LAND USE AND LANDSCAPE PATTERN CHANGES IN NAIMAN BANNER OF HORQIN SANDY LAND, CHINA

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Abstract. Quantifying the spatial-temporal dynamics of land use and landscape patterns is important for land management and ecological conservation in an ecologically fragile region. This study focused on Naiman Banner on the southern edge of Horqin sandy land, one of the largest sandy lands in northern China. Based on remote sensing (RS) and geographical information system (GIS), the spatial-temporal changes of land use and landscape pattern were investigated in Naiman Banner from 2002 to 2018. The results showed that the area of cropland and construction land area increased by 586.75 km^2 and 215.05 km^2, respectively. Meanwhile, the area of grassland, forest land, sandy land and water body decreased by 488.55 km^2, 177.44 km^2, 88.88 km^2 and 46.89 km^2, respectively. Forest land and grassland were mainly replaced by cropland, and sandy land was mainly converted into grassland. The area of cropland expanded towards the north of the study area. The largest patch index of cropland and construction land increased, while that of grassland decreased. The landscape change was mainly characterized by the largest patch index increased, which suggested the landscape became more homogeneous. The study is meaningful in the land use management and ecological environment protection in Naiman Banner of Horqin sandy land.
Keywords: *landscape metrics, spatial-temporal change, agricultural expansion, remote sensing, geographical information system*

Introduction

Land use and land cover change (LUCC) reflects the interactions between human and the environment (Bagaria et al., 2021). LUCC is one of the important aspects of studying global and regional environmental changes (Inalpulat and Genc, 2021; Deus and Tenedório, 2021). Monitoring the negative effects of LUCC has become a major priority for many scholars worldwide (Obeidat et al., 2019; Mohamed et al., 2020). Remote sensing (RS) and geographic information system (GIS) are efficient and cost-effective tools to assess LUCC (Mohamed et al., 2020). Based on RS, GIS technologies and statistical analysis methods, the trend and magnitude of land use changes can be well quantified (Minta et al., 2018). Recently, LUCC analysis has contributed to understanding land use changes in some ecologically vulnerable regions, such as wetland (Ansari and Golabi, 2019), oasis (Liu et al., 2021), sandy land (Liang and Yang, 2016) and coastal areas (Daniela and Marco, 2017). In addition, landscape pattern is defined as spatial arrangements of landscape patches (Wang et al., 2020). Quantifying landscape pattern changes is a major part of landscape ecology (Wan et al., 2015; Wu, 2013). Landscape

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metrics can be used to promote the quantification of landscape pattern changes at the class and landscape levels, for example, the fragmentation, diversity and heterogeneity of landscape (Deus and Tenedório, 2021; Obeidat et al., 2019).

In arid and semi-arid regions, human activities such as overgrazing, deforestation and land reclamation resulted in desertification (Duan et al., 2014). With the development of social economy and population growth, land degradation is widespread in arid and semi-arid regions (Hirche et al., 2011; Jiang et al., 2013), threatening the survival of local people, and impeding socioeconomic development and ecosystem security in the local areas. With RS and GIS technologies, much attention has been paid to studying the degradation of sand land ecosystem, like the study of desertification dynamics (Dawelbait and Morari, 2012; Guo et al., 2020), land use changes (Ge et al., 2016), and landscape pattern changes at regional scales (Hirche et al., 2011). It is beneficial to understand these changes in achieving the sustainable management of land.

Horqin sandy land, located in agro-pastoral ecotone, is one of the largest sandy lands in northern China (Ge et al., 2016). The eco-environment of Horqin sandy land is vulnerable to global climate change and human activities (Guo et al., 2020). In recent decades, local government and people have taken positive measures such as the grazing ban policy, pasture fences and forestation to restore the degraded sandy land, and the eco-environment of Horqin sandy land has been improved (Zhang et al., 2012). With rapid economic development, population growth, and agricultural reclamation activities, land use changes in Horqin sandy land were affected (Li et al., 2017; Zhou et al., 2017). Many previous studies focused on desertification monitoring (Duan et al., 2019; Wang et al., 2017) and grassland restoration (Yuan et al., 2012; Miao et al., 2015) in Horqin sandy land, little attention has been paid to land use and landscape pattern changes in Horqin sandy land in recent years. Moreover, the trend and magnitude of land use changes in recent years was ignored in the study area. In this study, a representative area was selected in Naiman Banner on the southern edge of Horqin sandy land, northern China. The RS and GIS techniques were applied to characterize its changes in land use and landscape patterns. The objectives of our study were: (1) to investigate the land use changes; (2) to examine the main changes in landscape patterns.

