extremely fragile and the formation of the special natural vegetations has taken a long historic time on the plateau. If the natural landscapes were seriously destroyed for economic development, it would be impossible to restore them.

Like other parts of West China, “Grain for Green” policy (Wang et al., 2007) is very important in the study area. Restructuring of land use should be based on land suitability (Wang et al., 2004, 2007), rather than only based on the temporary economic benefits of land use. Based on Liu (2000) and Wang et al. (2004, 2007), highly, moderately and marginally suitable croplands were about 0.1%, 1.8% and 3.8% of the total land in the study area, respectively. According to our field investigation, abandonment of marginal cropland usually occurred resulting from unsatisfactory climatic conditions and poor management, leading to serious soil wind erosion. Thus, all the marginal cropland (about 22,735 ha) should be converted into grassland for ecological purposes.

Grassland should be rationally used. Grazing should be controlled in areas with steep slopes and/or coarse soil texture, since the soil-forming conditions are unstable (Wang and Fu, 2004). Similar study by Rezaei et al. (2006) in Iran also indicated that an increasing slope gradient can influence all soil properties especially stability index, therefore, range sites with a slope gradient more than 56% should not be grazed by livestock due to erosion risk. The expansion of built-up land at the cost of loss of marsh, cropland and lower coverage grassland should be controlled. Otherwise, the landscape heterogeneity will further decline and the arid environments will seriously degrade.

6. Conclusion

Rapid economic development and environmental change spurred the land use change on the Tibetan Plateau during the period 1990–2000. Land use change over this period was studied in Dulan County based on the changes of various landscape metrics and the transition matrix of land use types. Land use change was mainly characterized by expansion of the land use types with higher economic benefits and shrinkage of some land use types with higher environmental value. The study indicates that socioeconomic development was the main driving force of land use change, while climatic changes were generally favorable to the agricultural development. However, excessively pursuing higher land use benefits likely results in seriously environmental degradation. Land use should be based on the sustainable protection of arid environments on the plateau. This study may contribute to the policy making for the rational land use and arid environmental protection on the Tibetan Plateau.

Acknowledgments

The authors are indebted to the National Basic Research Program of China (2005CB422006), Institute of Geographic Science and Natural Resources Research, Chinese Academy of Sciences (O66U0112SZ, CXIOG-A05-05), Ministry of Sciences and Technology (2005BA517A-03) for their financial support. The authors gratefully thank Professor Zhuang Dafang (Resources and Environment Data Center, Chinese Academy of Sciences) for kindly providing mapped data and the Meteorological Information Center, China Meteorological Administration for kindly proving the climatic data. The comments from the two anonymous reviewers have been greatly helpful for strengthening the arguments of the paper.

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