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Analyzing Land-use Change in Farming-pastoral Transitional Region Using Autologistic Model and Household Survey Approach

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Abstract: Land change science (LCS) strives to understand and model land-use change, which will further advance the understanding of multiple issues in the socio-ecological systems. Based on GIS/RS techniques, autologistic model, and household survey method, this study investigated major land use changes and their causes from 1978 to 2008 in Uxin Banner (county-level), Inner Mongolia in China and then developed an understanding of the relationships between household livelihood and land-use pattern. Results showed that cultivated land increased from 1988 to 2000, and leveled off after 2000. Built-up land increased stably for the period 1978–2008. The change of grassland and bare land differed among the three periods. From 1978 to 1988, grassland increased by 23.3%, and bare land decreased by 20.48%. From 1988 to 2000, bare land expanded by 1.7%, but grassland declined by 1.3%. From 2000 to 2008, an increase in grassland area by 1.8% was observed, but a decrease in bare land area by 9.0% was witnessed. The autologistic models performed better than logistic models as indicated by lower Akaike Information Criterion (AIC) values. Factors associated with human activities significantly correlated with the change of cultivated land, forest land, grassland, and built-up land. The produce prices and extensive cultivated land use are major issues in the farming area. This study suggests that completing land circulation systems and maintaining the stability of price are effective solutions. By contrast, reclamation and overgrazing are major concerns in the pastoral areas. Implementing environmental policies effectively, transferring population out of rural pastoral areas, and developing modern animal husbandry are effective ways to address these issues.

Keywords: farming-pastoral transitional region; land use change; driving force; livelihood; autologistic model; Uxin Banner (county-level); Inner Mongolia

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1 Introduction

Since 1995 when the International Geosphere-Biosphere Programme (IGBP) and the International Human Dimensions Programme on Global Environmental Change (IHDP) jointly initiated Land-Use and Land-Cover Change (LUCC) Project, the studies of LUCC have attracted much more attention (Rindfuss *et al*., 2004; Turner II *et al*., 2007). The Global Land Project (GLP, 2005) emphasized the need to develop land change science (LCS) strategies that incorporate the range of the sciences from the biophysical to the social. LCS seeks to understand the dynamics of land cover and land use as a coupled human-environment system to address theory, concepts, models, and applications relevant to environmental and social problems, including the intersections of the two (Turner II *et al*., 2007). It has been seen as pivotal to sustainability, vulnerability, and resilience approaches (Turner II *et al*., 2003). Many researches in the field of LCS were devoted to the analysis of relations between land use and the socio-economic and biophysical variables considered as the 'driving forces'

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of land use change (Shao *et al*., 2006).

Farming-pastoral transitional zone is an ecologically vulnerable ecotone which transits from agricultural areas to pastoral areas in the north of China (Wang *et al*., 1999). This zone has an annual precipitation ranging from 300 mm to 450 mm with high inter- and intra-annual variability. Desertification is the most severe ecological problem; so this region is the main distributed areas of desertification in China (Guo *et al*., 2008). Several studies have been conducted on the characterization of land-use change, driving forces, and model simulation, such as Zou *et al*. (2003), Deng *et al*. (2004), Song and Zhang (2007), Xie and Li (2008). Zou *et al*. (2003) have reported that the cropland mainly converts into forest, and grassland mainly transfers into cropland, urban and built-up land in the ecotone between agriculture and animal husbandry. Grassland degradation, indicated by the increase in bare land, occurs in larger areas in China, especially in Inner Mongolia. Population pressure, economic growth, and adjustment of agricultural structure lead to the increase in cropland. Overgrazing activities and climate change are two major influencing factors of grassland conversion. Taking Ordos City in Inner Mongolia as an example, Song and Zhang (2007) concluded that natural conditions, population pressure, economic benefits and amalgamation of nationalities interact to impact land-use change. For example, the period of warm and humid climate in the Qing Dynasty provided favorable conditions for reclamation, and the unprecedented increase in population prompts the degradation of farmland. Xie and Li (2008) disentangled the relationships between major land-use change processes and diverse drivers using logistic regression model in Ongniud Banner, a farming-pastoral transitional zone in Inner Mongolia. The problem of using conventional statistical methods, like linear and logistic regression, in land use spatial analysis is that these methods assumed the observations to be statistically independent and identically distributed. In reality, this assumption is not satisfied as land use tends to be spatially dependent. Spatial dependency, which might lead to the wrong conclusions, needs to be addressed in land use spatial analysis. Land use is also dependent on scales as patterns or processes occurring at one level might disappear at other levels. Therefore, different perspectives and scales of analysis are needed to fully understand land-use change.

This study selected Uxin Banner (county-level) in Inner Mongolia, a typical farming-pastoral transitional area, as the study area to investigate the relationships between land-use change processes and proximate driving forces from both empirical and narrative perspectives. The objective of this study is to investigate the trajectories and causes of long-term land use change. Three questions as follows would be addressed: 1) How have the major land use types changed since the end of 1970s in Uxin Banner? 2) To what extent do the driving factors influence the major land-use changes? 3) How is household livelihood related to land-use change?