Materials and methods

Study area

Naiman Banner is located in the south of Horqin sandy land (120°19′40″-121°31′44″E, 42°14′10″-43°32′20″N), and it is one of the counties in Inner Mongolia, China (*Fig. 1*). The topography of the study area is low in the north and high in the south, and the elevation ranges from 186 m to 792 m. The climate is characterized by the temperate continental climate, with an average temperature 6.8 °C (Zhou et al., 2014). The long-term mean annual precipitation is 360 mm, 75% of which is from June to September (Zuo et al., 2017). The study region covers an area of about 8100 km^2, with a population of 450,000 in 2018. Naiman Banner is mainly composed of cropland and grassland.

Data sources and processing

Landsat images in 2002, 2008 (Landsat 5 Thematic Mapper) and 2018 (Landsat 8 Operational Land Imager) were acquired from the United States Geological Survey (http://earthexplorer.usgs.gov/). All remote sensing images with a spatial resolution of

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30 m were selected in August, and the satellite images were mosaiced and geo-referenced. Land use types were classified by using visual interpretation in ArcGIS software after field surveys. According to the national standard of current land use classification (GB/T21010-2017), the land use was classified into six classes, including cropland, forest land, grassland, water body, construction land, and sandy land (*Fig. 2*). We used the Kappa coefficient to evaluate land use classification accuracy based on the field survey (Lamine et al., 2018), and the Kappa index was greater than 0.85. The field survey was conducted in June to July 2002, 2008 and 2018, and 180 verification points were collected by using geographic positioning system (GPS). The population and number of livestock were obtained from the Inner Mongolia statistical yearbook (2003-2018) and Tongliao statistical yearbook (2019).

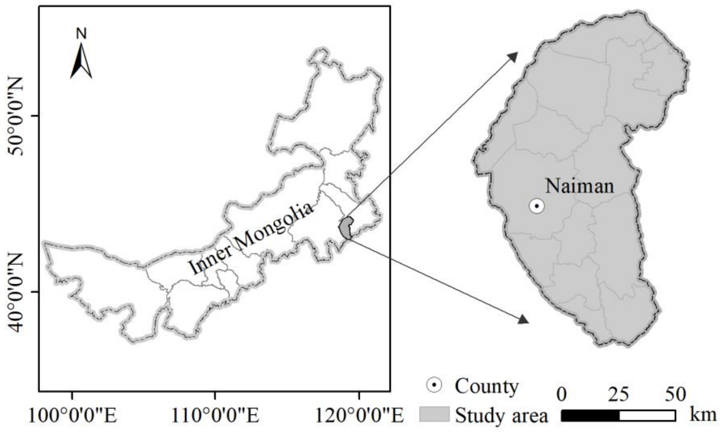

Figure 1. *Location of the study area*

Land use change rate

Land use change rate reflects the changes of different land use types (Alawamy et al., 2020). The formula of annual change rate as follows:

$$V = \frac{(A_j - A_i)}{T} \qquad \text{(Eq.1)}$$

where V is the annual change rate (km^2/year). A_i is the area of specific land use type at time i, and A_j is the area of specific land use type at time j. T is time intervals.

Land use transformation

The transition matrix was widely used to detect the conversions among different land use types (Lin et al., 2018; Daniela and Marco, 2017). In our study, the analysis of transition matrix that was obtained by the spatial overlay method in GIS software used to identify the land use transformations.

Landscape pattern analysis

Landscape metrics were used to depict the spatial-temporal characteristics of landscape pattern changes such as landscape fragmentation and heterogeneity (Dadashpoor et al., 2019). We selected widely-adopted landscape metrics that can

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reflect the composition and configuration of landscape pattern (Yu and Ng, 2008; Deus and Tenedório, 2021). Landscape metrics selected in the study are as follows: the number of patches (NP), mean patch size (MPS), largest patch index (LPI), interspersion and juxtaposition index (IJI) and Shannon's diversity index (SHDI) (*Table 1*). Landscape metrics were calculated by using FRAGSTATS software.

