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The Change of Land Use/Cover and Characteristics of Landscape Pattern in Arid Areas Oasis: An Application in Jinghe, Xinjiang

ZHANG Fei[1,2], TASHPOLAT·Tiyip[1,2], Hsiang-te KUNG[3], DING Jianli[1,4]

1. Department of Resources and Environment Sciences, Xinjiang University, Urumqi 830046, China
2. Key Laboratory of Oasis Ecology, Ministry of Education, Urumqi 830046, China
3. Department of Earth Sciences, Memphis University, TN 38152, USA
4. Graduate School, Xinjiang University, Urumqi 830046, China

Abstract This paper uses 3S technology in macroscopic. Combining the integrated technology of ecological quantity analytical method with GIS technology through ArcGIS and Fragstats, the authors study the images of 1972, 1990, 2001, and 2005 and obtained land use data in Jinghe County. Then, the change of land use/cover and landscape pattern had been analyzed in the Jinghe County of Xinjiang. The conclusions were as follows: (1) The trend of LUCC is that the area of oasis expands slowly in nearly 33 years between 1972 to 2005 in Jinghe County. (2) The water area is mainly influenced by Ebinur Lake, so the area expands a little in this period. (3) The area of salinization-land expands at first and reduces later. The area of sand land decreases and the other land class increases, while the probability of transfer is always high. (4) Landscape change is also obvious throughout the decades. Overall, landscape density increases, the largest path index decreases at first and expends later, the weight area index decreases, and the shape of landscape becomes regulated. The nearest distances, the degrees of reunite, and outspread decreases. It shows that the connection of the main path in 1972 is better than 2005, wherein the patch becomes more complex. From the changes of Shannon's Diversity Index and Shannon's Evenness Index, we know that the diversity of landscape and the Interspersion Juxtaposition Index increase. The degree of diversity landscape and fragmentation increase also shows that the land uses become more complex. All in all, it is essential to intensify the spatial relationships among landscape elements and to maintain the continuity of landscape ecological process and pattern in the course of area expansion.

Keywords arid area; oasis; land use/cover change (LUCC); landscape change; Jinghe County

CLC number P208; P237

Introduction

Land use/cover change has been an important research field even in the globe view, and it is one of the most sensitive indicators that echo the interactions between human activities and the natural environment. In arid environments, the land cover change often reflects the most significant impact on the environment due to human activities or natural forces. Remote sensing data have been used for environment change studies for decades, and large collections of remote

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► ZHANG Fei, Ph.D. candidate, mainly engaged in environmental ecology application of GIS and remote sensing.

► E-mail:zhangfei3s@yahoo.com.cn

sensing imagery have made the analysis of long-term changes of environmental elements and the impact of human activities possible.[1-2]

Land use/cover classification is the most practical way to analyze land cover in the remote sensing (RS) field. This approach has been extensively used for over two decades.[3] The recent growing interest in the classification of land cover for large areas has several different reasons: (1) the growing need for land cover information, (2) the low-cost of remotely sensed imagery (e.g., data from the Landsat sensor, from the Terra Satellite's Moderate Resolution Imaging Spectroradiometer, etc.), and (3) the application of the most recent advances of computer technology in the RS field. The combined use of geographic information systems (GIS) and RS imagery is a powerful tool for land cover data generation, and for storing, measuring, modeling, and analyzing spatial data.[4]

Detection of land use/cover change (LUCC) using digital image processing technique with multitemporal satellite data has been one of the first and most critical applications of RS.[5] There are two change detection technique categories: (1) 'from to' change (i.e., image classification) and (2) binary change and non change information (i.e., image differencing, image rationing, vegetation index differencing, fractals, etc.).

Landscapes change constantly. In a natural environment, these changes are in a state of equilibrium and evolve slowly. However, in an ecosystem subject to anthropogenic stresses, the changes are accelerated and affect ecological functions and processes. This has largely resulted in desertification, deforestation, habitat fragmentation, and the loss of biodiversity, and will eventually cause global warming, as well as reduction in environmental services.[6-7]

There are a number of studies on landscape pattern changes in spatial and temporal scales. Since landscape pattern and landscape function are mutually influenced, using landscape pattern to analyze landscape function has been commonly employed in this type of study.[8-9] Analysis of landscape pattern change plays an important role in understanding landscape baseline and its possible future changes. It can provide indicators and strategies for monitoring and modeling many aspects of environmental change.[10] It can also help to better understand the relationship between human activities and landscape changes, and direct policy makers to make the appropriate decision toward sustainable development.

The application of landscape metrics to land use/ land cover change has been discussed as a way to address the above needs.[11-14] Empirical studies have also been carried out in landscape assessment,[15] landscape monitoring,[16] and landscape planning and design.[17] Since remote sensing provides cost-effective multispectral and multitemporal data, it has become a common data source for comparative studies at both temporal and spatial scales.[13] These studies mainly focus on the analysis of landscape pattern, and an integrated evaluation of landscape change due to economic development is still rare.

Landscape ecology mainly studies structure, function, and change of landscape, with spatial pattern as one of the main contents. Landscape pattern refers to type, number, spatial distribution, and location of landscape cells. By analyzing dynamic changes of landscape pattern and spatial relation of landscape patches, we can analyze amounts, location, type, shape, area, and direction of landscape cells; evaluate the macro, regional, and ecological environment and forecast future tendency; and reveal dominant factors and driving factors of formation and development of landscape pattern that will ultimately help promote landscape sustainability.[18] Therefore, this paper will explore the LUCC and the landscape pattern change of the Jinghe County region and propose suitable and comprehensive measures for the sustainable development, which will be of utmost importance in the decision making on the land utilization of the region.