2 Materials and Methods

2.1 Study area

Uxin Banner (37°38′54″–39°23′50″N, 108°17′36″–109°40′22″E), located in the southwest of Ordos City in Inner Mongolia, China is the hinterland of the Mu Us sandy land (Fig. 1), with an area of 11 645 km^2. The average elevation is about 1300 m. This area is characterized by temperate continental climate with annual precipitation from 300 mm to 400 mm. The seasonal rainfall concentrates on June–September. The dominant land cover classes are grassland and desert. The total population increased from 66 812 in 1978 to 103 066 in 2007. In particular, non-agricultural population increased rapidly from 7612 in 1983 to 25 873 in 2007 (data were collected from the Uxin Statistics Bureau, not published). In recent years, Uxin Banner has been experiencing rapid economic growth. The gross domestic production (GDP) increased from 6.64×10^8 yuan (RMB) in 1998 to 7.00×10^9 yuan (RMB) in 2007 and the per capita income of rural families′ increases from 2316 yuan (RMB) in 1998 to 6289 yuan (RMB) in 2007. The agriculture and animal husbandry is still the basic industry, and its production increased from 4.39×10^8 yuan (RMB) in 1998 to 1.00×10^9 in 2007 (data were obtained from the Uxin Bureau of Animal Husbandry, not published). However, desertification and soil erosion are still two major ecological problems (Liu and Ci, 1997; Guo *et al*., 2008). The area affected by wind erosion and desertification accounts for 94.8% of total region (11 645 km^2), and the soil erosion area is about 9189 km^2. Land use has been experiencing great change since the 1970s.

2.2 Data and processing

Land-use change analysis was based on land-use maps

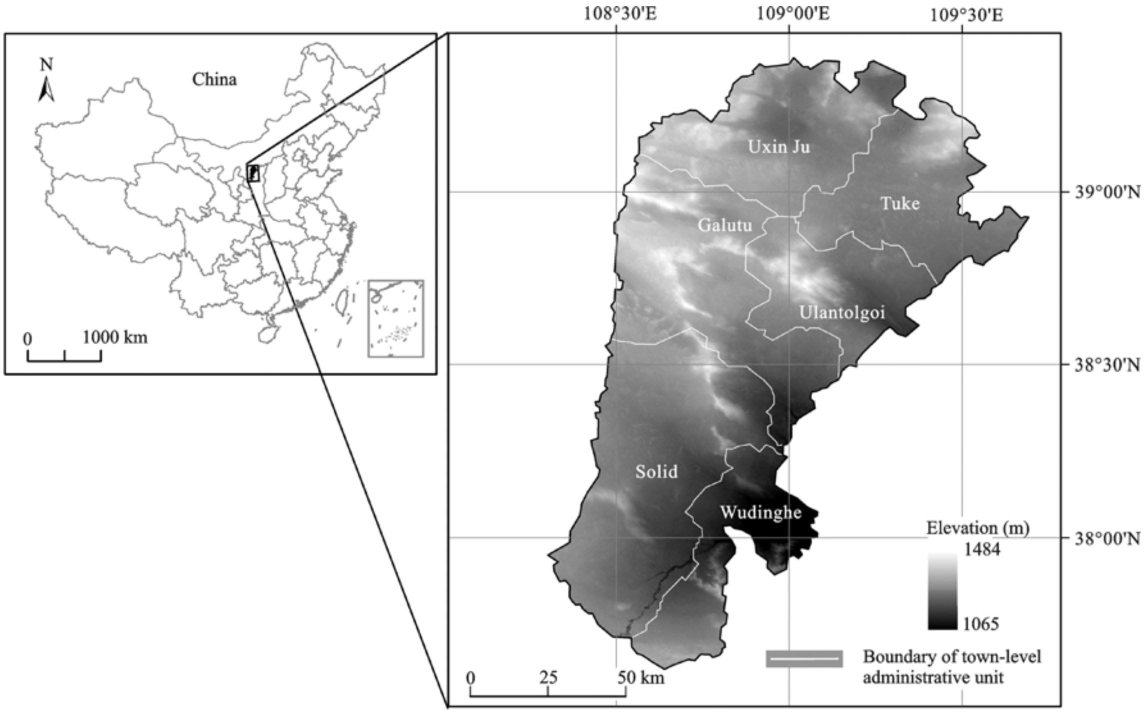

Fig. 1 Location of study area

in 1978, 1988, 2000, and 2008. Eight land use classes were defined including cultivated land, forest land, high-density grassland (land dominated by herbaceous vegetation with a percent cover > 50%), middle-density grassland (land dominated by herbaceous vegetation with a percent cover between 20% and 50%), low-density grassland (land dominated by herbaceous vegetation with a percent cover between 5%–20%), water body, built-up land (rural settlements, urban areas and roads), and bare land. Land use data in 1988 and 2000 were obtained from Data Center for Resources and Environmental Sciences of China Academy of Sciences, which were interpreted from historical Landsat TM/ETM+ images following national land use classification system. The classification accuracy is important to characterize land-use change in this analysis. Although the accuracy assessment is not available within this study area, Liao *et al*. (2011) has evaluated the national 1∶250 000 land cover products in the eastern Inner Mongolia based on 190 samples. The results show that the overall accuracy reaches 84.21% and the accuracies of built-up land, cultivated land, water, grassland and forest land get to 100% (10 samples), 92.54% (67 samples), 87.50% (20 samples), 81.36% (59 samples), and 66.18% (34 samples), respectively. Therefore, the land use datasets are reliable for land change analysis in this research.

