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A new artificial oasis landscape dynamics in semi-arid Hongsipu region with decadal agricultural irrigation development in Ning Xia, China

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Abstract Understanding the ecological mechanisms and processes driving changes in our landscapes is significant for ecological conservation. This work used remote sensing with the extending contingency-based method to quantify the interchange relationship of land use types, and landscape metrics including spatially nuanced difference at patch level to track immigrants' resettlement impacts at the semi-arid Hongsipu region with decadal agricultural pumping irrigation development in Ning Xia, China. Landsat-TM images acquired in 1989, 1999, 2003, and 2008 were used to study landscape changes in three periods, the earlier development from 1989 to 1999, the middle period in 1999–2003, and final stage in 2003–2008. The results showed the over 50 % landscape area experienced drastic change in each period with heavy immigrants' perturbations since 1998. The nearly natural landscape with 1:1 area between desert and steppe in 1989 10 years before development, however, became the overwhelming barren landscape with almost 80 % of the study area in 2008, grassland and shrub land almost disappeared respectively, and cultivated land climbed to the third large type from about 2 % in 1989 to more than 16 % in 2008. The landscape became more fragmented, more regular shape with human

disturbance spreading from the northwest low mountain and flat basin to the southeast diluvial fan, even high mountain at the end. Although Hongsipu pumping irrigation zone alleviates poor population pressure in the fragile ecological southern mountainous areas of Ningxia, the new artificial oasis creates another possible new ecological risk of the study area. Therefore, besides the economic development, the ecological conservation and restoration measures should be also the primary objectives in order to successful resettlement immigrants.

Introduction

Hongsipu pumping irrigation zone, the largest Yellow River irrigation area to create farmland in the desert, has been exploited to resettle immigrants from drought-stricken and economic-poor southern mountainous areas of Ningxia since 1998 in China, and been finished in 2009. During decade development and construction, national investment was totally 2.25 billion RMB, immigrants were about 2.00×10^5, as a county administrative unit, its planning area covers nearly 1999.1 km^2. In 2008, its gross domestic production was up to 0.5 billion RMB, and peasant per capita income was 2660 RMB, increasing about five times since the beginning of construction (Han and Gao 2010). With the ecological immigration project and ecological management project implementation, land use became more intensive, such as efficient water-saving and facility agriculture, irrigated land, woodland and grassland increased gradually, the rate of forest preservation and coverage reached 80 and 39 % respectively, while

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abandoned land exploited constantly (Han and Gao 2010; Lu et al. 2015).

As an artificial oasis, it is difficult to sustain Hongsipu irrigation zone without causing desertification in an ecological fragile system. 3.03×10^8 m³ water is pumped from Yellow River to irrigate the oasis each year, soil and local vegetation have been changed or modified by large-scale land reclamation, irrigation and grazing, as well as cutting fuel, collecting medicinal herbs across this region. For example, some land just cultivated for 3 years has suffered secondary salinization, and in the 2.66×10^4 ha land suitable for cropland, 7.33×10^3 ha land had high secondary salinization risk (Yin et al. 2001; Pan et al. 2001; Zhang and Jia 2011), also, about 41.3 % soils was sandfied to varying degrees (Jin and Ma 1998; Yang and Song 2011); on the other hand, grassland degraded seriously, vegetation coverage was reduced from 43.3 % in 1980s to 26 % in 2001, averagely (Lan and Guo 2003). As a consequence, it is vitally important to understand the current status and trend of landscape change for the oasis, better land-use policies and management strategies can be developed for protecting the fragile ecosystem and maintaining a sustainable development. To our knowledge, this kind of investigation has not been performed.

Specifically, a wide variety of remote sensing methods have been developed for detecting land use change in bi-temporal categorical and multi-spectral imagery (Weismiller et al. 1977; Wickware and Howarth 1981; Hodgson et al. 1988; Abuelgasim et al. 1999; Hussain et al. 2013). Post classification comparisons, performing a pixel-by-pixel overlay of two thematic maps to generate a change (or similarity) map (Jensen et al. 1987; Hodgson et al. 1988; Dai and Khorram 1999; Hussain et al. 2013), represents a common approach used for change detection in practice. Because this technique offers the advantages of minimizing the impacts of atmospheric, sensor and environmental differences between multi-temporal images, and is relatively easy to perform (Mas 1999; Lu et al. 2004). It also provides a contingency table from which the transition matrix can be compiled, but the other statistics such as Kappa to summarize cell-to-cell agreement and disagreement was rarely adopted in landscape change quantification, which is a considerable tradition of map comparison in the context of remote sensing accuracy assessment (Foody 2002; van Vliet et al. 2011).

A major drawback of the contingency-based methods is that they do not attempt to account for spatial relations, meaning that all disagreements at the cellular level are weighted identically, regardless of their individual impact on landscape structure (Hagen-Zanker 2006), thus they do not necessarily capture the similarity of patterns (Power et al. 2001). An alternative approach, which has its roots in landscape ecology, is to express the change between maps by the differences in metrics that quantify the spatial structure of the landscape (McGarigal et al. 2002). Landscape metrics derived from land use and land cover maps have been used to quantify environmental change specifically in arid and semi-arid regions (Kepner et al. 2000; Seixas 2000; Sun et al. 2005; Xie et al. 2014). But often, landscape structure metrics at class and landscape level were used in landscape change, in this quantification the notion of spatial location also is lost without addressing patch-by-patch (or cell-by-cell) level comparison (Hagen-Zanker 2006). Hagen-Zanker (2006) puts forward the moving window based structure comparison method for spatially nuanced map difference.

Therefore, the specific objectives of the present study are: 1) taking 10 years before development, 1989 landscape as a baseline, to study landscape change in three periods, the earlier development from 1989 to 1999, the middle period in 1999–2003, and final stage in 2003–2008 in Hongsipu region for understanding the interactions between land-use and demography with development, and as a baseline for setting appropriate management; 2) to expand a methodological implementation with contingency table and landscape approach comparison for a better understanding of the possible ecological consequences such as desertification and restoration strategies.

Methods

Study area

The study area is located in Ningxia province in northwest China (between 105°43′-106°14′ E and 37°28′-37°37′ N), covering 1976.01 km² (Fig. 1). The area has an arid continental climate with an average annual temperature of 8.4 °C (average maximum 22.7 °C in July). The annual daily mean sun duration is 3036.4 h, with a global radiation of 143.9 kcal/cm². Mean annual precipitation in the area is 258 mm, 50–62 % of which occurs in July, August and September. Annual average evaporation is 2300 mm, nine times annual precipitation, thus spring and summer drought is severe in the area. The pumping irrigation zone lies in a basin surrounded by Luo mountain, Niushou mountain and Yantong mountain on the east, north and south, the geomorphic types include hill, diluvial fan, diluvial-fluvial plain and eolian sandy land. Elevations in the region range from 2200 to 1200 m, sloping generally downwards from the southeast to the northwest. Kushui river passes through the north area, and Hongliugou river develops from Luo mountain across the center area, they both are intermittent rivers with only 0.27×10^8 m³ annual runoff, and poor water quality with average 4.5 g/L high degree of mineralization. In addition, the study area borders the Yellow river to the southwest. Soils include sierozem, entisol, eolian sand and saline soil, and sierozem covers 81.8 % of the total area.