1 Materials and methods

1.1 Study area

Jinghe County is located in the most western part of Xinjiang Province, between 44°00′ and 45°10′ N and 81°46′ and 83°51′E. It covers an area of 11275 km^2, and the climate type is temperate semiarid continental monsoon climate. Mean annual air temperature is about 7.2℃. The prefecture has a population of about 120905 inhabitants. Mean annual precipitation is 700 mm, with most of the rainfall occurring in July and August; only a little rainfall between November and

January. In the region, ground vegetation types are various, and the eco-environment is relatively fragile. In recent years, the eco-environmental problems, such as vegetation degradation and land desertification, have become serious because of climate change and unreasonable human activities, setting back regional economic development and regional welfare. Therefore, it is very important to study the features, changes in intensity, and processes of macro landscape pattern of the Jinghe County, so as to understand the eco-environment feedback mechanism and seek a way to optimize landscape pattern under ecological security in the west of Xinjiang.

1.2 Data sources

Four multitemporal remotely sensed images were acquired for change detection for this study, including Landsat MSS (21 September 1972), Landsat TM (5 October 1990), Landsat ETM+(25 September 2001), and CBERS-2 data (22 October 2005). Images chosen from the same season can also reduce the misclassification error related to spectral analysis of different land use/cover types. In addition, land use maps acquired were of Jinghe County in 1995 and 2003, as well as the contour map of study area, the topographic maps with scale of 1:100000 and 1:50000, and vector data to assist in field investigations and accuracy assessment of the image classification.

1.3 Data processing and land use types

Each image was enhanced by using linear contrast stretching and histogram equalization to improve the image to help identify ground control points for rectification. The dates of the images were rectified to Gauss-Kruger projection. These data were resampled by using the nearest neighbor algorithm, so that the original brightness values of pixels kept unchanged. The Landsat ETM+ image was geo-referenced to a 1:50000 map using 30 ground control points (GCPs). The other images were geometrically corrected and registered on the map coordinates using image-to-image registration with the master ETM+ image. Efforts were made to control registration errors to within half a pixel of the image concerned, so that the errors caused by misregistration would be less critical. The spatial resolution of images affects landscape metric computation greatly.[19] To make the classified land cover images comparable in terms of landscape metrics, the images must have the same spatial resolution. Our approach is to resample the classified images to 30 m, which is close to the lowest spatial resolution of all images using the majority rule aggregation, the method that Petit and Lambin[20] proposed. After resampling, a majority filter (3×3) was applied to the classified images for the removal of isolated pixels to minimize potential analytical errors. After interactive interpretation of the Landsat TM images on computer screen, the land use map was produced at a scale of 1:100000 and stored in Arc/Info coverage format for further analysis.

The supervised classification is the most common method in obtaining land use/cover information. In this research, after data preprocessing, a training sample was selected according to spectrum features. Unlike the conventional classifications of land use/cover, the maximum likelihood classification was used to map the land use/cover of Jinghe County. According to the land classification system for remote sensing interpretation, the class was divided into six subclasses, i.e., farmland, forestland, grassland, water area, salinized-land, sandyland, and other objects (including rural-urban industrial land, unused land, barren land, glacier, etc.). When finishing supervision classification, manual-work interpretation was done in the image classified, and the precision of classification result was assessed. If the precision of classification result was lower, manual-work interpretation was to be implemented and assessed again until the supervision classification image in accordance with the precision request was obtained.

1.4 Spatial Analyst GIS software[21]

We computed two groups of landscape metrics with FRAGSTATS3.3: (1) the class level, which means each patch type in the landscape mosaic; (2) the landscape level, which means the landscape mosaic as a whole. FRAGSTATS, spatial pattern analysis program for categorical maps developed by McGarigal in 2002, offers a comprehensive choice of landscape metrics at the patch, class, and landscape levels, including more than 60 landscape metrics. However, many of them can be highly correlated[22] so that an important principle is to select uncorrelated metrics. In our analysis of the landscape structure of Jinghe prefecture at the class level, eleven metrics were selected. For the analysis of structure at the landscape level, 11 indices also were selected.

1.5 Models

Regional differences in land use change rate were determined by using the land use dynamic degree model that could be mathematically expressed by the following equation:[23]

$$S = \left\{ \sum_{ij}^{n} (\Delta A_{i-j} / A_i) \right\} \bullet (1/t) \bullet 100\% \qquad (1)$$

where S is the land use dynamic degree, during the time interval t expressed in year (%); A_i is the area of the ith land use type at the beginning of the monitoring period; ΔA_{i-j} is the area of the ith type land use converted into the jth land use type; and n is the total number of land use types. The land use dynamic degree is thus defined as the annual change rate of the total land area that was converted into other land use types. The dynamic degree represents thus, in a comprehensive manner, the change of land use for a given region.

Regional differences in the land use change rate were determined with the model as follows:[24]

$$S_R = (A_i - UA_i) / A_i / (T_2 - T_1) \bullet 100\% \qquad (2)$$

where S_R is the regional change rate of the ith land use type from time T_1 to T_2 (%); A_i is the area of the ith land use type at time T_1 ; and UA_i is the area of the ith type land use that remains unchanged during the period from T_1 to T_2. Thus, ($A_i - UA_i$) is the land area of the ith land use type that changed to another land use type from T_1 to T_2. In other words, the model represented the time rate of change of one type of land use into another type relative to the situation at T_1.