Land-use data in 1978 and 2008 were interpreted from Landsat MSS/TM images by the authors through human-machine interactive interpretation. To avoid the error from seasonal difference, the acquisition time of the Landsat MSS/TM images were in the period of July–October when vegetation is in its maturity. The images in 1978 were geometrically rectified based on the corresponding images of 2008 through the nearest neighbor resampling algorithm with the root-mean-square error less than 0.5 pixel sizes. The main ground reference data were the 56 training samples of grassland collected in the field. Each sample was a square with 30 m × 30 m, whose coordinates, vegetation type, grass density were recorded. The data for accuracy assessment were mainly from Google Earth and 1∶100 000 vegetation map from the Uxin Bureau of Animal Husbandry. Tree hundreds random points within the study area were used to extract the interpreted land use classes of corresponding pixels. The actual land use classes of these random points were determined through Google Earth and vegetation map. The overall classification accuracies of 1978 and 2008 are 88.2% and 88.5%, respectively, and the overall Kappa statistics of 1978 and 2008 are 0.63 and 0.67, respectively. Figure 2 shows the land-use maps of Uxin Banner in 1978, 1988, 2000, and 2008. The land use data set of 1978 which was interpreted from Landsat MSS images was resampled to a grid size of 30 m × 30 m in order to be consistent with the resolution of land use data sets for other periods. Socio-economic data in 1978, 1988, 2000, and 2008 were collected from the Uxin Statistics Bureau. The Shuttle Radar Topography Mission (SRTM) DEM data with a spatial resolution of 90 m were used to create the slope layer, and the basic geographical information data were applied to generate layers of other independent variables such as the distance to rural settlement, the distance to town, and the distance to road.

Household survey was conducted in Wudinghe, Galutu, and Tuke within the study area in August, 2008. We utilized participatory rural appraisal and its tools including plot survey, observation, semi-structure interview, and questionnaire (Chambers, 1994; Cramb *et al*., 2004). The investigation contents are about basic household information, livelihood, land use, attitude to environmental policies, awareness of environment, and response to environment. 161 households were interviewed, and 161 pieces of questionnaire were made among which 153 were effective. On the basis of living standard, major income sources, labor allocation, and land-use pattern, we divided the households into three categories: pure-agricultural household, agro-pastoral household, and non-agricultural dependent household (Tan *et al*., 2001; Ouyang *et al*., 2004; Zhang *et al*., 2008; Zhu *et al*., 2010).

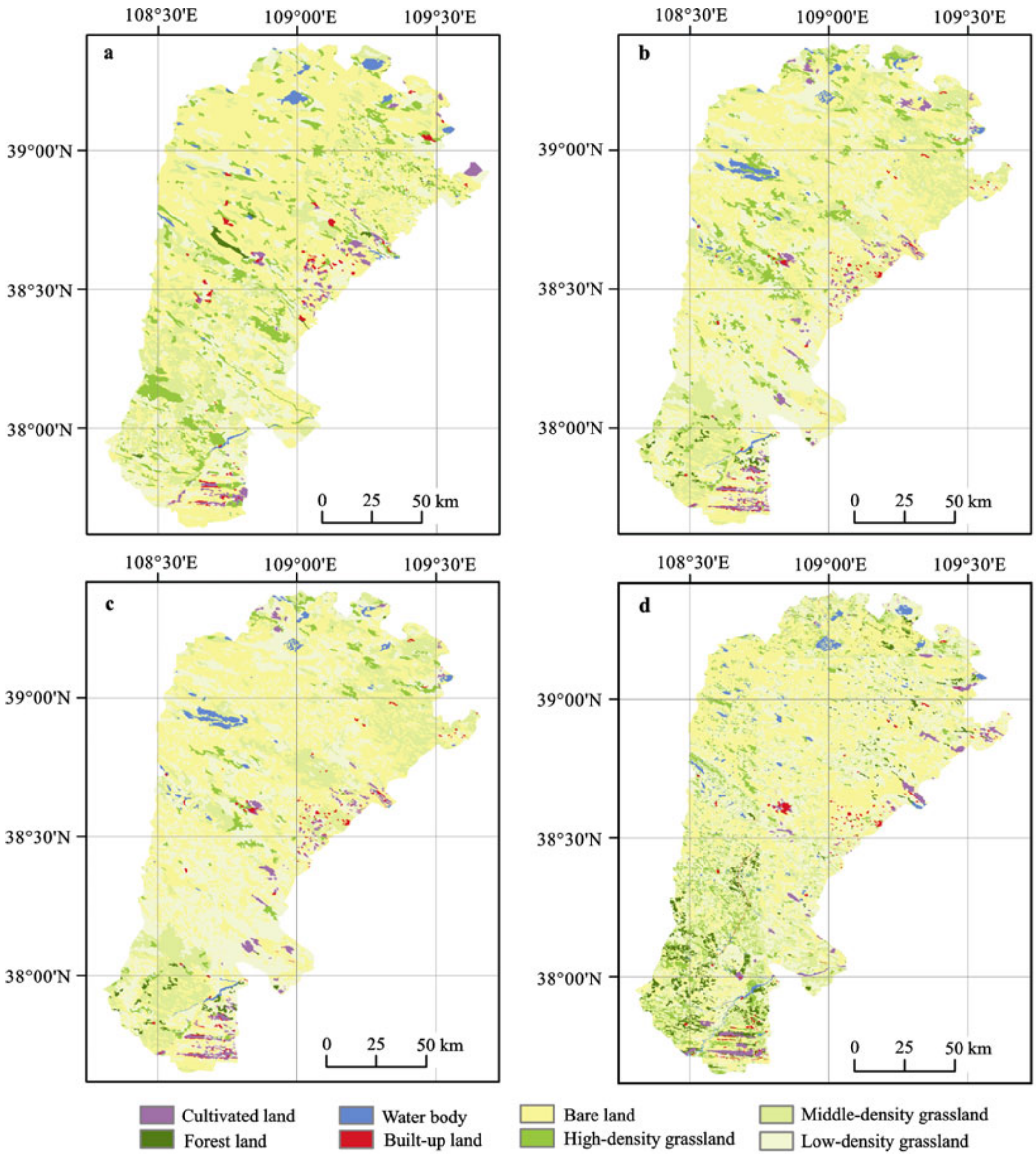

Fig. 2 Land-use maps in 1978 (a), 1988 (b), 2000 (c), and 2008 (d) in study area

2.3 Methods

2.3.1 Land-use change characterization

The pace of land-use change can be measured by models of land use dynamics which are not only to simply characterize the change of single land use type, but also reflect the overall land use dynamics (Wang and Bao, 1999). The singularity degree of land use dynamics indicates the change rate of single land use class over a span of time (Wang and Bao, 1999), which can be expressed as:

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \quad (1)$$

where K represents the singularity degree of land-use dynamic; U_a and U_b denote the area of a land use class at the beginning and end of the time span, respectively; T indicates the time length. If the time interval is set as one year, then the value of K indicates annual change rate of a single land use class.