Fig. 1 Study area (Landsat TM true color image dated 25 June 2008)
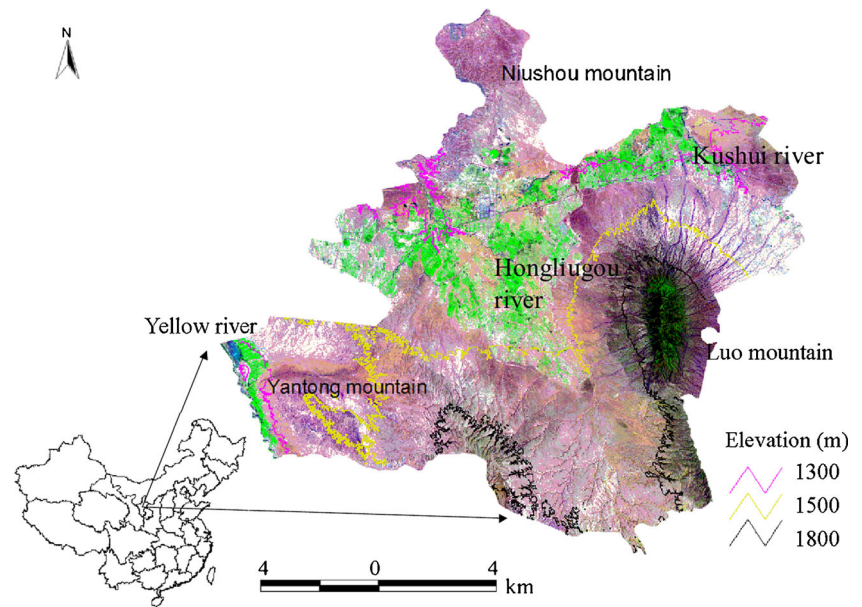
Data sources and pre-processing

When selecting remote sensing data for change analysis, it is better to use the same sensor, same radiometric and spatial resolution data with anniversary or very near anniversary acquisition dates in order to minimize the effects of external sources such as sun angle, seasonal and phenological differences. Thus, we used cloud free images (Landsat-TM path 129, row 34) acquired in 24 August 1989, 12 August 1999, 15 August 2003, and 25 June 2008. All these scenes correspond to the summer season, so vegetation cover under luxuriant growth period with similar phenological conditions. To avoid or minimize the influence of the anthropogenic activities, 10 years before development, 1989 was taken as a natural landscape baseline to measure the new artificial oasis landscape dynamics in different development periods. The 1: 50, 000 topographic maps and irrigation zone 10-year planning map (including irrigation channel, village, farmland) were collected to aid analysis, also acquired the census of the different periods irrigation channel construction and irrigation water quantity.

To compensate for variations in the sensor radiometric responses over time and for variations in natural conditions of solar irradiance and solar angles, all images were radiometrically corrected. Digital numbers were firstly converted into exoatmosphere reflectance values, and then were rectified using dark-object subtraction technique (Pat and Chavez 1988). Accurate geometric registration of images is another important pre-processing for multi-date change analysis (Stow and Chen 2002). The scene acquired in 1989 was converted to Beijing54 coordinate system using common control points extracted from the 1: 50 000 topographic maps. Using a two-degree polynomial rectification algorithm, this procedure yielded a registration accuracy equal to average 0.78 pixel, then the geometric rectification 1989 scene was used as reference to coregister images acquired in subsequent years with an average 0.53 pixel good image-to-image coregistration accuracy. The pixel size was resampled to 30 m × 30 m with a nearest-neighbor interpolation method to preserve radiometric integrity.

Land use classification

The accuracy and usefulness of the comparison results depend on the accuracy of the land use classifications (Singh 1989; Lambin and Strahler 1994), thus the supervised image classification and map-editing techniques were adopted to produce a most reliable classification mapping using a unified land use classification scheme to ensure that the classifications of the multi-temporal images well-matched each other. The land-use classification system was two-level system, the first level included six types: cultivated land (CL), woodland (WL), grassland (GL), built-up areas (BU), water areas (WA) and bare land (BL). Woodland type was subdivided into three types: forestland (FL) with trees closure degree over 30 %, sparse forestland (SFL) with trees closure degree in 10–30 % and sparse shrubland (SL) with shrubs cover below 30 %. Bare land also was classified to four subtypes according the geomorphic types: hill BL (HBL), diluvial fan BL (DFBL), gully BL (GBL) and eolian sandy BL (ESBL).