2 Results and discussion

2.1 Analysis of land use/land cover change

Fig.1 is the result of the classification. It can be seen from the study provided by the ENVI software that the classification accuracy of the four image data sets was 89.38%, 90.39%, 94.37%, and 91.02%, respectively. Kappa coefficient was 0.87, 0.88, 0.93, and 0.89.

Land use statistics and a transition matrix are important information for analyzing the temporal and spatial changes of land use and examining the driving forces behind those changes. In 1972, Jinghe was dominated by grassland, other object, and forestland, which together account for 79.11% of the total area (see Table 1). In contrast, farmland area covered only 128.54 km^2, a mere 1.14% of the total area. This indicated that Jinghe was not an agriculturally dominated area. In 1990, forestland and grassland were reduced to 4956.71 km^2, a loss of more than 15% over the 18th year. There were significant expansions in salinized-land and other with an increase of 536.46 km^2 and 270.6 km^2, respectively. The expansion of salinized-land was largely due to the natural factors and social and economic ones. Natural factors include

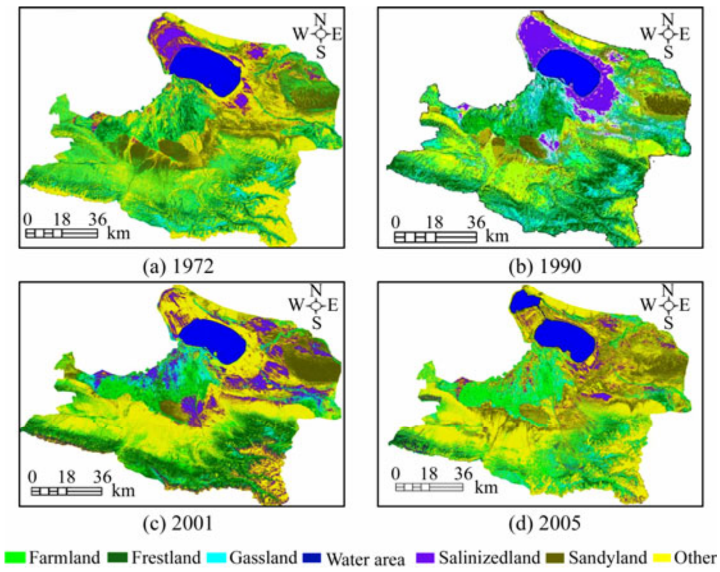

Fig.1 Classified land use/cover maps, Jinghe

climate, hydrology, geology, soil, vegetation, etc. Social and economic factors often include population, politics, economy, culture, etc. Meanwhile, other object area had a large increase in 1990 (3 199.85 km^2) in contrast with that in 1972 (2 929.25 km^2), which reflects the acceleration of urban development.

A similar pattern of land use change was found between 1990 and 2001. The total loss of grassland was 835.02 km^2, about 21.61% of what it was in 1990. The most striking feature in this period was the rapid expansion of other object with an increase of 4357.79 km^2. In 1990, Jinghe was dominated by grassland, salinized-land, and other object, which together account for 77.24% of the total area (see Table 1), while in 2001, Jinghe was dominated by grassland, salinized-land and other object, which together account for 77.41% of the total area (see Table 1).

From 2001 to 2005, forestland expansion was at a rapid speed, while grassland shrinking continued from 3028.47 km^2 to 2786.73 km^2. In 2001, Jinghe was dominated by grassland, forestland, and other objects, which together account for 76.319% of the total area (Table 1).

Table 1 Area and percentage of land use in Jinghe oasis

LUCC type	1972		1990		2001		2005	
	Area(km$^{2)}$	Percent(%)	Area(km^2)	Percent(%)	Area(km$^{2)}$	Percent(%)	Area(km^2)	Percent(%)
A	128.54	1.140	303.75	2.694	388.65	3.447	408.49	3.623
B	1424.93	12.638	1093.22	9.696	1104.16	9.793	1435.65	12.733
C	4564.91	40.487	3863.49	34.266	3028.47	27.686	2786.73	24.716
D	573.33	5.085	575.70	5.106	583.71	5.177	691.95	6.137
E	1108.90	9.835	1645.36	14.593	1248.59	11.074	1050.60	9.318
F	545.15	4.835	593.74	5.266	470.73	4.175	519.10	4.604
G	2929.25	25.98	3199.85	28.38	4357.79	38.65	4382.59	38.87

Note: A: Farmland, B: Forestland, C: Grassland, D: Water area, E: Salinized-land, F: Sandyland, G: Other objects. The same below.

2.2 Analysis of transition matrix

Transition matrixes were common various land use types in the study area. Tables 2 to 5 show the transform among land use types from 1972 to 2005 in Jinghe region.

During the period 1972–1990, farmland mainly transforms into other objects and grassland, and the metastasis rate is 32.01% and 29.46%. Forestland is similar to farmland, and the metastasis rate was 48.62% and 19.88%. Grassland mainly transforms into other objects and forestland, and the metastasis rate is 41.41% and 11.10%. Water area has no much transform basically. Salinized-land and sandyland mainly transform into other objects, and the metastasis rate is 55.83% and 29.79%. While other objects mainly transform into sandyland and grassland, the metastasis rate is 15.94% and 14.77%. In grassland in 1990, the contribution rate of other objects is 22.64%. In farmland in 1990, the contribution rate of grassland is 37.68%.