The comprehensive degree of land use dynamics reflects the change rate of overall land use classes over a span of time (Wang and Bao, 1999). It can be expressed as:

$$LC = \left[\frac{\sum_{i=1}^{n} \Delta LU_{i-j}}{2\sum_{i=1}^{n} LU_i} \right] \times \frac{1}{T} \times 100\% \quad (2)$$

where LC represents the comprehensive degree of land use dynamics; LU_i indicates the area of the ith land use class at the beginning; ΔLU_{i-j} denotes the absolute value of the area that the ith land use class converses to other land use classes over a period of time.

2.3.2 Autologistic model

Logistic regression is useful for situations where the dependent variable has a binary output, e.g. the presence or absence of a characteristic or an outcome. The model is widely used to predict the probability that a case will be classified into one as opposed to the other of the two categories of the dependent variable. The logistic regression model with m explanatory variables is given by:

$$\ln\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \sum_{j=1}^{m} \beta_j X_{ij} \quad (3)$$

where P_i represents the response probability of one state for location i whose range is from 0 to 1; X_{ij} shows the jth explanatory variable for the location i; β_0 is the intercept and β_i is the regression coefficient of the jth explanatory variable. The model has been widely applied in the field of land change science (de Koning *et al*., 1998; Serneels and Lambin, 2001; Meng and Yan, 2009). However, this model does not incorporate spatial covariates and assume that the explanatory variables are spatially homogenous (Wu *et al*., 2008). Since the regression coefficients and significance of contribution of individual variables are sensitive to the presence of autocorrelation (Kok and Veldkamp, 2001; de Nijs and Pebesma, 2010), Augustin *et al*. (1996) proposed the autologistic model which consists of a term called the auto covariate in Equation (4). The autocovariate is composed of a spatially weighted average $autocov_i$ of nearby values of the response variable y. The autologistic model is therefore written as:

$$\ln\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \sum_{j=1}^{m} \beta_j X_{ij} + \gamma autocov_i \quad (4)$$

$$autocov_i = \frac{\sum_{k=1}^{n_i} w_{ik} y_i}{\sum_{k=1}^{n_i} w_{ik}} \quad (5)$$

where $autocov_i$ is a weighted average of the number of presence amongst a set of n_i neighbors of point i; γ is the coefficient of the autocovariate component; w_{ik} is the weight between unit i and unit k; y_i is the observation at unit i (1 or 0). This model considers spatial autocorrelation and heterogeneous environment, in which the occurrence of an event in neighboring units conditions the likelihood that unit i will itself experience the event. Various methods are available to determine spatially weighted matrix, depending on the research questions and underlying process. The method used here might be written as:

$$w_{ik} = \begin{cases} 1 & d_{ik} \le h \\ 0 & d_{ik} > h \end{cases} \quad (6)$$

where d_{ik} is the distance between point i and point k and h is bandwidth. The maximum pseudo-likelihood estimate is used to determine the coefficients, which is conducted in R software. We chose the major land-use changes as dependent variables as indicated by substantial conversion area (Table 1). y_i = 1 means the occurrence of specified land-use change, while y_i = 0 indicates that that change does not occur. We pre-selected the factors that influence land-use change potentially as independent variables (Table 1). The samples for the input of models were drawn randomly, and there were no less than 200 samples for the inputs of each model. The Akaike Information Criterion (AIC) was applied to indicate how well logistic models and auto logistic models perform. The lower the AIC value is, the better the model fits.

3 Results and Analyses

3.1 Land-use change

During 1978–1988, the area of cultivated land, forest land, built-up land, and grassland increased by 17.2%, 26.3%,15.6%, and 23.3%, respectively, while bare land decreased by 20.4% (Table 2). The LC value of the period 1978–1988 was 13.9%, larger than the other periods. This indicates the overall changes of land-use classes were dramatic. About 3.3%, 19.9%, and 44.2% of the total cultivated land in 1978 transferred into built-up land, bare land, and grassland, respectively. The increase in forest land was mainly from grassland and bare land. Built-up land expanded by 4.84 km^2 which was mainly from grassland, bare land and cultivated land. The amount of transfer from bare land to grassland (2268.67 km^2) was much more than that of the reverse transition (1008.35 km^2), suggesting the mitigation of desertification process.

Table 1 Variables included in autologistic regression model

Period	Dependent variable	Independent variable (abbreviation)
1978–1988	To cultivated land	Elevation (EL), Slope (SL), Distance to water body (DW), Distance to town (DT), Distance to rural settlement (DRS), Distance to road (DR), Increase in population density (PD), Increase in non-agricultural population (NAP), Increase in rural employees (RE), Increase in per capita income (IN)
	To forest land	
	To built-up land	
	To high-density grassland	
	Out of low-density grassland	
	Out of bare land	
1988–2000	Out of high-density grassland	
	To low-density grassland	
	To bare land	
2000–2008	Out of cultivated land	
	To forest land	
	To high-density grassland	
	Out of low-density grassland	
	Out of bare land	

Note: All independent variables as shown in right column were incorporated into each autologistic regression model corresponding to each land use process as indicated by dependent variable

During 1988–2000, the areas of cultivated land, forest land, and built-up land remained stable as indicated by the small difference in the total area of each land use class of the two periods (Table 2). The K value of each land use type was relatively small, and LC value was only 0.5%, which implies that the single and overall land use classes do not change dramatically. Cultivated land in 1988 mainly changed into grassland and barren land by 13.4% and 2.3%, respectively. The expansion of built-up land mainly comes from grassland and bare land. Amount of transfer from grassland (528.75 km^2) to bare land is much more than the amount of the reverse change (49.50 km^2), which implies that desertification deteriorates.