Table 1. *Landscape metrics used in the study (adopted from Obeidat et al., 2019)*

Metrics	Units	Abbreviation	Description	Justification
Number of patches	None	NP	Total number of patches in the landscape	Fragmentation
Mean patch size	km^2	MPS	The average size of patches	Fragmentation
Largest patch index	%	LPI	The ratio of largest patch area to investigated area	Dominance
Interspersion and juxtaposition index	%	IJI	Degree of interspersion of patch types	Uniformity
Shannon's diversity index	None	SHDI	Proportional abundance of each patch type multiplied by that proportion	Diversity

Results

Land use dynamics

The area of cropland and construction land increased from 3291.85 km^2 and 34.28 km^2 in 2002 to 3878.60 km^2 and 249.33 km^2 in 2018, respectively (*Fig. 2*; *Table 2*). In contrast, the area of grassland, forest land, water body and sandy land decreased by 488.55 km^2, 177.44 km^2, 46.89 km^2 and 88.88 km^2 from 2002 to 2018, respectively. Cropland was the most dominant land use type, and its area proportion shows an increasing trend from 40.64% in 2002 to 47.88% in 2018. Grassland had the largest decrease during the study period, and the proportion of grassland decreased from 40.00% to 33.97%. The construction land area was accounted for 0.42% of the study area in 2002, and rapidly increased to 3.08% in 2018.

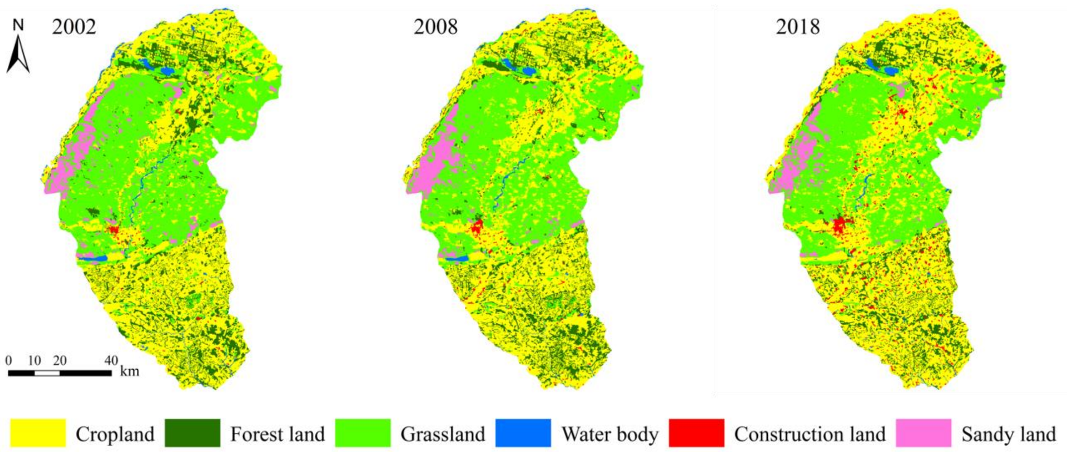

Figure 2. *Land use classification map of the study area in 2002, 2008 and 2018*

During 2002-2008, the annual change rate of cropland and construction land was positive (*Fig. 3*), while that of forest land, grassland, water body and sandy land was negative. The annual change rate of cropland was the highest (44.75 km^2/year), followed by construction land (4.97 km^2/year). The annual change rate of grassland witnessed the biggest reduction (38.51 km^2/year). During 2008-2018, cropland

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decreased at the rate of 31.82 km^2/year, while construction land increased at the rate of 18.52 km^2/year. The annual change rate of construction land during 2008-2018 was three times larger than that during 2002-2008.