During the period 1990–2001, farmland mainly transforms into forestland and grassland, the metastasis rate is 33.70% and 21.52%. Forestland mainly transforms into forestland, and the metastasis rate is 30.05%. Grassland mainly transforms into other objects and forestland, the metastasis rate is 24.71% and 11.8%. Salinized-land mainly transforms into grassland, and the metastasis rate is 32.23%. Sandyland mainly transforms into other objects and the metastasis rate is 29.26%. In grassland in 2001, the contribution rate of other objects is 27.84%. In farmland in 2001, the contribution rate of grassland is 26.67% and next is other objects up to 25.99%.

During the period 2001–2005, farmland mainly transforms into grassland and forestland, and the metastasis rate is 32.31% and 25.82%. Forestland mainly transforms into grassland and other objects, and the metastasis rate is 28.39% and 24.69%. Grassland mainly transforms into forestland and other objects, and the metastasis rate is 19.64% and 19.23%. Water area mainly transforms into other objects, and the metastasis is 18.92%. Salinized-land mainly transforms into grassland, and the metastasis rate is 31.13%. Sandyland mainly transforms into other objects, and the metastasis rate highly up to 97.30%. While other objects mainly transforms into salinized-land, and the metastasis rate is 11.93%. In grassland in 2005, the contribution rate of other objects is 47.56%. In farmland in 2005, the contribution rate of grassland is 22.44%.

All in all, during the period 1972–2005, farmland mainly transforms into grassland, forestland, and other objects, and the metastasis rate is 34.25%, 27.29%, and 23.95%, respectively. Forestland mainly transforms into other objects, and its metastasis rate is up to 36.37%. Grassland mainly transforms into other objects, and its metastasis rate is up to 27.94%. Water area mainly transforms into salinized-land and next is other objects, and the metastasis rate up to 13.85% and 12.33%. Salinized-land mainly transforms into other object and sandyland. The metastasis rate is up to 41.50% and 38.71%. Sandyland mainly transforms into other objects, and the metastasis rate highly up to 55.25%. While other objects mainly transforms into grassland, and the metastasis rate is 14.53%. In grassland in 2005, the contribution rate of other objects is 43.71%. In farmland of 2005, the contribution rate of grassland is 44.31%. Therefore, we can draw the conclusion that the other objects were reclaimed and utilized by people during in these periods. Parts of farmland, forestland, grassland, salinized-land, and sandyland were occupied by other objects.

2.3 Dynamic degree of land use/cover

To better understand dynamics of land use changes, the land use dynamic degree was calculated for each of the period in the Jinghe region according to the Eq.(1) and Fig.2. According to that in Table 6, the Jinghe region was an area with very slow changing of land use on the whole. For comparison purpose, the region was divided into three groups based on the dynamic degree values in this paper. The first group is during the 1972–1990 period with a relatively slow changing of land use, in which the dynamic degree is 1.63%. The second group is during the 1990–2001 period and 1972–2005 period had a moderate land use changing, in which the dynamic degree changed is 2.44% and 2.23%. The third group had a relatively fast changing of land use, in which dynamic degree is 4.36%.

Table 2 Transform matrix of LUCC in Jinghe from 1972 to 1990 (km^2, %)

1972		1990							Total
		Farmland	Forestland	Grassland	Water area	Salinized-land	Sandyland	Other objects	(Share rate %)
Farmland	A	88.20	102.73	172.46	0.16	4.70	29.48	187.40	585.48
	B	15.06	17.55	29.46	0.03	0.80	5.04	32.01	5.23
	C	13.27	10.63	8.81	0.03	0.87	2.23	3.65	
Forestland	A	87.38	375.11	304.92	1.30	8.28	10.61	745.79	1533.83
	B	5.70	24.46	19.88	0.08	0.54	0.69	48.62	13.71
	C	13.14	38.80	15.58	0.22	1.53	0.80	14.52	
Grassland	A	250.48	351.11	972.14	9.24	47.92	220.66	1310.36	3164.20
	B	7.92	11.10	30.72	0.29	1.51	6.97	41.41	28.28
	C	37.68	36.32	49.67	1.53	8.86	16.66	25.52	
Water area	A	0.79	1.92	2.21	536.26	1.44	0.16	28.53	571.32
	B	0.14	0.34	0.39	93.86	0.25	0.03	4.99	5.11
	C	0.12	0.20	0.11	88.97	0.27	0.01	0.56	
Salin-ized-land	A	15.91	5.46	39.34	51.49	450.93	157.78	911.61	1632.75
	B	0.97	0.33	2.41	3.15	27.62	9.66	55.83	14.59
	C	2.39	0.57	2.01	8.54	83.33	11.91	17.75	
Sandyland	A	28.18	0.44	22.16	0.0097	14.02	427.53	208.95	701.47
	B	4.02	0.06	3.16	0.00	2.00	60.95	29.79	6.27
	C	4.24	0.05	1.13	0.00	2.59	32.28	4.07	
Other objects	A	193.70	129.69	442.98	0.73	13.19	478.21	1739.72	2999.33
	B	6.46	4.32	14.77	0.02	0.44	15.94	58.00	26.81
	C	29.14	13.42	22.64	0.12	2.44	36.10	33.88	
Total		664.80	966.71	1957.06	602.73	541.12	1324.59	5134.75	11188.38
(Share rate %)		5.94	8.64	17.49	5.39	4.84	11.84	45.89	100.00

Note: The row is the *i*th type of land use of the initial stage, while the column is the *j*th type of land use of the terminal stage of study time internal; *A* is area of the initial stage land use changed to other types of land use of terminal stage; *B* is the percentage of the *i*th type of land use of the initial stage changed to the *j*th type of land use of the terminal stage; *C* is the percentage of the *j*th type of land use of the terminal stage changed from the *i*th type of land use of the initial stage (same below).