During 2000–2008 land use change was characterized by a decrease in cultivated land, bare land, significant increase in forest land, and stable rise in built-up land (Table 2). The larger K value indicates that single land use type has been experiencing dramatic change. Meanwhile, the LC value was 4.0%, the secondary among the three periods, which suggests all land use types change to a moderate extent. Cultivated land converted to grassland (57.5%), bare land (23.0%), forest land (9.2%), and built-up land (3.0%). The increase in built-up land mainly came from cultivated land. Amount of transfer from bare land to grassland (2396.50 km^2) was more than that of reverse transition (2095.25 km^2), suggesting the mitigation of desertification.

3.2 Analysis of driving forces

Table 3 shows the results of autologistic models of land-use change and its influencing factors in Uxin Banner during the periods of 1978–1988, 1988–2000, and 2000–2008. Overall, autologistic models perform better than logistic models indicated by the lower AIC values (Table 3). During the period 1978–1988 the expansion of cultivated land negatively correlates with the distance to rural settlements, implying that land near the settlements tends to be reclaimed to cropland. The correlation coefficient with the distance to town is also significantly negative. As for forest land, the coefficient with the increase in population is positive and statistically significant, which means that population growth is favorable for the increase in forest land. As for built-up land, the coefficient with the slope is negative and statistically significant. It indicates that the increase in build-

Table 2 Land-use change during period of 1978–2008 in Uxin Banner of Inner Mongolia, China

Phase	Statistical type	Cultivated land	Forest land	Water body	Built-up land	Bare land	High-density grassland	Middle-density grassland	Low-density grassland
1978	Area (km^2)	168.92	45.72	120.24	48.16	6132.41	1067.87	1641.03	2396.63
	Area (%)	1.45	0.39	1.03	0.41	52.77	9.18	14.12	20.62
1988	Area (km^2)	198.00	57.75	139.00	53.00	4884.25	702.75	2030.75	3560.75
	Area (%)	1.70	0.50	1.20	0.46	42.01	6.04	17.47	30.63
2000	Area (km^2)	197.25	58.50	141.00	51.00	4967.50	296.25	1874.75	4043.50
	Area (%)	1.70	0.50	1.21	0.44	42.71	2.55	16.12	34.77
2008	Area (km^2)	160.50	376.00	164.75	65.25	4518.00	676.25	1998.50	3652.25
	Area (%)	1.38	3.24	1.42	0.56	38.91	5.82	17.21	31.45
1978–1988	Change (km^2)	29.08	12.03	18.76	4.84	–1248.16	–365.12	389.72	1164.12
	K (%)	17.22	26.31	15.60	10.05	–20.35	–34.19	23.75	48.57
1988–2000	Change (km^2)	–0.75	0.75	2.00	–2.00	83.25	–406.50	–156.00	482.75
	K (%)	–0.03	0.11	0.12	–0.31	0.14	–4.82	–0.64	1.13
2000–2008	Change (km^2)	–36.75	317.50	23.75	14.25	–449.50	380.00	123.75	–391.25
	K (%)	–2.33	67.84	2.11	3.49	–1.13	16.03	0.83	–1.21

Notes: K is singularity degree of dynamics; '–' means decrease of area

up land is distributed in the even areas. The increase in population density has the most considerable influence on the expansion of built-up land as indicated by the large, positive, and statistically significant coefficient of the independent variable, the increase in population density. The expansion of built-up land negatively correlates with the distance to road, which suggests the built-up land such as rural or urban settlements tends to expand or be constructed near the roads. For the period 1978–1988, the increase in high-density grassland negatively correlates with the distance to rural settlement and road, but positively correlates with slope. The decrease in low-density grassland is largely influenced by the distance to road as indicated by the negative and statistically significant coefficient. The decrease in bare land in this period has a negative correlation with the distance to road and a positive correlation with population density.

For the period 1988–2000, the decrease in high-density grassland is mainly influenced by the distance to rural settlement as indicated by the significant negative coefficient (Table 3). The relationship of this period is opposite to that of the previous period 1978–1988, which is probable that human activities such as grazing result in the degradation of grassland. The increase in low-density grassland correlates negatively with the increase in non-agricultural population. The increase in bare land is mainly impacted by the distance to rural settlement with positive correlation, which means that the land near the settlements is likely to be utilized fully.

From 2000 to 2008, the coefficients for the distance to rural settlements and the distance to roads are negative and statistically significant in terms of cultivated land (Table 3). This implies that the cultivated land near the rural settlements and roads tends to change into other land such as built-up land or forest land. The increase in forest land negatively correlates with the distance to town, because trees are probably to be planted near the town. Meanwhile, the coefficients of the distance to rural settlement and the distance to road are also negative and statistically significant; this implies that the increase in forest land tends to be distributed near the rural settlements or roads. For the period 2000–2008 the increase in high-density grassland correlates positively with the increase in non-agricultural population. The decrease in bare land positive correlated with the distance from the distance to rural settlement, which implies that desertification tends to occur surrounding rural settlements.