The maximum likelihood supervised classification (MLC) has been a satisfactory method in classifying remotely sensed data (Mather 1985; Bolstad and Lillesand 1991), and was employed to classify individual images independently. The success of the classification, however, depends basically on the quality of category training samples. Based on the
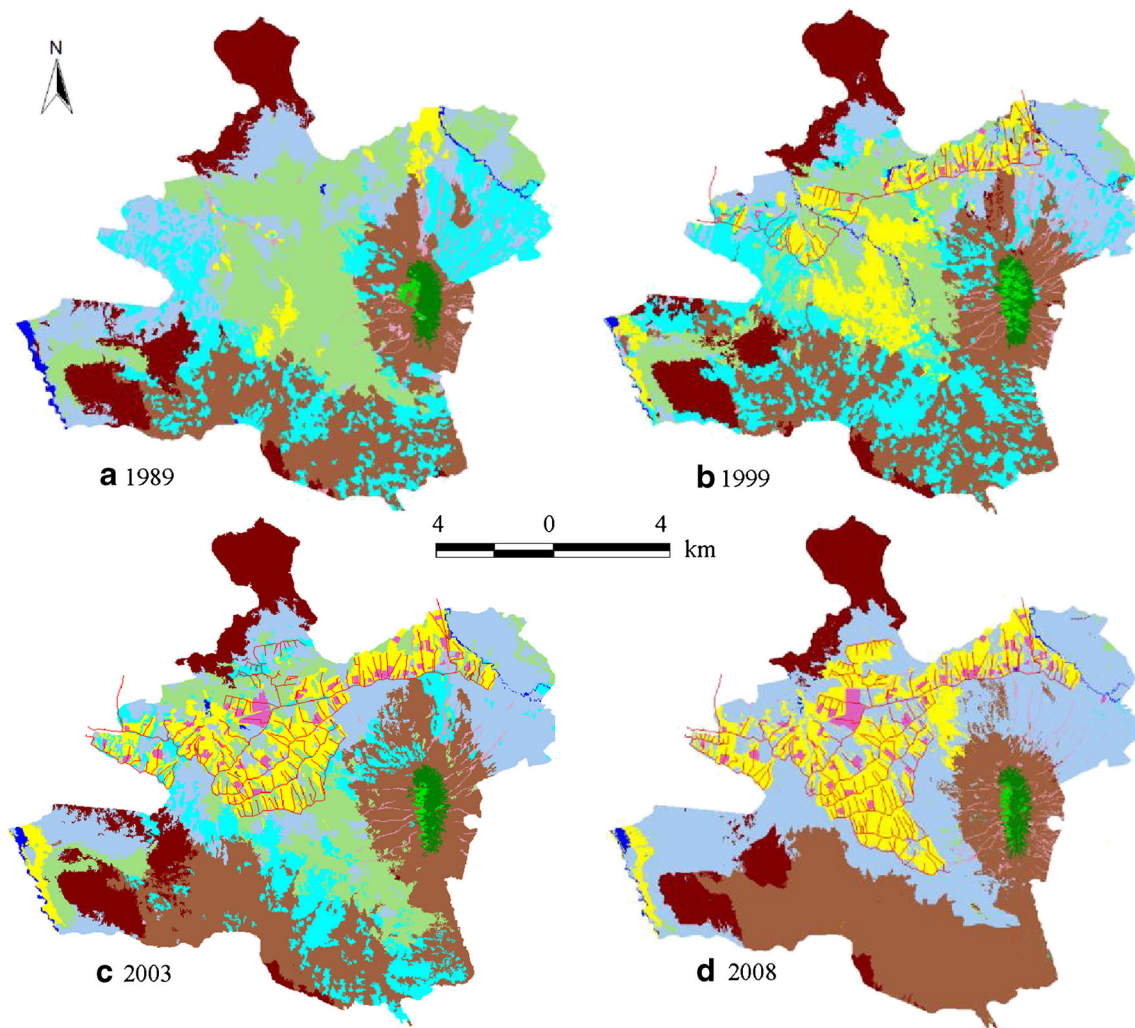
Fig. 2 Land use maps derived from image classification in 1989–1999–2003–2008

Table 1 Land use type areas and percentage in 1989–2008

Type	Subtype	1989		1999		2003		2008	
		Hectares	Percentage	Hectares	Percentage	Hectares	Percentage	Hectares	Percent
CL		3938	2	20,393	10	22,322	11	32,448	16
WL	2572	1	2215	1	2364	1	1.20	2088	1
	576	0	1103	1	507	0	0.26	529	0
	36,355	18	40,014	20	24,467	12	12.38	133	0
	Sum	39,502	20	43,331	22	27,338	14	2751	1
GL		48,994	25	29,722	15	30,280	15	666	0
BU		0	0	643	0	3103	2	3873	2
WA		1301	1	933	0	771	0	654	0
BL	43,150	22	48,151	24	49,622	25	25.11	59,069	29
	21,355	11	21,892	11	21,378	11	10.82	18,745	9
	3554	2	2206	1	1474	1	0.75	1947	1
	35,807	18	30,330	15	41,311	21	20.91	77,444	39
	103,865	53	102,579	52	113,786	58	57.59	157,207	79

irrigation zone 10-year planning map, early on-site visit re-cords in 2003 were used to define the 2003 training samples. Through comparing the other year images with the 2003 image by visual interpretation, the training sites in 2003 where did not change, were kept as training samples for the corresponding year classification, respectively. The overall classification accuracy in 2003 was 82.19 %, and that was 74.53, 70.40 and 77.43 % in 1989, 1999 and 2008, respectively, assessed with ground truth ROIs in ENVI software. The classification accuracy can satisfy the change analysis after visual interpretation using map-editing method.

The map-editing phase consisted of a visual inspection directly on the monitor, correcting the commission and omission errors in the MLC classification maps. Under the ArcView geographic information system environment, the each year classification map was in vector format, and each polygon was checked through superimposing the satellite composite images and irrigation zone 10-year planning map to perform visual interpretation. This map-editing can make full use of an analyst's experience and knowledge of the texture, shape, size and patterns of the images. To minimize possible classification errors, the classification and map-editing of all images was carried out by the same person. Formal accuracy assessments were not performed because we can consider the accuracy of the final classification maps (Fig. 2) as similar to that of visually generated maps. In the map-editing phase, the each year irrigation channel map also was delineated with the help of the census of irrigation channel construction, satellite composite images and irrigation zone 10-year planning map (Fig. 2).

Change analysis

The post-classification change detection was used to determine differences between the 4 years on a pixel-by-pixel basis to pinpoint any changes in map format. In this study we

Table 2 Land use change percentage in 1989–1999–2003–2008

Type	Subtype	1989–1999	1999–2003	2003–2008	1989–2008
CL		8.3	0.9	5.1	14.4
WL	FL	−0.2	0.2	−0.1	−0.2
	SFL	0.3	−0.3	0	0
	SL	1.8	−7.8	−12.3	−18.3
Sum		1.9	−8.0	−12.4	−18.6
GL		−9.7	0.3	−14.9	−24.4
BU		0.3	1.2	0.5	1.9
WA		−0.2	−0.1	0	0
BL	DFBL	2.5	0.7	4.7	8
	HBL	0.2	−0.2	−1.3	−1.3
	GBL	−0.6	−0.3	0.2	−0.8
	ESBL	−2.7	5.5	18.2	21
	Sum	−0.6	5.6	21.9	26.9

Table 3 Bi-year landscape similarity Kappa value

	1989	1999	2003	2008
1989	1	0.42	0.41	0.32
1999		1	0.46	0.38
2003			1	0.49
2008				1

mainly considered the changes that could potentially lead to land degradation to highlight the spatial locations of where these changes had occurred.

The changes for the three time periods also was represented in a series of change contingency tables that depicted (a) the total area of change between the classes, (b) "from–to" land use classes, a transition matrix can be compiled from contingency table by normalization using former date classes area, which details the decreases in one category to late date classes, also (c) a composition matrix from contingency table by normalization using late date classes area, which indicates land use classes structures from former date land use classes. In this study, Kappa coefficient was adopted to measure the similarity of bi-temporal landscape change, respectively, based on a contingency table.

Landscape metrics analysis

While change analysis with contingency table technique quantified several facets of the change (including its spatial location), it did not reveal changes in the geometry and fragmentation of the land use classes. Therefore, firstly, a suite of landscape metrics were calculated that provided an overall perspective of the class level, and landscape level changes. The metrics included Patch density (PD) and mean patch area (AREA_MN) for fragmentation, largest patch index (LPI) for dominance, mean patch fractal dimension (FRAC_MN) for shape complexity. Shannon's diversity index (SHDI) was also selected for the three time periods landscape diversity. FRAG STASTS (McGarigal et al. 2002) was used to calculate the selected landscape metrics.