Table 3 Transform matrix of LUCC in Jinghe from 1990 to 2001(km^2, %)

1990		2001							Total (Share rate %)
		Farmland	Forestland	Grassland	Water area	Salinized-land	Sandyland	Other objects	
Farmland	A	152.58	122.70	78.35	0.24	2.48	0.49	7.24	364.13
	B	41.90	33.70	21.52	0.07	0.68	0.13	1.99	3.25
	C	25.95	7.99	2.47	0.04	0.15	0.07	0.24	
Forestland	A	87.29	491.63	350.11	2.55	10.78	1.71	220.75	1165.02
	B	7.49	42.20	30.05	0.22	0.93	0.15	18.95	10.39
	C	14.21	29.74	10.27	0.37	0.64	0.24	4.67	
Grassland	A	183.27	424.03	1667.49	8.22	276.09	145.66	888.09	3593.67
	B	5.10	11.80	46.40	0.23	7.68	4.05	24.71	32.05
	C	26.67	25.89	47.97	1.39	16.86	21.55	19.74	
Water area	A	0.44	10.56	10.13	534.61	13.53	0.04	8.57	579.65
	B	0.08	1.82	1.75	92.23	2.33	0.01	1.48	5.17
	C	0.07	0.69	0.31	93.47	0.82	0.01	0.31	
Salinized-land	A	37.92	113.87	553.61	1.83	605.13	98.35	306.22	1717.53
	B	2.21	6.63	32.23	0.11	35.23	5.73	17.83	15.32
	C	5.99	2.39	9.98	0.30	36.26	14.32	5.23	
Sandyland	A	5.95	1.06	32.70	0.00	3.93	270.03	129.75	443.44
	B	1.34	0.24	7.37	0.00	0.89	60.89	29.26	3.96
	C	1.09	0.07	1.10	0.00	0.26	39.76	4.74	
Other objects	A	120.28	371.38	474.44	25.01	723.91	186.08	1446.52	3348.36
	B	3.59	11.09	14.17	0.75	21.62	5.56	43.20	29.86
	C	25.99	33.22	27.84	4.43	45.00	24.03	65.05	
Total		587.89	1535.47	3168.89	572.47	1636.03	702.46	3007.77	11211.80
(Share rate %)		5.24	13.70	28.26	5.11	14.59	6.27	26.83	100.00

Table 4 Transform matrix of LUCC in Jinghe from 2001 to 2005 (km^2, %)

2001		2005							Total (Share rate %)
		Farmland	Forestland	Grassland	Water area	Salinized-land	Sandyland	Other objects	
Farmland	A	250.65	274.38	343.29	3.09	18.92	1.69	170.34	1062.59
	B	23.59	25.82	32.31	0.29	1.78	0.16	16.03	9.48
	C	68.84	26.88	11.06	0.53	1.52	0.36	3.84	
Forestland	A	23.66	158.79	115.61	3.93	4.41	0.25	100.56	407.25
	B	5.81	38.99	28.39	0.97	1.08	0.06	24.69	3.63
	C	6.50	15.56	3.72	0.68	0.36	0.05	2.27	
Grassland	A	81.72	257.98	641.39	6.87	65.34	7.42	252.54	1313.57
	B	6.22	19.64	48.83	0.52	4.97	0.56	19.23	11.72
	C	22.44	25.28	20.66	1.18	5.26	1.59	5.70	
Water area	A	0.02	8.57	12.35	495.08	41.79	0.08	130.16	688.05
	B	0.00	1.25	1.79	71.95	6.07	0.01	18.92	6.14
	C	0.01	0.84	0.40	85.30	3.37	0.02	2.94	
Salinized-land	A	0.13	6.30	422.25	3.81	235.02	1.99	144.21	1356.43
	B	0.01	0.46	31.13	0.28	17.33	0.15	10.63	12.10
	C	0.14	0.84	13.60	2.78	13.83	56.89	10.62	
Sandyland	A	0.51	8.52	92.12	16.13	171.71	266.31	470.83	483.91
	B	0.11	1.76	19.04	3.33	35.48	55.03	97.30	4.32
	C	0.04	0.62	2.97	0.66	18.93	0.43	3.25	
Other objects	A	7.34	305.80	0.76	49.65	703.90	190.33	3163.15	5898.78
	B	0.12	5.18	0.01	0.84	11.93	3.22	53.62	52.62
	C	2.02	29.96	47.56	8.55	56.70	40.66	71.36	
Total		364.10	1020.61	3104.15	580.31	1241.56	468.13	4432.99	11210.58
(Share rate %)		3.25	9.10	27.69	5.18	11.07	4.18	39.54	100.00

Table 5 Transform matrix of LUCC in Jinghe from 1972 to 2005 (km^2, %)