Table 2. *Changes in area and percentage of land use types*

Land use type	2002		2008		2018	
	Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)
Cropland	3291.85	40.64	3560.37	43.95	3878.60	47.88
Forest land	1061.47	13.10	1047.55	12.93	884.03	10.91
Grassland	3240.14	40.00	3009.09	37.15	2751.59	33.97
Water body	108.75	1.34	81.96	1.01	61.86	0.76
Construction land	34.28	0.42	64.12	0.79	249.33	3.08
Sandy land	364.50	4.50	337.84	4.17	275.62	3.40

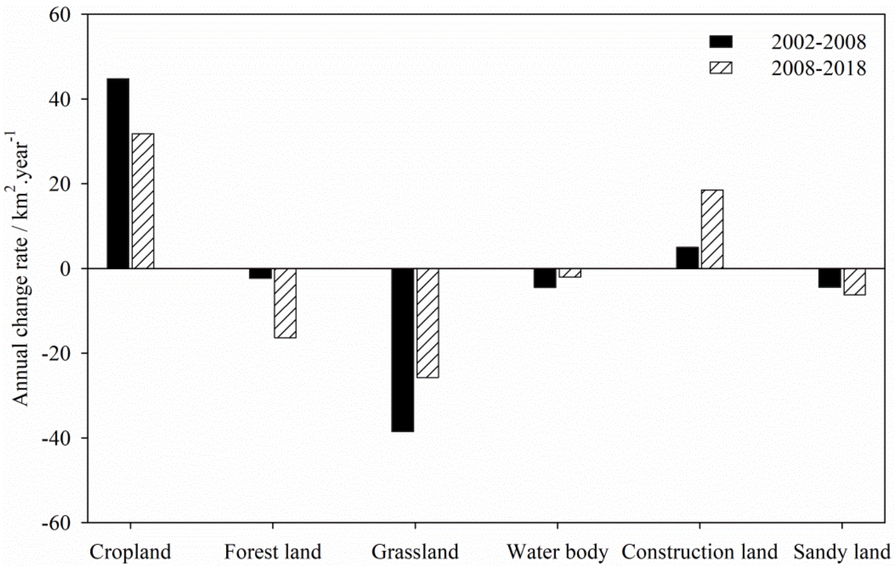

Figure 3. *The annual change rate of each land use types*

Land use conversions

From 2002 to 2008, grassland and forest land were mainly converted to cropland (*Table 3*). About 418.06 km^2 and 386.73 km^2 of grassland and forest land turned into cropland, respectively. The increased area of construction land was related to the transition of cropland and forest land. About 14.83 km^2 and 13.15 km^2 of cropland and forest land were occupied by construction land, respectively. Water body was mainly converted to cropland, and sand land mainly converted to grassland. From 2008 to 2018, 436.49 km^2 and 74.62 km^2 of forestland were converted to cropland and construction land, respectively (*Table 4*). A total of 109.13 km^2 of sandy land was transformed into grassland. Grassland was mainly converted into cropland and forest land, and the large water body area was converted into cropland.

During 2002-2008, the transition to cropland was mainly in the middle and north of Naiman Banner (*Fig. 4*). The transition to grassland occurred in the south and north. Sandy land conversions were primarily distributed in the middle. During 2008-2018, cropland gradually expanded towards the south of Naiman Banner, and grassland

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shrunk in the south, middle and north. The transitions to grassland and construction land were mainly concentrated in the south and north. The water body transition occurred in the middle of the study area.

Table 3. *Land use transitions from 2002 to 2008 (km²)*

2002	**2008**					
	Cropland	**Forest land**	**Grassland**	**Water body**	**Construction land**	**Sandy land**
Cropland	2717.05	355.84	193.57	10.31	14.83	0.32
Forest land	386.73	583.41	75.22	2.70	13.15	0.19
Grassland	418.06	101.24	2606.47	4.26	9.14	100.93
Water body	32.55	4.38	7.14	64.55	0.04	0.07
Construction land	5.21	1.59	1.45	0.01	26.04	-
Sandy land	0.94	0.76	125.37	0.18	0.95	236.27

Table 4. *Land use transitions from 2008 to 2018 (km²)*

2008	**2018**					
	Cropland	**Forest land**	**Grassland**	**Water body**	**Construction land**	**Sandy land**
Cropland	3008.21	329.50	126.85	12.27	83.60	0.15
Forest land	436.49	469.17	64.21	2.46	74.62	0.24
Grassland	389.25	81.03	2447.90	6.99	34.51	49.53
Water body	36.40	2.45	2.80	40.01	0.32	0.04
Construction land	7.54	1.44	0.53	0.15	54.50	-
Sandy land	0.60	0.49	109.13	0.07	1.83	225.67