Besides the general patterns analysis of the multi-temporal landscape, patch fractal dimension(FRAC)was further analyzed the local changes based on the patch-level, which can be as a measure of human disturbance on hot spots for setting appropriate land use management and restoration strategies.

Table 4 Landscape metrics of the 4-year landscape

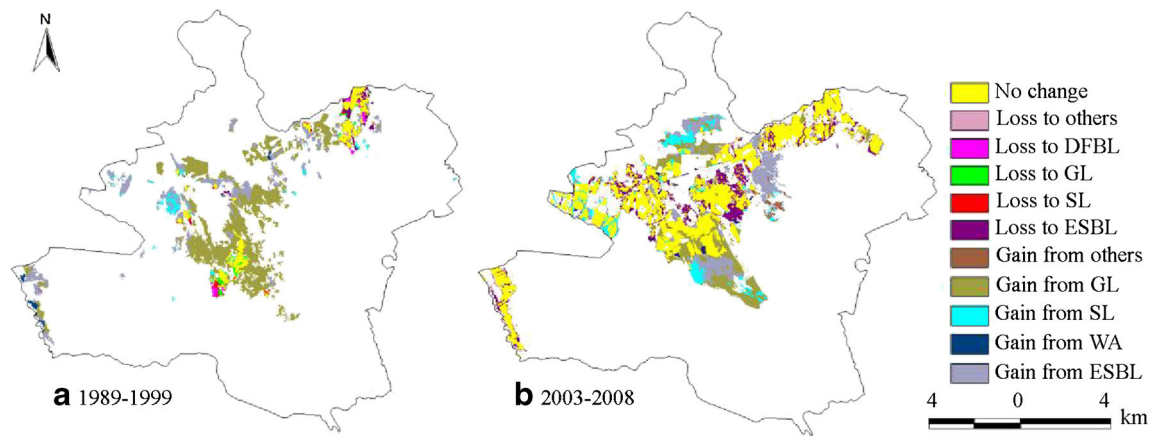|	PD	LPI	AREA_MN	FRAC_MN	SHDI
1989	0.4	18.9	222.7	1.1	1.8
1999	0.7	10.8	140.7	1.1	1.9
2003	0.8	12.3	125.8	1.1	1.9
2008	1.4	29.2	69.2	1.1	1.5

Fig. 3 Cultivated land change in the stage of 1988–1999 and 2003–2008

As human disturbance increases, FRAC normally decreases. The Hagen-Zanker (2006) comparison method was used to quantify FRAC spatial difference in this study. First 4 years FRAC metric maps were produced, in the next step, the metric maps were converted into moving averages by calculating for every cell the weighted average of its neighborhood. Finally, the average maps were compared by evaluating their difference cell-by-cell. The resulting map gives a spatial account of the difference in FRAC. For more detailed information of the method, the reader is referred to Hagen-Zanker (2006) and the Map Comparison Kit (MCK) software user guide (RIKS BV 2009), which was employed for FRAC change analysis. The MCK software was originally designed for analysis of land-use maps, now the software yields general methods for pattern recognition (Visser and de Nijs 2006).

Results

Land use changes in the study period

Results for land use extent (hectares and percent) and their relative changes for each period are presented in Tables 1

and 2. 1989 landscape, 10 years before development, had about 2 % total area cultivated land and no built-up areas. As the zonal landscape type, grassland was the first large type with up to 25 % total area, shrub land was the third type with around 18 % total area, they occupied about half the study area together before development. Bare land covered about 53 % total area indicating a balance between desert and steppe (Table 1). In 1999 the early Hongsipu pumping irrigation zone development, cultivated land increased largely from 3, 938 ha (about 2 %) in 1989 to 20, 393 ha (more than 10 % of the study area) in 1999, grassland reduced approximately by 10 % from 25 % (48, 993 ha) in 1989 to 15 % (29, 722 ha) in 1999, whereas, bare land still covered half the study area (Tables 1 and 2). In the final development stage, bare land covered almost 80 % of the study area, particularly, the eolian sandy bare land and diluvial fan bare land became the first, second large type, respectively, cultivated land climbed to the third large type from 11 % in 2003 to 16 % (32, 448 ha) approximately in 2008. In contrast, grassland and shrub land almost disappeared respectively, indicating a fragile artificial oasis in the overwhelming barren land landscape (Tables 1 and 2).

Table 2 shows major changes, especially with reference to 1989 landscape that included (a) cultivated land significant net
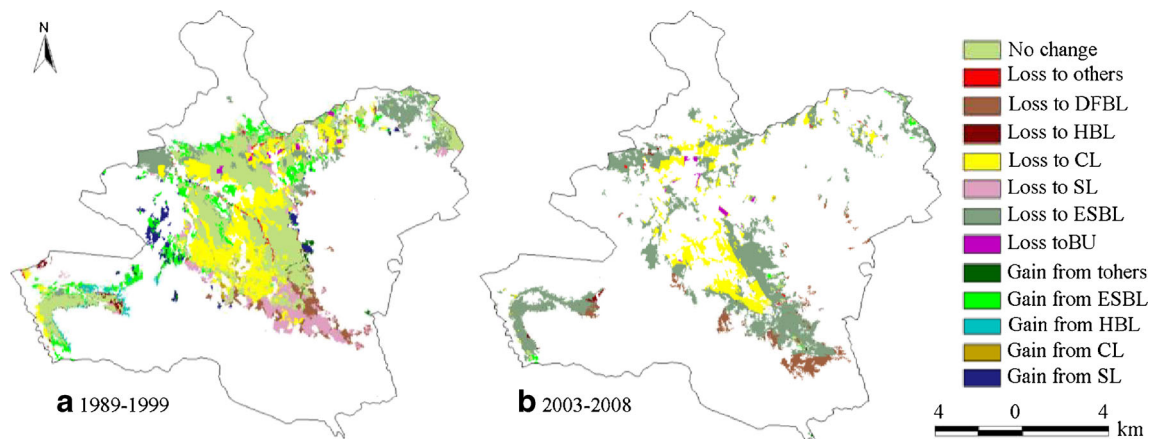