3.3 Relationship between household livelihood and land use change

Household livelihood strategy was closely related to land use, and land use activities were influenced by different livelihood strategies (Yan *et al.*, 2009; Zhu *et al.*, 2010). Table 4 illustrates livelihood strategy of different types of households and Table 5 shows the perception of living standard and improving approaches of three

Table 3 Autologistic model of land use change and its influencing factors during periods of 1978–1988, 1988–2000 and 2000–2008

Period	Dependent variable	EL	SL	DT	DRS	DR	DW	PD	NAP	RE	IN	AIC_1	AIC_2
1978–1988	To cultivated land			-0.06^{*}	-1.13^{***}							122	149
	To forest land	0.04^{*}		-0.26^{**}				0.85^{**}				58	62
	To built-up land		-0.47^{*}			-0.52^{*}		0.53^{*}				69	81
	To high-density grassland		0.12^{*}		-0.36^{***}	-0.23^{**}				0.06^{*}		633	669
	Out of low-density grassland					-0.14^{**}	-0.03^{**}		-0.03^{*}	0.03^{*}		1509	1533
	Out of bare land					-0.09^{**}	-0.02^{**}	0.09^{*}				3108	3114
1988–2000	Out of high-density grassland	0.01^{*}			-0.32^{**}		-0.06^{**}			-0.07^{**}		468	481
	To low-density grassland			0.03^{*}					-0.19^{*}	-0.07^{***}		531	544
	To bare land			-0.05^{*}	0.37^{**}							161	161
2000–2008	Out of cultivated land	-0.01^{**}		0.07^{**}	-0.96^{***}	-0.46^{*}						182	205
	To forest land			0.05^{**}	-0.29^{**}	-0.27^{*}						337	352
	To high-density grassland	0.01^{***}							0.04^{*}		-0.01^{*}	754	760
	Out of low-density grassland			0.02^{***}			0.02^{*}			-0.04^{*}		2565	2587
	Out of bare land	-0.01^{**}		0.01^{*}	0.11^{**}							2836	2846

Notes: ***: $p < 0.01$; **: $p < 0.05$; *: $p < 0.1$; AIC_1: AIC value of autologistic model; AIC_2: AIC value of logistic model. Meanings of variable abbreviation are explained in Table 1

household categories: pure-agricultural households, agro-pastoral households, and non-agricultural dependent households.

Pure-agricultural households generally have small household size and older age structure. Their major production activities include planting grain and cash crops, and breeding livestock. For some families, their members do some work outside at unfixed time. Livelihood strategy is comparatively single and thus the livelihood risk is higher. Their primary living pressure is low income due to natural disasters, livestock plagues, and low benefits from cultivation. To improve their livelihood, some households are prior to increasing the number of livestock, enhancing agricultural intensification through increasing investments and improving technology; others turn to non-agricultural industrial sectors. These households have no rangelands, and so have no grazing activities. The average area of cultivated land per household is 0.012 km^2. The land is distributed dispersedly, which might impede the intensified production. The larger and closer to the house the plot is, the more investments the farmers are willing to make into the land. The planting structure is diverse, which reduces the livelihood risk caused by natural disasters and fluctuations of produce price. These households impact cultivated land differently. With the farmers allowed to transfer their land more freely, some households of this kind which possess abundant capital and labors tend to buy more cultivated land. To get more money, they adjust planting structure by increasing the area of cash crops and improving the soil conditions. All these measures benefit the intensification of land use. On the other hand, some households tend to allocate more labors to non-agricultural activities, but they are still not willing to transfer their land. As a result, these households are gradually less dependent on agricultural activities, and their extensive land use is not beneficial to land protection.

Agro-pastoral households engage in both cultivating and grazing activities. The major sources of income include animal husbandry and government subsidies. To improve their livelihood, most expect to increase the number of grazing animals (Table 5). About 43% of these households consider the shortage of grassland as the living pressure, and 26% of these households think the increase in livestock as the improving approach. Therefore, they usually place an excessive number of livestock over grassland without considering their carrying capacity. The households of this kind have rangelands with an area of 1.347 km^2 per household, and have cultivated land with an area of 0.028 km^2 per household. Cultivated land is mainly reclaimed from grassland close to their houses. The rain-fed cultivated land which are reclaimed from grassland in the pastoral areas tend to be abandoned during drought years, which is considered as one reason for grassland degradation and desertification. The implementation of 'restoring grazing to grasslands' policy since 2000 has prevented overgrazing activity. However, the conflict between the expectation of increasing livestock number and the limitation of grassland carrying capacity and the conflict between the economic benefits and environmental protection are still acute within rural pastoral areas.

Non-agricultural dependent households engage in both agricultural and non-agricultural activities. Their major source of income is non-agricultural activities. As the comparative advantage of non-agricultural sectors is higher than that of agricultural activities, these households allocate more investments such as capital and labor to non-agricultural activities. With the reallocation of labors to off-farm employment, women and elders have to assume the role of farmland management, which

Table 4 Livelihood strategies of different household categories in study area

Household category	Cultivating	Breeding	Grazing	Out-working	Salary-working	Trading	Sideline	Transporting	Others
Pure-agricultural	√	√		√					
Agro-pastoral	√	√	√	√					
Non-agricultural dependent	√	√	√	√	√	√	√	√	√