1972		2005							Total
		Farmland	Forestland	Grassland	Water area	Salinized-land	Sandyland	Other objects	(Share rate %)
Farmland	A	127.85	289.45	363.33	0.44	8.24	16.86	254.02	1060.77
	B	12.05	27.29	34.25	0.04	0.78	1.59	23.95	9.48
	C	19.23	29.94	18.57	0.07	1.52	1.27	4.95	
Forestland	A	18.77	139.40	96.14	0.10	1.96	2.53	148.12	407.25
	B	4.61	34.23	23.61	0.02	0.48	0.62	36.37	3.64
	C	2.82	14.42	4.91	0.02	0.36	0.19	2.89	
Grassland	A	149.30	225.70	500.92	4.72	17.80	44.54	365.96	1309.67
	B	11.40	17.23	38.25	0.36	1.36	3.40	27.94	11.71
	C	22.46	23.35	25.60	0.78	3.29	3.36	7.13	
Water area	A	1.39	6.84	3.48	494.39	95.16	0.95	84.69	686.93
	B	0.20	1.00	0.51	71.97	13.85	0.14	12.33	6.14
	C	0.21	0.71	0.18	82.03	17.59	0.07	1.65	
Salinized-land	A	61.34	10.25	109.74	24.35	61.40	523.40	561.17	1352.09
	B	4.54	0.76	8.12	1.80	4.54	38.71	41.50	12.09
	C	9.23	1.06	5.61	4.04	11.35	39.51	10.93	
Sandyland	A	11.16	6.47	26.81	8.90	112.13	49.62	266.72	482.71
	B	2.31	1.34	5.55	1.84	23.23	10.28	55.25	4.31
	C	1.68	0.67	1.37	1.48	20.72	3.75	5.19	
Other objects	A	294.57	287.91	855.33	66.01	244.04	686.48	3450.99	5888.65
	B	5.00	4.89	14.53	1.12	4.14	11.66	58.60	52.63
	C	44.31	29.78	43.71	10.95	45.10	51.83	67.21	
Total		664.80	966.71	1957.06	602.73	541.12	1324.59	5134.75	11188.07
(Share rate %)		5.94	8.64	17.49	5.39	4.84	11.84	45.89	100.00

Table 6 also summarizes the calculated land use conversion rates according to Eq.(2) for the Jinghe region overall and different periods. Among land use types, the annual conversion rate of farmland and forestland were the highest in this region. Among periods, Jinghe County had the highest rate of farmland change during the period from 1972 to 1990, which was attributed to the conversion of grassland into farmland. The largest change rates in forestland and grassland were in period from 2001 to 2005. These changes may have been influenced by the "Making Green with Tress" policy.

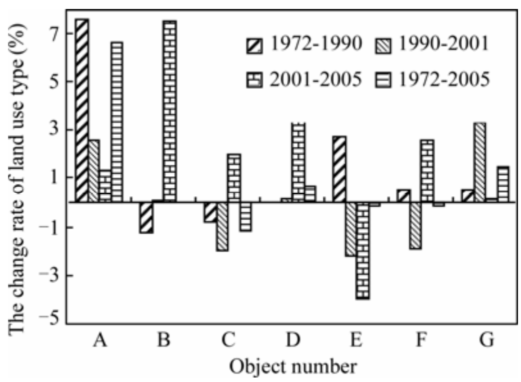

Fig.2 Velocity of land use change from 1972 to 2005

2.4 Comparison of landscape metrics

As many of landscape indices are highly correlated,[22, 25-26] an important principle is to select uncorrelated indices. In this paper, we computed two groups of indices: (1) At the class level, the selected 11 indices were area of the patch (CA), percent in landscape (PLAND), number of patches (NP), patch density (PD), area-weighted mean shape index (AWMSI), Edge density (ED), Largest patch index (LPI), Fragmentation index (FI), patch cohesion index (COHESION), Splitting index (SPLIT), and interspersion and juxtaposition index (IJI) (Table 7). (2) At the landscape level, the selected 11 indices were Total landscape area (TA), LPI, PD, Area-weighted mean shape index (SHAPE_AM), Mean Euclidean nearest neighbor distance (ENN_MN), Shannon's diversity index (SHDI), Shannon's evenness index (SHEI), IJI, COHESION, SPLIT, and contagion index (CONTAG) (Table 8).

Table 6 Land use dynamic degree in Jinghe Country between 1972 to 2005 (%)

Study period of time	S_A	S_B	S_C	S_D	S_E	S_F	S_G	S
1972-1990	7.57	–1.29	–0.85	0.02	2.69	0.50	0.51	1.63
1990-2001	2.54	0.09	–1.96	0.13	–2.19	–1.88	3.29	2.44
2001-2005	1.28	7.51	2.00	4.64	–3.96	2.57	0.14	4.36
1972-2005	6.60	0.02	–1.18	0.63	–0.16	–0.14	1.50	2.23

Landscape indices in FRAGSTATS are quite effective in describing landscape changes relating both human activities and natural impacts.[25] However, in real practice, attention should be paid to both scale and data sources. Prior research has shown that the analysis of landscape structure and its changes were closely related to scale,[26] and the maximum and minimum resolution of research results were decided by landscape scope and patch sizes.[27] Diversified landscape indices drawn from different sets of grid