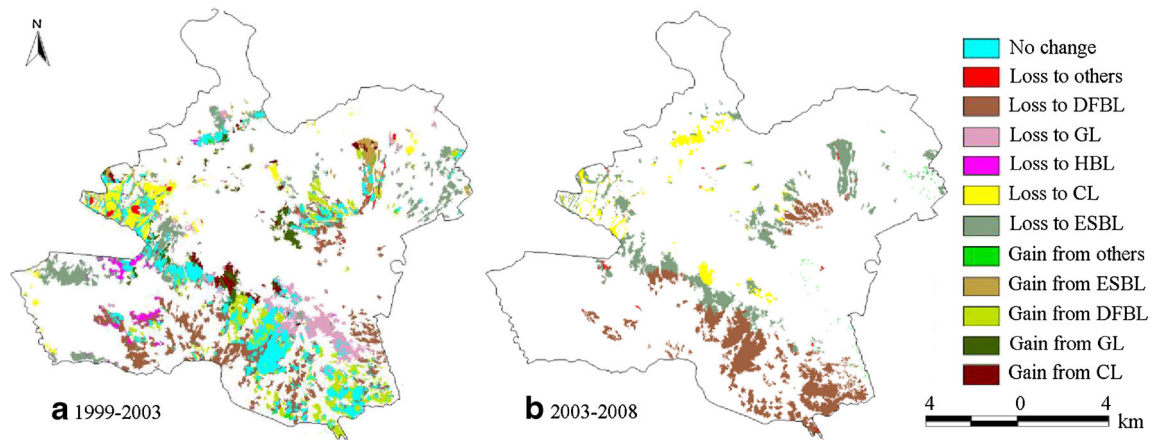**Fig. 4** Grassland change in the stage of 1989–1999 and 2003–2008

Fig. 5 Shrubland change in the stage of 1999–2003 and 2003–2008

gain in the early development period (from 1989 to 1999) and in the final development stage (2003–2008), in contrast, Built-up areas increased considerably in the middle development period (1999–2003), (b) grassland decreased rapidly in the early development period, then almost disappeared in the final development stage, similarly, shrub land loss was largely in the middle development period and almost vanished in the final stage, and (c) a distinct gain of diluvial fan bare land in
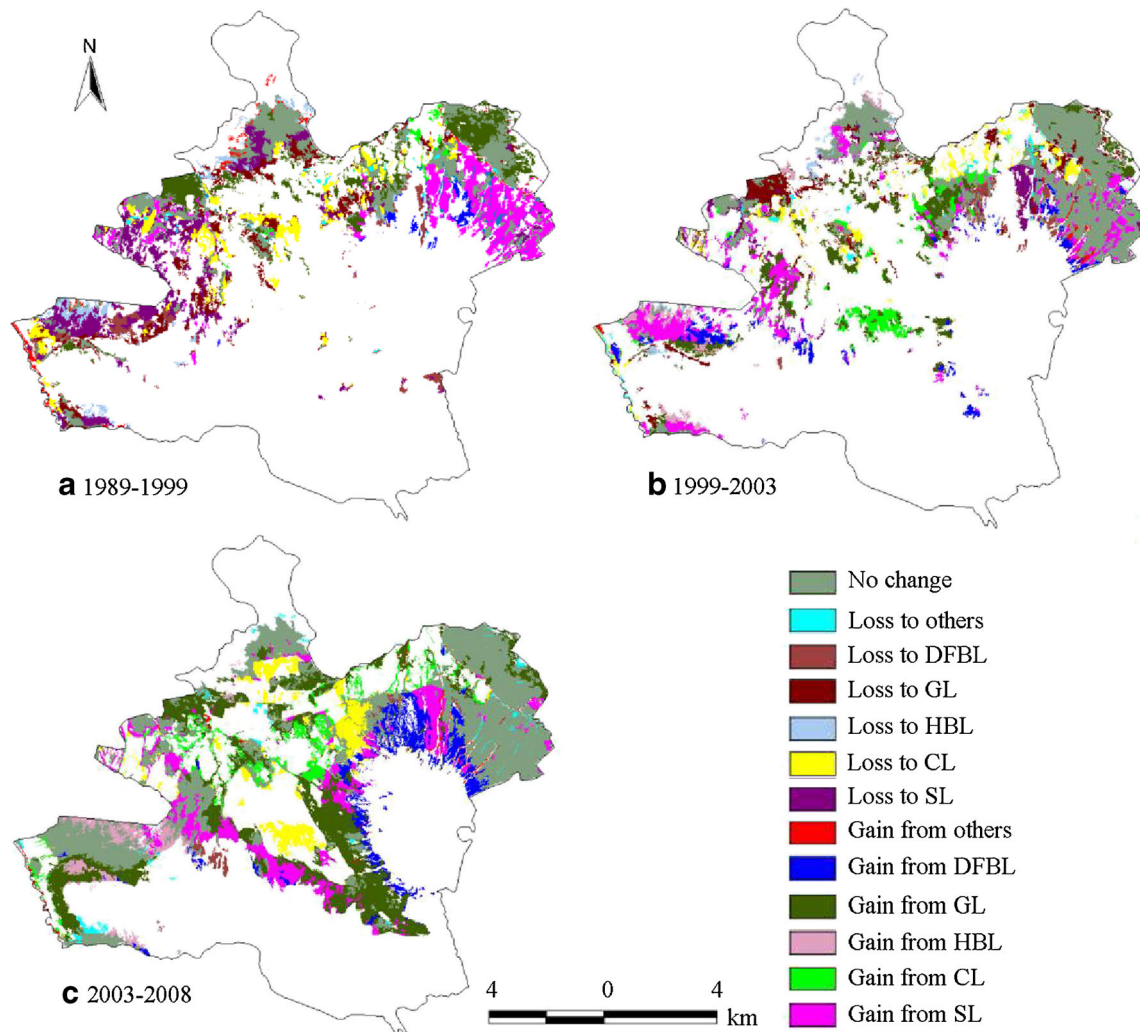

Fig. 6 Eolian sandy bare land change in the stage of 1989–1999, 1999–2003 and 2003–2008

the early and the final development stage, similarly, a considerable increase of eolian sandy bare land in the middle and final development period.

Table 3 lists kappa values of the bi-year landscapes any one of which below 0.50 indicating the over 50 % landscape experienced drastic change in each period. Table 4 lists the selected landscape metrics of the 4 years landscapes. The continuous increase in PD, decline in AREA_MN and FRAC_MN for the study area indicates the landscape became more fragmented, more regular shape with the heavy human disturbance on the landscape. The SHDI increased in the early and middle development periods with the creation and expansion of cultivated land and built-up areas, on the contrary, SHDI reduced in the final stage for the loss of grassland and shrub landscape accompanying less equitable proportional distribution of types areas. In addition, LPI decreased firstly with the early development, then increased in the middle and final stage. The results imply the drastic changes happened not only in quantity also in spatial pattern caused by human activities.

Some major changes and types interchangeable relationship

These major changes could potentially lead to land degradation, thus their types interchangeable relationship and landscape metrics changes at class level were further investigated. Figures 3, 4, 5, 6 and 7 highlight the spatial locations of where changes had occurred for cultivated land, grassland, shrub land, eolian sandy bare land and diluvial fan bare land, respectively. Table 5 represents land use type transition proportions, and Table 6 gives the type composition from the former date' types. Table 7 reveals changes in the geometry and fragmentation of the five land use types.