Notes: '√' indicates that household category is to adopt this activity. Cultivating includes crops (corn, potato, cereal, *etc*.), vegetables, fruits (apple, peach, melon, *etc*.); breeding is defined as raising livestock in corral including pig, cattle, sheep, chicken, duck and others; grazing is defined as raising livestock mainly in rangeland without restriction including sheep, cattle, horse, and so forth; out-working includes full-time employment (working outside for a whole year to get wages) and part-time employment (working at unfixed time); salary working is a type of job that is paid monthly, including worker, teacher, soldiers, drivers, village cadre, and so forth; trading includes operating small shop, merchandising agricultural products, and so on; sideline includes small-scale manufacture (making beancurd, running mill, *etc*.), handcraft (haircut, decoration, repair, drilling well, *etc*.); transporting is defined that a type of job that delivers goods or passengers for others to get pay, for example, driving bus, car, tractor and other agricultural vehicles; others include renting land

Table 5 Perception of living standard and improving approaches of different household classes in study area

Household type	Living evaluation (%)			Living pressure (%)	Improving approaches (%)	Help needed (%)
	Satisfaction	Medium	Non-satisfaction			
I	54.5	29.1	16.4	Lacking money, 31; no literacy or techniques, 32; medical problems, 27; offspring's education fees, 15; unreasonable prices of production materials or produce, 13; children' employment, 12; building house for children' marriage, 12; no pressure, 21	Expanding breeding scope, 52; planting crops better, 46; doing more work outside via increasing labors or time, 20; enriching sideline activities, 8; planting fruit trees, 6; trading, 6	Techniques and training, 63; information about acquiring wealth, 56; capital, 54; national investments, 27; relief, 10; not needed, 8
II	75.0	20.0	5.0	Shortage of rangeland, 43; lacking money, 20; offspring's education fees, 15; no literacy or techniques, 13; children' employment, 8; medical problems, 8; unreasonable prices of production materials or produce, 8; building house for children' marriage, 5; no pressure, 30	Expanding breeding scope, 72; planting crops better, 31; expanding grazing scale, 26; doing more work outside via increasing labors or time, 23; trading, 15; planting fruit trees, 3; enriching sideline activities, 3	Capital, 83; techniques and training, 53; information about acquiring wealth, 45; national investment, 43; relief, 5; not needed, 8
III	58.6	32.8	8.6	Lacking money, 29; shortage of rangeland, 23; unreasonable prices of production materials and produce, 20; children' employment, 16; building house for children' marriage, 11; no literacy or techniques, 9; offspring's education fees, 9; medical problems, 9; no pressure, 7	Expanding breeding scale, 39; planting crops better, 36; doing more work outside via increasing labors or time, 21; trading, 20; expanding grazing scale, 18; planting fruit trees, 7; enriching sideline activities, 2.	Capital, 72; information about acquiring wealth, 53; techniques and training, 53; national investments, 23; relief, 7; not needed, 2

Notes: Percentage represents ratio of household number mentioning same item to total number of corresponding household type. Household classification is mainly based on labor allocation and land-use pattern is unbeneficial to land intensification.

4 Discussion

Cultivated land increased stably during the period 1978–2000, which is consistent with the conclusions of previous studies such as Wang *et al*. (1999), Deng *et al*. (2004), and Song and Zhang (2007). The autologistic results show that the increase in cultivated land is closely linked with the distance to rural settlement and the distance to town. These factors imply that human activities are the underlying dominant drivers of cultivated land expansion. Population growth, the increase in food demand and the labor availability prompt farmers to reclaim more land largely from grassland or bare land. From 2000 to 2008, cultivated land in the whole region decreased, which negatively correlates with the distance to rural settlement and the distance to road. This implies that the decrease in cultivated land can be attributable to the expansion of built-up land and the dependence of non-agricultural activities. In terms of policy and institution, the implementation of household responsibility system since the 1980s makes the farmers possess cultivated land to reach their objectives by investing more labors or increasing multiple cropping indices. However, the land systems, which are characteristic of collective ownership and unified collective operation, lead to the uncompensated, unlawful, fragmented, and/or excessive use of farmland. The transformation to the socialist market economy system in the late 1980s and early 1990s prompts the further expansion of cultivated land. Farmers pursue the maximum profits by using land, labor, and capital fully against the background of free market. The decrease in cultivated land from 2000 to 2008 can be attributable to the 'grain-for-green' policy implemented in 2000 in Uxin Banner. Farmers receive subsidies to compensate the loss due to change their cultivated land to forests or grassland. This policy also contributes significantly to the rapid increase in forests since 2000. By 2006 the total area in Uxin Banner where the 'grain-for-green' policy has been conducted is 467.36 km^2, of which the reforestation area from cultivated land amounts to 64.67 km^2, and that from desert is equal to 402.69 km^2 (data were collected from the Uxin Bureau of Forestry, which are not published). Previous studies have showed that this policy enhances net primary productivity, improves environment, and increases farmers' income (Wang *et al*., 2007).

Since 1978 grassland has experienced an 'increase-decease-increase' process. These changes can be partially attributable to natural factors such as topology, soil properties, and climate change. Factors associated with human activities also play an important role in grassland change. Just as indicated by the autologistic model results, the changes in grassland of different density and bare land significantly correlate with the distance to rural settlement, the distance to road, and the increase in population density, non-agricultural population density, and rural employee density. These results are generally consistent with following studies, such as Zou *et al*. (2003), Deng *et al*. (2004), Xie and Li (2008). Most of the above factors are associated with grazing activity which plays an important role in grassland change. Driven by profit maximization, grazing households tend to excessive use of grassland, which results in grassland degradation and desertification. Reclamation is another important factor underlying grassland change. If the benefits from reclamation are higher than costs, then it is very likely that grassland convert into cropland which is unstable. If the marginal benefits from the reclaimed lands are lower than marginal costs, it is probable to abandon this unstable cropland which is difficult to restore. In terms of policy and institution, the implementation of 'restoring grazing land to grasslands' policy since 2002 has increased or restored much area of grassland. By granting grazing households reasonable economic compensation, measures such as grazing prohibition, grazing suspending, rotational grazing and re-seeding are made to rehabilitate grass and enhance productivity, and to mitigate the conflicts between the production of grassland and the demand of animal husbandry. During the period 2002–2006, grazing land of 24 km^2 were restored to natural grassland, of which grazing prohibition area amounts to 5.33 km^2, rotational grazing area is 0.67 km^2, grazing suspending is equal to 18 km^2, and re-seeding area equals 4.67 km^2 (data were collected from the Uxin Bureau of Animal Husbandry, which are not published).