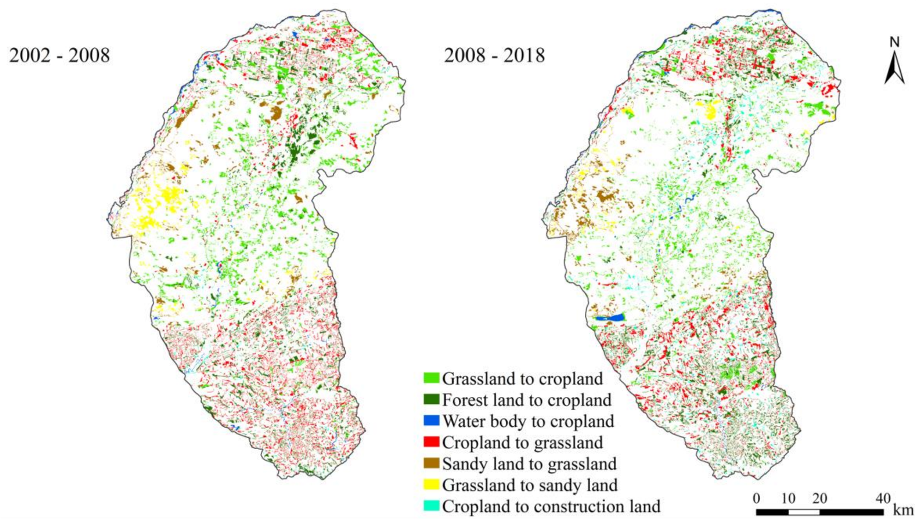

Figure 4. *Spatial change of land use transitions*

Landscape pattern changes

At the class level, the number of patches (NP) of forest land was the highest, and that of the water body was the lowest (*Fig. 5*). The NP of construction land increased, while

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that of forest land, grassland and sandy land decreased from 2002 to 2018. The NP of construction land drastically increased from 108 in 2002 to 571 in 2018. The mean patch size (MPS) of grassland was the highest, while that of the construction land was the lowest. Except for forest land and water body, the MPS of cropland, grassland, construction land and sandy land increased from 2002 to 2018. The largest patch index (LPI) of cropland was the largest, and that of water body the lowest. The LPI of cropland increased from 21.87% to 24.64% during 2002-2018, and that of construction land increased from 0.10% to 0.36%. In contrast, the LPI of grassland decreased by 4.95%. Except for the cropland and water body, the interspersion and juxtaposition index (IJI) of forest land, grassland and construction land decreased from 2002 to 2018.