In the early development period, cultivated land was converted on two places: one along the northeast long axis of flat basin onwards with the irrigation channel construction, the other along the southwest short axis of basin without irrigation

channel (Figs. 2 and 3). The gain of cultivated land mainly came from grassland, and eolian sandy bare land, then shrub land (Fig. 3, Table 6). Initially grassland was converted to cultivated land, then, as land became more scarce, eolian sandy bare land and shrub land at the relatively high elevation and slope land were explored for cultivated land with the irrigation channel construction in 2003–2008 (Fig. 3). Meanwhile, in the fragile ecosystem, cultivated land quickly reverted to eolian sandy bare land during the development periods (Table 5), especially in the final stage (Fig. 3). Table 7 further suggests cultivated land became more fragmented with smaller mean patch size in the final stage because of the unreasonable use and degradation.

Figure 4 suggests grassland, besides converted to cultivated land, mainly changed to eolian sandy bare land, shrub land and diluvial fan bare land, also recovered some from these types (Tables 5 and 6). However, the remnant grassland degraded sharply to barren land at the final development stage without gain from other types (Table 5, Fig. 4). As the landscape matrix before development, grassland provided the landscape largest path of about 19 % total area, and became more and more fragmented with sharpening reduction of patch size and was in severe danger with cultivated land reclamation process (Table 7). Similar patterns were observed for shrub land, the other zonal landscape type. Shrub land had a little net gain and kept a dynamic balance with the same interchange rates between bare land types in the early development period, but with the more increasing immigrants and continuing heavy disturbance, the balance was broken with more degradation to diluvial fan bare land and eolian sandy bare land, particularly in the final development stage (Fig. 5, Tables 5 and 6).

Figure 6 shows the eolian sandy bare land extended in the flat basin with grassland and shrub land two times' large-scale degradation. The fluctuation of its PD and AREA_MN further indicates its drastic change, in addition, its LPI increased continuously with the largest patch covering 21 % total area of the
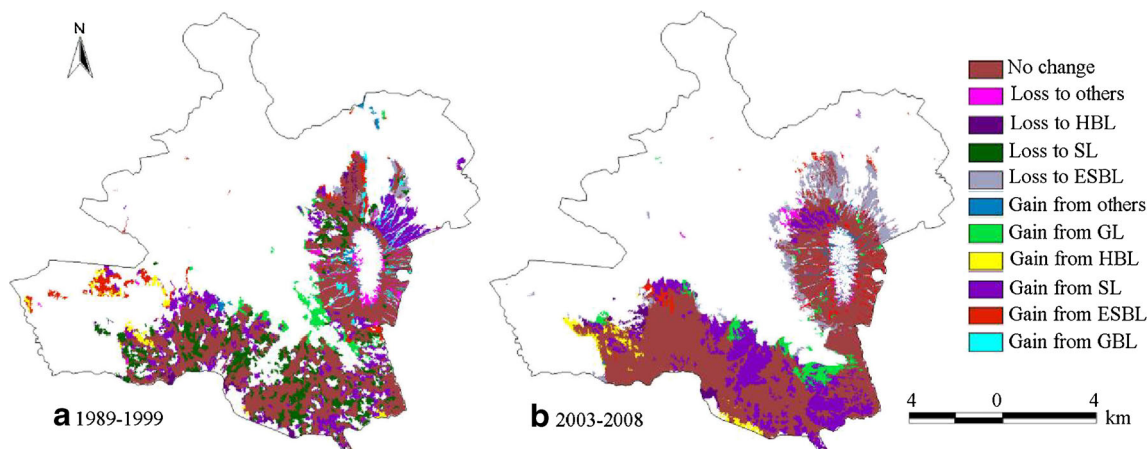

Fig. 7 Diluvial fan bare land change in the stage of 1988–1999 and 2003–2008

Table 5 Transition proportion of land use types (%)

	CL	FL	SFL	SL	GL	BU	WA	DFBL	HBL	GBL	ESBL
1989		1999									
CL	61.1	0.0	0.0	5.9	9.8	0.9	0.1	8.6	0.0	0.0	13.6
FL	0.0	62.2	31.6	0.0	0.0	0.0	0.0	6.0	0.0	0.2	0.0
SFL	0.0	25.6	36.3	5.4	0.0	0.0	0.0	30.7	0.0	2.0	0.0
SL	1.9	0.0	0.0	41.9	4.3	0.1	0.1	28.7	0.6	1.2	21.2
GL	25.0	0.0	0.0	10.2	43.4	0.7	0.5	4.6	0.7	0.1	14.9
WA	20.0	0.0	0.0	6.6	0.0	0.3	33.9	0.7	0.0	1.9	36.4
DFBL	0.1	1.1	0.2	22.6	0.5	0.0	0.0	70.0	2.5	1.3	1.8
HBL	0.1	0.0	0.0	3.7	3.5	0.0	0.0	5.0	85.4	0.0	2.3
GBL	1.8	0.2	0.2	7.8	3.0	0.0	2.7	34.8	2.7	28.4	18.5
ESBL	13.1	0.0	0.0	24.0	15.1	0.7	0.3	6.4	5.5	0.3	34.6
1999		2003									
CL	55.0	0.0	0.0	7.4	19.2	4.5	0.5	0.4	0.2	0.1	12.8
FL	0.0	72.7	2.6	0.2	0.0	0.0	0.0	24.4	0.0	0.2	0.0
SFL	0.0	59.2	38.6	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0
SL	8.2	0.0	0.0	29.5	12.1	0.8	0.0	27.3	2.8	0.3	19.0
GL	16.1	0.0	0.0	7.7	43.1	3.1	0.1	3.0	3.0	0.1	24.0
BU	21.5	0.0	0.0	0.3	0.2	77.6	0.0	0.0	0.0	0.0	0.4
WA	15.3	0.0	0.0	3.2	17.4	0.0	41.4	0.3	0.0	3.8	18.7
DFBL	0.3	0.2	0.1	13.3	8.2	0.1	0.0	68.8	2.6	0.7	5.7
HBL	0.3	0.0	0.0	0.6	2.7	0.0	0.0	7.8	79.9	0.0	8.7
GBL	2.0	0.1	0.0	3.4	0.7	0.2	1.1	40.3	0.0	35.2	17.1
ESBL	8.4	0.0	0.0	7.3	13.2	1.3	0.8	4.4	2.1	0.5	62.0
2003		2008									
CL	78.3	0.0	0.0	0.0	0.0	1.7	0.4	0.0	0.0	0.4	19.2
FL	0.0	76.7	4.5	0.0	0.0	0.0	0.0	18.7	0.0	0.1	0.0
SFL	0.0	17.5	75.2	0.0	0.0	0.0	0.0	7.2	0.0	0.1	0.0
SL	10.3	0.0	0.0	0.0	0.1	0.1	0.0	51.1	0.3	0.3	37.7
GL	20.5	0.0	0.0	0.0	1.3	0.9	0.1	9.0	0.8	0.2	67.1
BU	2.1	0.0	0.0	0.0	0.0	97.6	0.0	0.0	0.0	0.0	0.4
WA	8.1	0.0	0.0	0.0	0.0	0.0	58.0	0.2	0.7	0.0	33.0
DFBL	0.6	0.4	0.1	0.1	0.1	0.0	0.0	82.5	2.0	1.9	12.3
HBL	0.2	0.0	0.0	0.0	0.0	0.0	0.0	5.5	79.3	0.0	15.1
GBL	3.0	0.0	0.0	0.0	0.3	0.0	0.0	23.2	0.2	44.5	28.6
ESBL	13.8	0.0	0.0	0.2	0.5	0.5	0.2	2.2	1.2	0.3	81.3

landscape at the final stage (Table 7). The diluvial fan bare land were mainly converted from shrub land in the southeast mountain regions (Fig. 7, Table 6), and provided the landscape largest patch since 1999 replacing of grassland (Tables 4 and 7). The bare land types had the high restoration ability to shrub land and grassland in the early development, particularly the eolian sandy and diluvial fan bare land, but lost the restoration ability in the final stage (Table 5, Figs. 6 and 7).