Household livelihood is closely linked to land-use pattern. The prices of produce exert great impact on the availability of economic resources and further on land-use decisions. With regard to pure-agricultural households with the high-degree marketization, the produce prices influence directly planting structure and further land-use patterns. As the prices of a crop increase, the area of this crop will increase rapidly during the next season. The increase in household income will stimulate farmers to make more investments in terms of fertilizer, technology and management (Tan *et al.*, 2001). For these households, the prices of produce and agricultural materials (such as fertilizer and pesticide) are two major concerns. With regard to pure-agricultural households with the low-degree marketization, the fluctuations of the produce prices do not have much influence on land-use patterns since the agricultural products are mainly consumed by themselves (Li, 2002). For non-agricultural dependent households, more economic resources will be allocated to non-agricultural activities as a result of lower comparative advantage of agricultural products. Since the produce is mainly to meet the households′ need or the income from agricultural activities accounts for a small part of entire income, the produce prices do not affect land use too much. The less investment usually results in extensive use of cropland. This result is consistent with the conclusion of Zhang *et al.* (2008) in the eastern Tibetan Plateau. The produce prices and the extensive use of cropland are the main problems in the farming areas. To solve these problems, it is necessary to establish complete land circulation system which allows the farmers to transfer their land use rights freely and orderly through land market. For one thing, some pure-agricultural households can acquire more land to realize mechanized farming; for another, non-agricultural households can get reasonable compensations by transferring their land use rights. This will promote agricultural industrialization and sustainable use of farmland (Zhong and Huang, 2007). Another important point is to maintain the stability of produce prices by the macro-regulation of market. Because the persistence of low produce prices will reduce incentives of farmers, which results in abandoning marginal cropland. With regard to agro-pastoral households, the produce prices will affect reclamation and number of livestock. The increase in prices tends to prompt farmers to reclaim cropland from grassland. Also, the increase in the prices of animal husbandry products will increase specific type of livestock, and further exert different impact on grassland. Reclamation and overgrazing activity are two major concerns in the pastoral areas. First, to prevent overgrazing activities the ′restore grazing areas to grasslands′ policy should continue to implement. This policy is very effective to allow grassland to reproduce, grow, and restore. Second, the ′grain-for-green′ policy should continue to be carried out to return cropland to grassland and new policy should be formulated to prevent farmers to reclaim. Third, transferring population out of rural pastoral areas and supplying them with job opportunities is an effective way to restore severely degraded grassland. Fourth, in the pastoral areas with high-quality forage, the modern animal husbandry should be developed to achieve both environmental and economic benefits.

Post-classification comparison involves a pixel-by-pixel or segment-by-segment comparison of land-cover maps derived from satellite images taken at two or multiple points in time (Coppin *et al.*, 2004; Lu *et al.*, 2004). The accuracy of changing map is directly dependent on both the accuracy associated with the input classified maps and the interaction of these errors over time. The errors in the classification maps are due to the mis-registration and misclassification. More efforts should be made to account for the errors in land transition matrix (Pontius and Li, 2010), and to assess the accuracy associated with maps of land-cover change by a simulation approach (Burnicki *et al.*, 2007). Spatial autocorrelation and spatial heterogeneity are challenges associated with the use of multiple regression analysis to spatial data. Through random sampling method and autologistic model, the spatial autocorrelation and heterogeneity are considered in the models to meet the assumption of multiple regressions. Further research can be made to improve the algorithm of autologistic model in the future (Ward and Gleditsch, 2002) and consider the multi-scale feature of driving forces (Veldkamp and Fresco, 1997; Overmars *et al.*, 2003).

5 Conclusions

Drawing on GIS/RS techniques, autologistic model, and household survey, this paper analyzed major land use changes and their causes during the period 1978–2008, and investigated the relationship between household livelihood and land use. This study has great implications for policy formulation to benefit household livelihood improvement and land use sustainability in the farming-pastoral transitional zone. Since 1978, Uxin Banner has been experiencing great land-use change.

From 1978–2008, cultivated land increased and leveled off, while built-up land increased stably. During 1978–1988, grassland increased by 23.3%, while bare land decreased by 20.4%. During 1988–2000, bare land increased slightly by 1.7%, in comparison to a decline in the area and density of grassland. During 2000–2008, forest land increased significantly with more than five times of the area in 2000 and the area of grassland also increased by about 1.8%; by contrast, bare land reduced by 9.0%. Compared with logistic model, autologistic model could consider spatial autocorrelation and spatial heterogeneity of explanatory variables, and it therefore performs better in fitting the data. Factors associated with human activities are generally incorporated into models with higher statistical confidence level. Household livelihood is closely linked with land-use patterns. The prices of produce exert great impact on the availability of economic resources and further on land-use decisions. In the farming areas, produce prices and extensive land use are major concerns. Therefore, completing land circulation systems and maintaining the stability of prices are two effective solutions. In the pastoral areas, reclamation and overgrazing are major issues. So implementing environmental policies effectively, transferring population out of rural pastoral areas, and developing modern animal husbandry will be helpful to address these problems.

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