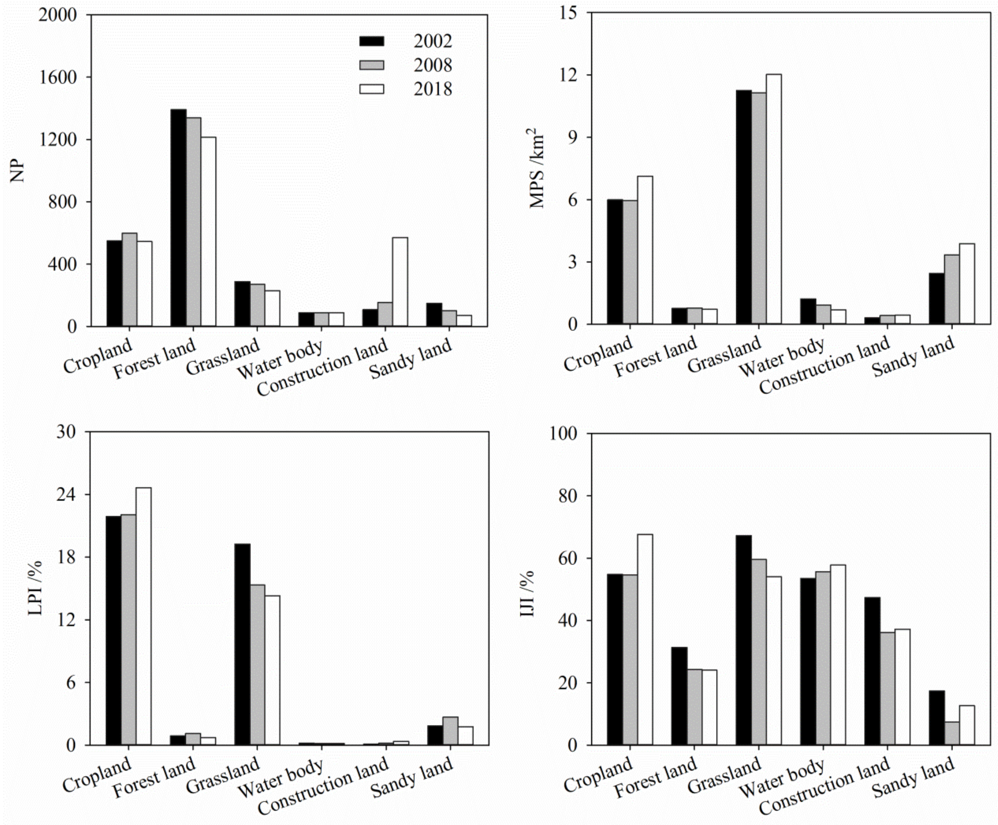

Figure 5. *Landscape pattern metrics of different land use types*

At the landscape level, the NP slightly decreased during 2002-2008 and then increased by 171 during 2008-2018 (*Table 5*). The LPI increased from 21.87% in 2002 to 22.06% in 2008 and to 24.64% in 2018. The IJI decreased from 52.53% in 2002 to 49.08% in 2008 and increased from 49.08% in 2008 to 55.83% in 2018. Shannon’s diversity index (SHDI) changed a little during 2002-2018.

Table 5. *Landscape level metrics in Naiman Banner*

Year	NP	LPI	IJI	SHDI
2002	2576	21.87	52.53	1.22
2008	2548	22.06	49.08	1.21
2018	2719	24.64	55.83	1.22

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Discussion

The major land use change was characterized by the rapidly expansion of cropland and construction land during 2002-2018. In particular, the area of cropland expanded from the north to south in Naiman Banner of Horqin sandy land. The agricultural expansion was mainly attributed to population growth and farmers pursuing economic interests in Horqin sandy land (Li et al., 2017). This result is in line with the previous study showing that cropland increased from 2074.93 km^2 in 1975 to 3314.42 km^2 in 2005 in Naiman Banner (Zhang et al., 2009). Moreover, the previous study also identified the loss of grassland was mainly the result of cropland expansion during 1975-2005. In contrast, we observed forest land and grassland were mainly occupied by cropland during 2002-2018. These results reflected that the pattern of cropland expansion significantly changed. Forest land and grassland were reclaimed first in the study area because their soil fertility was higher than that of cropland (Liu and Zhao, 2010). In addition, forest land and grassland near cropland were susceptible to agricultural reclamation activities. Therefore, the phenomenon of expanding cropland by grassland and deforestation was observed in Naiman Banner during the study period.

Agricultural land is the major consumer of water resources in Horqin sandy land (Zheng et al., 2012). In our study area, agricultural irrigation largely depends on underground water, and cropland expansion always causes excessive water use (Ainiwaer et al., 2019). The water body is largely converted to cropland in the study area, which further aggravating the water shortage. Additionally, the previous study reported that over-cultivation might cause desertification in the agro-pastoral ecotone (Zhou et al., 2017). Thus, the local government should control land reclamation, protect water resources, and minimize the impact of aimless reclamation on land degradation in this region.

Previous studies showed that build-up areas rapidly expanded in Horqin sandy land (Li et al., 2017; Yue et al., 2017). The increased area and mean patch size of construction land indicated its expansion in our study area. The expansion rate of construction land changed differently during the 2002-2008 and 2008-2018 periods. The area of construction land expanded quickly during 2008-2018, reflecting the periodic characteristics of urban development in the study area. The result was similar to the previous study where the urban development speed in Dalate Banner, Inner Mongolia, differed during two periods (Chang et al., 2007). Population growth associated with socioeconomic development accelerated urban development in Horqin sandy land (Yue et al., 2017), resulting in new construction land.