Figure 8 indicates the whole area suffered the human severe disturbance in the development periods, and the disturbance spread from the low northwest mountain and flat basin firstly to the southeast diluvial fan and high mountain at the end. The northeast, center and south areas should give more attention where the local fractal dimension fluctuated sharply. When examined with relation to the land use maps and types change maps, the northeast where the grassland and shrub land were replaced by cultivated land and eolian sandy bare land. The center, where the human living and agriculture activity mainly located, was surrounded by eolian sandy bare land. And the south area, where shrub land disappeared and diluvial fan bare land covered the whole area. Conversely, the center flat basin, where the negative re-natural processes may be accelerated with some cultivated land degradation to eolian sandy bare land, increased the fractal dimension at the final stage.

Table 6 Composition proportion of land use types (%) from previous date

	CL	FL	SFL	SL	GL	BU	WA	DFBL	HBL	GBL	ESBL
1999		**1989**									
CL	11.8	0.0	0.0	0.6	1.3	5.6	0.5	0.7	0.0	0.0	1.8
FL	0.0	72.1	73.4	0.0	0.0	0.0	0.0	0.3	0.0	0.2	0.0
SFL	0.0	6.6	18.7	0.1	0.0	0.0	0.0	0.4	0.0	0.5	0.0
SL	3.5	0.0	0.0	38.1	5.3	3.1	3.0	21.6	1.0	20.1	25.4
GL	60.0	0.0	0.0	12.5	71.6	52.2	26.5	4.6	1.5	1.6	24.1
WA	1.3	0.0	0.0	0.2	0.0	0.7	47.1	0.0	0.0	1.1	1.6
DFBL	0.2	21.1	7.2	24.3	0.8	0.0	0.1	62.8	4.8	25.3	2.6
HBL	0.1	0.0	0.0	2.0	2.5	0.0	0.1	2.2	83.3	0.3	1.6
GBL	0.3	0.3	0.7	0.7	0.4	0.0	10.5	2.6	0.4	45.7	2.2
ESBL	23.0	0.0	0.0	21.5	18.2	38.5	12.3	4.8	8.9	5.1	40.8
2003		**1999**									
CL	50.2	0.0	0.0	6.2	12.9	29.7	12.4	0.2	0.2	0.9	6.3
FL	0.0	68.2	11.4	0.0	0.0	0.0	0.0	1.1	0.0	0.2	0.0
SFL	0.0	27.7	84.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
SL	14.7	0.3	0.0	48.2	16.0	10.8	1.6	22.0	5.2	9.1	18.4
GL	21.4	0.0	0.0	9.3	42.4	29.3	3.5	1.8	4.2	2.0	17.3
BU	0.6	0.0	0.0	0.0	0.0	16.1	0.0	0.0	0.0	0.0	0.0
WA	0.6	0.0	0.0	0.1	0.5	0.0	49.4	0.0	0.0	2.3	0.4
DFBL	0.6	3.8	4.5	26.3	13.1	1.0	0.3	67.0	6.0	21.7	6.7
HBL	0.3	0.0	0.0	0.5	1.9	0.3	0.0	3.4	81.4	0.1	4.6
GBL	0.2	0.1	0.1	0.3	0.1	0.1	3.1	1.8	0.0	52.8	0.9
ESBL	11.4	0.0	0.0	9.0	13.2	12.9	29.6	2.7	3.0	10.9	45.5
2008		**2003**									
CL	53.9	0.0	0.0	0.0	1.5	9.8	12.2	0.0	0.0	4.1	5.5
FL	0.0	86.8	20.3	0.0	0.0	0.0	0.0	0.8	0.0	0.1	0.0
SFL	0.0	17.5	75.2	0.0	0.0	0.0	0.0	7.2	0.0	0.1	0.0
SL	7.8	0.0	0.0	4.9	5.2	0.5	1.6	21.2	0.4	3.9	11.9
GL	19.2	0.0	0.0	0.7	59.5	6.7	6.0	4.6	1.2	3.8	26.3
BU	0.2	0.0	0.0	0.0	0.0	78.2	0.0	0.0	0.0	0.0	0.0
WA	0.2	0.0	0.0	0.0	0.0	0.0	68.4	0.0	0.0	0.0	0.3
DFBL	1.0	9.0	7.6	48.7	5.3	0.0	0.5	69.3	5.3	48.8	7.9
HBL	0.1	0.0	0.0	0.0	0.0	0.0	0.0	2.0	90.4	0.0	4.2
GBL	0.1	0.0	0.0	0.4	0.6	0.0	0.0	0.6	0.0	33.7	0.5
ESBL	17.6	0.0	0.0	45.3	28.0	4.9	11.4	1.5	2.6	5.6	43.4

Discussion and conclusion

The semi-arid Hongsipu region landscape experienced very high spatial-temporal change with decade agricultural irrigation development for resettling immigrants since 1998, and the nearly natural landscape with a balance between desert and steppe before development was built into a fragile artificial oasis in the overwhelming barren land landscape.

Agricultural activities and desertification

In the semi-arid environment, unreasonable large-scale agricultural activities and land conversion were prone to cause desertification. Currently, the sandy desertification is the first threatening degradation of the oasis. It was noted that grassland and cultivated land had the opposite change both in quantity and in spatial pattern indicating land conversion was the main cause of grassland desertification. In addition, overgrazing and collecting medicinal herbs were blamed for grassland degradation in the study area (Lan and Guo 2003). When more immigrants moved in the middle development, more shrub land was cut for building, for cooking and heating, besides for cultivated land. As a consequence, shrub land almost disappeared. These activities broken the balance between desert and steppe, the steppe degraded severely, on the other hand, the bare land types lost the ability to revert to steppe.