Table 7 Landscape indexes at class level of Jinghe oasis from 1972 to 2005

Year	Type	CA (ha)	NP	PLAND (%)	PD (1/100ha)	ED (m/ha)	LPI (%)	FI	IJI (%)	COHESION	AWMIS	SPLIT
1972	A	12857.99	1447	1.1444	0.1293	3.0032	0.0798	0.4798	74.1151	39.0399	1.3423	187817.5299
	B	142437.36	951	12.6497	0.085	4.7077	0.6175	1.0108	60.4381	79.0743	3.1428	8573.2608
	C	456447.92	1446	40.4843	0.1292	6.7517	1.8434	1.2999	67.745	86.6405	4.5285	1567.3954
	D	57392.69	30	5.0866	0.0027	0.1647	5.3114	0.6335	54.3899	97.4442	1.4075	354.4735
	E	110822.61	289	9.8443	0.0258	1.4402	2.4631	1.3377	45.8463	92.3864	4.6778	1547.9682
	F	54542.22	584	4.7073	0.0522	2.5055	2.83	1.6582	49.0536	94.4886	8.1126	569.7279
	G	292916.08	623	25.9134	0.0557	12.5389	19.1469	2.0779	84.6941	98.8882	22.3808	14.994
1990	A	30362.62	911	2.6588	0.0813	3.9155	0.0642	1.2242	74.1353	71.6664	2.5734	16776.013
	B	109392.88	679	9.7791	0.0606	5.4525	3.1191	2.9618	55.4529	93.5373	7.5202	585.5107
	C	386316.25	1136	34.3012	0.1013	7.372	3.8718	3.1091	80.7635	94.1154	7.9827	257.3297
	D	57599.59	110	5.1551	0.0098	0.195	4.8077	0.577	79.7372	94.1303	1.4759	432.6007
	E	164432.31	589	14.621	0.0525	2.2404	9.437	1.0877	74.8402	95.3445	5.5557	110.8582
	F	59353.4	376	5.4264	0.0335	2.48	1.9757	1.5409	62.2639	90.6326	4.5801	1537.1654
	G	319952.29	710	28.3582	0.0633	10.9217	11.9506	2.8357	78.9457	97.6833	13.4403	57.9982
2001	A	38833.6	104	3.5062	0.0099	3.8468	1.2404	2.5478	58.3568	92.4219	6.0154	4942.0899
	B	110413.8	631	9.812	0.06	1.7019	0.1271	2.7337	69.0572	51.2157	1.5478	150219.7691
	C	302858.16	1110	27.7273	0.1055	9.5415	5.6303	2.9752	67.7394	95.6356	10.2901	144.4456
	D	58336.63	135	5.1755	0.0128	0.3671	5.1117	0.9218	68.2298	94.1632	1.5909	382.6882
	E	124832.44	806	11.0664	0.0766	4.626	1.154	2.0609	50.611	86.331	3.7452	2397.7689
	F	46981.27	264	4.0356	0.0251	1.5795	2.0818	1.2765	55.1268	91.9291	5.3984	2048.5933
	G	435772.73	820	38.157	0.0779	8.5439	21.1916	2.6056	61.7307	98.2402	13.8555	19.1091
2005	A	40839.14	1083	3.5741	0.0968	4.654	3.2073	2.3056	66.8199	88.7212	5.2846	955.5026
	B	143518.56	594	12.6476	0.0531	2.1478	0.2441	2.6476	72.1104	68.5649	2.3043	51944.3862
	C	278688.21	1205	24.7321	0.1077	8.0889	1.0311	3.0331	71.2191	83.6719	3.8944	3701.8294
	D	68971.23	132	6.1455	0.0118	0.5436	4.4346	0.8778	75.243	93.0123	1.5012	90.4428
	E	105081.25	686	9.343	0.0613	5.6803	0.349	3.4741	52.5369	70.6476	2.2290	32.1222
	F	51953.42	980	4.6222	0.0876	1.2728	2.726	0.8673	38.0653	90.1078	5.6985	40.6983
	G	438299.57	440	38.8755	0.0393	12.576	48.4363	3.1443	86.26	99.6633	38.2937	69.2674

Table 8 Landscape indexes of landscape level in Jinghe County from 1972 to 2005

Year	TA (ha)	PD/ (1/100ha)	LPI (%)	SHAPE_AM	ENN_MN (m)	CONTAG (%)	IJI (%)	COHESION	SPLIT	SHDI	SHEI
1972	1119316.871	0.1798	19.1469	12.678	1543.84	38.4248	82.0757	98.8281	13.7598	1.3965	0.6204
1990	1121209.342	0.3023	11.9506	10.1695	1487.4989	34.0269	75.9085	97.2049	18.6712	1.4474	0.698
2001	1122428.633	0.3677	21.1916	9.8923	1452.3095	34.8008	64.2141	96.326	25.8777	1.4944	0.768
2005	1119051.391	0.4575	48.4363	9.0423	1403.213	31.9659	62.968	96.4906	26.182	1.4962	0.7689

data at different scales or different grid sizes introduce variability in landscape structure analysis. Because data adopted in this paper were collected in four different periods, LUCC maps used for the analysis of its changes could be directly affected by the resolution of the data source and the classification system of the map.

2.4.1 *Comparison of landscape metrics at class level*

As seen in Table 7, we compare the change in landscape metrics at class level. Grassland, farmland, and other objects are the highest variable patch type: grassland area decreased from 456447.92 ha in 1972 to 278688.21 ha in 2005, while farmland and other objects area increased from 12857.99 ha in 1972 to 40839.14 ha in 2005, from 292916.08 ha in 1972 to 438299.57 ha in 2005, respectively, whereas their number of patches decreased from 1447 to 1083 and from 623 to 440, respectively. This indicates that many dispersive patches ware merged into larger ones, and landscape heterogeneity declined. The interspersion and juxtaposition index of the farmland patches and sandyland patches decreased, indicating less uniform landscape configuration. The changes in these metrics reflect that the distribution of farmland, grassland, and other objects in Jinghe prefecture was more fragmentary in 2005. Area weighted mean shape index of forestland, grassland, salinized-land, and sandyland showed a little decline, illustrating a reduction in the shape complexity. Through more than 33 years of land management, not only did the grassland decline by more than 170000 ha but also the newly reclaimed farmland tended to surround the old grassland. However, the fragmentation indices of farmland, forestland, grassland, water area, salinized-land, and other objects became larger (Table 8), especially salinized-land, displaying a more fragmented and dispersive patch spatial distribution due to human impact. As dominant landscape type in the study area, grassland played an important role in agriculture and pasture livestock development of the region. Its fragmentation index increased dramatically from 1.2999 in 1972 to 3.0331 in 2005. The severe fragmentation would influence the well development of agriculture and pasture livestock. Consequently, the patch grain size became smaller and fragmentation degree evidently arises, thus resulting in the decline of importance in the whole landscape mosaic.