At the landscape level, we observed a rather fragmented landscape in Naiman Banner. This could be explained by the significant increase in the number of patches of construction land. It reflected that human activities played an important role in influencing landscape fragmentation in the study area, chiming with many previous studies (Fan and Ding, 2016; Hou and Gao, 2020). An increase in the largest patch index at the landscape level was mainly due to the significant expansion of cropland in our study area. It was because the increase of cropland in the largest patch index was the biggest during the study period. The small patches of cropland merged into large patches during agricultural development, decreasing the NP of cropland. A similar landscape pattern was also observed in the agro-pastoral ecotone of northern China (Zhou et al., 2017).

Among socio-economic factors, previous studies have reported that agricultural expansion and residential development were caused by regional population growth

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(Japelaghi et al., 2019). In our study, the number of populations significantly increased from 2002 to 2018 (*Fig. 6*), which was one of the most important factors causing the land use changes in Naiman Banner. In particular, more food and dwelling area were needed with the growth of populations (Ge et al., 2016; Japelaghi et al., 2019), which further causing land reclamation in the study area. Although grassland reclamation can bring economic benefit, it also can lead to land degradation due to soil erosion. Except for population growth, land use changes were also attributed to the regional environmental protection policies and ecological restoration projects (Li et al., 2017). The main anti-desertification projects implemented in this area, included the Three-North Shelterbelt Project started in 1978, the Grain for Green Project started in 2002, and the Beijing-Tianjin Sandstorm Source Control Project during 2001-2010 (Duan et al., 2014; Li et al., 2017). In recent years, the local government has been controlling the number of livestock which significantly decreased during 2009-2018 (*Fig. 6*). The grazing exclusion policy was carried out, which further reduced the vegetation destruction in Horqin sandy land (Miao et al., 2015). The straw checkerboard barriers in sandy land lightened soil erosion and promoted the recovery of degraded sandy land in the study area. The area of sandy land in the study area was reduced and mainly transformed into grassland, which is consistent with the results of previous studies (Duan et al., 2014; Wang et al., 2017).

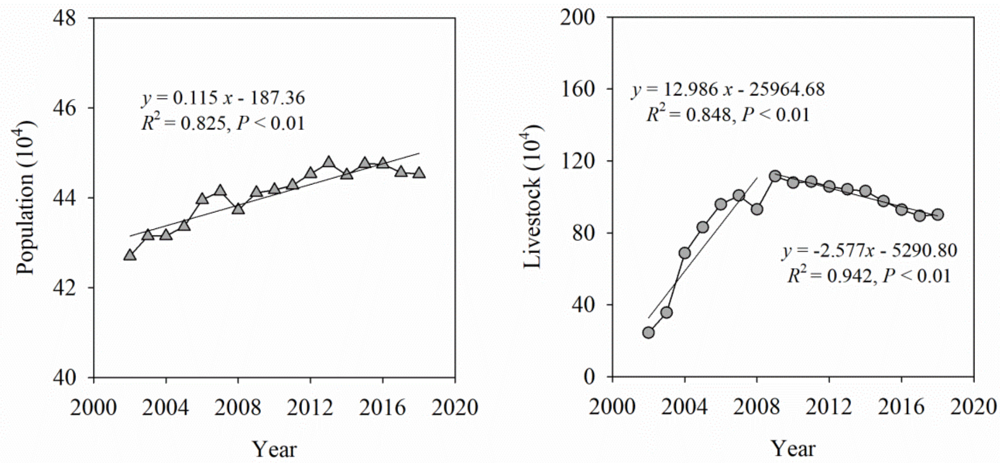

Figure 6. *Changes of population and the number of livestock in Naiman Banner from 2002 to 2018*

Conclusion

The land use changes in Naiman Banner of Horqin sandy land, China, was dramatic from 2002 to 2018. The analysis of LUCC showed that the rapid expansion of cropland was mainly at the expense of grassland and forest land, and the increases in the area of construction land was mainly at the cost of cropland and forest land during the last 16 years. Land use changes affected the composition and configuration of landscape in this study. During the study, the increase in the largest patch index and mean patch size of cropland revealed the overdevelopment of agriculture. Population growth resulted in agricultural reclamation and construction land expansion led to land use conversions, affecting the landscape patterns of Naiman Banner. The decision-makers should protect grassland and forest land and mitigate the negative effects of agricultural reclamation on

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the ecological environment in Horqin sandy land. Sustainable land management approaches and conservation policies may contribute to solving regional ecological problems, especially land degradation.

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