Table 7 Landscape metrics of some land use types in 1989–2008

Type	Year	PD	LPI	AREA_MN	FRAC_MN
CL	1989	0.0	0.6	151.5	1.1
	1999	0.1	5.1	146.8	1.1
	2003	0.0	5.3	245.2	1.1
	2008	0.5	5.2	30.2	1.1
SL	1989	0.1	4.3	181.8	1.1
	1999	0.1	4.7	147.2	1.1
	2003	0.2	1.9	76.9	1.1
	2008	0.1	0.0	0.5	1.1
GL	1989	0.0	18.9	500.8	1.1
	1999	0.1	3.6	153.3	1.1
	2003	0.1	7.4	116.0	1.1
	2008	0.0	0.1	20.9	1.2
DFBL	1989	0.0	12.7	667.1	1.1
	1999	0.1	10.8	411.9	1.1
	2003	0.3	12.3	97.1	1.0
	2008	0.2	29.2	133.5	1.1
ESBL	1989	0.1	3.3	147.7	1.1
	1999	0.2	7.3	75.5	1.1
	2003	0.1	7.5	204.4	1.1
	2008	0.3	21.8	136.1	1.1

The surface soil texture of cultivated land was mainly sandy soil or sandy loam soil, and cultivated land was directly surrounded by eolian sandy bare land without grassland and shrub land protection. Thus, under the strong windy climate in spring and winter season, the surface fertile soil was always blew away with reducing soil fertility, and often buried by shifting sand from the surrounding sandy land. During a whole winter season, the burying sand depth of cultivated land was often up 5–10 cm, some cultivated lands were abandoned because of this (Pan et al. 2001), in the final development stage, cultivated land became eolian sandy bare land. In addition, the shifting sand also buried the irrigation channels to lower water use efficiency.

In order to combat or alleviate sandy desertification, the first measure is to build forest network in cultivated land areas, the second is to limit human activities and replant grass or shrub in the eolian sandy bare land in the flat basin areas. In addition, compared to the 2.66×10^4 ha land suitable for cropland in the study area (Yin et al. 2001), there exceeded 5.8×10^3 ha no-suitable cultivated land in 2008, as such, these cultivated land should also be replanted grass or shrub. The third is to establish natural reserve zone in the mountain areas to hasten shrub vegetation restoration as the outer protection circle of the oasis.

The salinity of some soil parent material in the flat basin is high, and the impermeable barrier in some soil is shallow (Pan et al. 2001). Consequently, soil secondary salinization is the second high risk of desertification type in the study area under the high annual average evaporation and over-irrigation situation. Accordingly, it is necessary to change the high-cost water traditional agriculture to water-saving, salt tolerant and/or high-economic cash crops. It has planned that 60 % of cultivated land should adopt modern agricultural types in 2012 (Han and Gao 2010). During decade development and construction, Hongsipu pumping irrigation zone was to alleviate poverty and high population pressure in the fragile ecological southern mountainous areas of Ningxia, however, the new artificial oasis creates another new ecological risk of the desert-steppe system. Therefore, besides the economic development, the ecological protection and restoration measures are the primary objectives in order to successful resettlement immigrants.

A landscape-based approach with remote sensing

In this study, post classification comparisons based on remote sensing data with the extending contingency-based method can provide not only the interchange relationship of the land
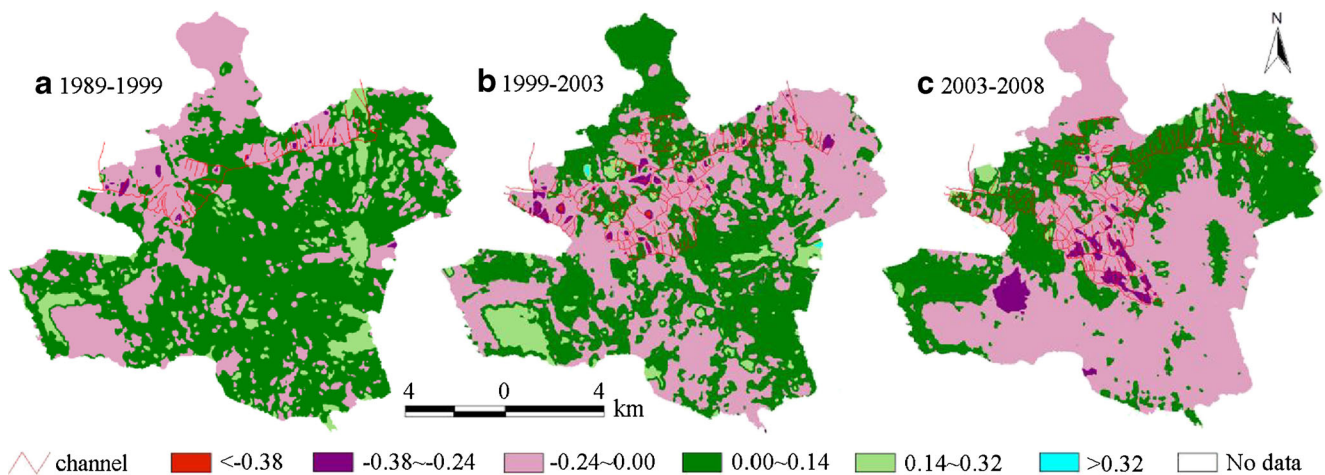

Fig. 8 FRAC metric change in the stage of 1988–1999, 1999–2003 and 2003–2008

legend: channel | <-0.38 | -0.38~-0.24 | -0.24~0.00 | 0.00~0.14 | 0.14~0.32 | >0.32 | No data

use types, also their interchange spatial locations. In addition, Kappa can be used as the index of landscape change in quantity and location to compare the change degree of the different time or different regions. Furthermore, to recognise to which extent similarity of location and quantity are represented in the Kappa statistic, it is split into two statistics: Kappa Histo in quantity and Kappa Location (Hagen 2002).

A landscape-based approach can quantitatively determine landscape structures, functions and their dynamics, which can help to understand the ecological mechanisms and processes that drive changes in landscape (Turner et al. 1989). Remote sensing, digital image processing, and spatial analysis have proven to be useful technologies in both assessing and monitoring environmental and landscape change in Minqin County (Sun et al. 2005, 2007). The advantage of landscape approach for oasis dynamics has been discussed by Sun et al. (2007), particularly, it can help to quickly make decisions and prioritize measures for combating desertification. However, spatially nuanced difference at patch level maybe more helpful to linking the landscape pattern to ecological processes and prioritizing measures on local structure. In this study, local fractal dimension on patch level change was compared on the Hagen-Zanker (2006) method to measure human disturbance spread, but the linkage between human disturbance and the changing characteristics of landscape should be further studied. In Hongsipu pumping irrigation zone, human disturbance, land conversion and irrigation channel construction disrupted landscape connectivity. Water transportation networks maybe be adopted to describe linkage between human disturbance including the response to various management-driven perturbations and the changing characteristics of the landscape. More research about the relationship between human disturbance and natural ecological system in the artificial oases should be carried out in provincial and local level for human-land sustainable development in future.

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