Other objects are the patch type with the largest class area in the region. An interesting feature is that the changes in various metrics showed an opposite tendency compared to the grassland. For instance, other objects area percentage of the total landscape area increased from 25.91% in 1972 to 38.88% in 2005, while the grassland area percentage of the total landscape area decreased from 40.48% in 1972 to 24.73% in 2005. Patch number decreased, and the interspersion and juxtaposition index increased. Therefore, other objects became more clumped and continuous. Such growth and decline changes in grassland and other objects areas resulted from projects returning land from farming to grassland and land management of transforming other objects into grassland in the last 30 years.

Except for grassland and other objects, forestland and salinized-land area are another highly variable patch type. In the last 30 years, the forestland area expanded by 1081.2 ha; while salinized-land area reduced by 5741.36 ha, and its patch number increased strongly. The development of forestland area, compared to the expansion of other objects, displayed a similar expansion process in the region. Other patch types also had notable variation. For instance, the water area increased by 11578.54 ha during the last 30 years. Its percentage in the total landscape area increased from 5.09% to 6.12%, and the patch number also increased. The expansion of water area mainly has a relation with Ebinur Lake, and this is closely related to the plentiful water resources.

2.4.2 *Comparison of landscape metrics at landscape level*

Table 8 shows changes of LUCC landscape indices at the landscape level. As a measure of diversity in community ecology, SHDI is sensitive to rare patch types and is applied to describe landscapes. Meanwhile, SHEI is applied to describe the even distribution of area among patch types, which results in maximum evenness. As such, evenness is the complement of dominance. Consequently, spatial continuity of landscape patches had also changed and transformed significantly. For instance, ENN_MN changed from 1543.84 m to 1403.21 m. In contrast, IJI decreased year by year. This indicates that patches in LUCC landscapes became more interconjugated and better connected in larger scale patches, leaving only a few dominant and leading LUCC types. IJI is based on patch adjacencies and not on cell adjacencies like CONTAG. As such, it does not provide a measure of class aggregation like CONTAG, but rather isolates the interspersion or intermixing of patch types, and contagion is inversely related to edge density. Therefore, we derived the contagion index for each class in order to measure the clumping trends of the patches in this class. In general, a higher CONTAG implies a more contiguous and homogeneous spatial pattern. For example, when edge density is very low, with a single grade occupying a very large percentage of the landscape, contagion is high, and vice versa. Contagion is affected by both dispersion and interspersion of patch types. Low levels of patch type dispersion (i.e., high proportion of like adjacencies) and low levels of patch type interspersion (i.e., inequitable distribution of pairwise adjacencies) result in high contagion, illustrating that the spatial distribution of various patches in the landscape became compacted.

3 Conclusion

(1) This paper describes how the technologies of satellite remote sensing and GIS analysis are combined to address land-use and land cover changes in Jinghe County, China, during the period of 1972 to 2005. It was found that farmland and other objects have notably increased in area, while grassland has decreased significantly. Farmland development was uneven in different parts of Jinghe prefecture and was closely related to the loss of grassland and the expansion of other objects.

(2) The structure of the landscape in Jinghe prefecture has changed significantly during the 33-year study period. The grassland areas have become more fragmented and are characterized by the proliferation of much smaller and less connected patches. Additionally, the heterogeneity of the whole landscape declined. This was demonstrated by the change in various landscape metrics in both the class and landscape level. The landscape has become more continuous, more clumped together and more homogeneous.

(3) Current research results can be further improved from the following aspects. First, to minimize classification errors caused by spectral similarity of land cover types, the contextual knowledge should be taken into account in the classification to solve the belonging of 'confused' pixels. This will lead to a more accurate result in the landscape pattern and dynamics analysis. Second, ecological, social, political, and economic factors should be incorporated in the analysis of change detection. The added awareness of the landscape context from these factors will assist in making objective statements about the changes in time series. Finally, the emphasis of this study is to assess landscape complexity, and its dynamic process in the past and current time. A natural future development of our study is to predict future landscape pattern by combining spatial statistics with prediction models, such as the Markov model or cellular Automata model.

From 1972 to 2005, as a whole, patch amounts of landscape changed slightly and development degree was lower in the study region. The dynamic changes of landscape diversity showed that landscape pattern of the study area represented an unreasonable tendency. The structure of the ecological system was relatively simple, and in different phases, the diversity of spatial pattern changed drastically, which had a close relation to human activities, local policies, regional climate, and change of the ecological environment. In the future, the area of farmland and other objects will continually and slightly increase. Their dominant status will be strengthened, and the fragmentation degree will grow. Grassland and salinized-land will keep on declining, and fragmentation degree will decrease. The development of unused lands is considered a future key to long-term planning of the study region.

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