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Land use and landscape change driven by gully land consolidation project:

A case study of a typical watershed in the Loess Plateau

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Abstract: Exploring the impact of land consolidation on the changes of local land use and the landscape patterns is important for optimizing land consolidation models and thus accelerating the sustainable development of local communities. Using a typical small watershed in Yan'an City (Shaanxi, China), the impact of gully land consolidation on land use and landscape pattern change, based on high-resolution remote sensing image data and landscape pattern analysis, was investigated. The results showed that: (1) The terraces, sloping fields, shrub land and grassland at the bottom and both sides of the gully were converted mainly to high quality check dam land. Also, some of the shrub land, due to biological measures, was converted to more ecologically suitable native forest. Thus, the areas of check dam land and forests increased by 159 and 70 ha, while that of shrub land, grassland and sloping fields decreased by 112, 63 and 59 ha, respectively. (2) The average patch area and patch cohesion index for the check dam land increased, which indicated that the production function improved. The landscape shape index and the patch cohesion index for forestland and shrub land were maintained at a high level, and thus the ecological function remained stable. (3) At the watershed level, the degree of fragmentation of the landscape decreased and the landscape became more diversified and balanced; the anti-jamming capability of the landscape and the stability of the ecosystem improved also. Research suggests that implementing gully land consolidation in a rational manner may contribute to improvements in the structure of local land use and the patterns of landscape.

Keywords: land consolidation; watershed; land use; landscape; Yan'an City; Loess Plateau

1 Introduction

The hilly and gully region of the Loess Plateau is one of the most ecologically fragile areas

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in China. In the 1950s, the average soil erosion modulus per year in this region was as high as 10,000–20,000 t/km^2. Also, the sustainable development of agriculture and measures aimed at poverty alleviation have been affected by severe soil and water erosion, while unreasonable land use has been one of the prime reasons for soil and water erosion (Chen *et al*., 2001). The region has been highlighted as being at great risk in terms of ecological safety (Fu *et al*., 2002; Gao and Zheng, 2004). The Grain for Green Project (GGP) has significantly improved the vegetation coverage and the ecological environment on the Loess Plateau (Cao *et al*., 2018; Liu *et al*., 2018a). However, with the implementation of the GGP, the region has seen a sharp reduction in cultivated land. For example, from 2000 to 2008, the area of cultivated land decreased by 10.8% (Lv *et al*., 2012), while farmland in Yan'an decreased by about 30%. These reductions have had negative impacts on food security and on the livelihoods of local farmers, triggering new contradictions on the human-environment system. In view of this, Yan'an City has undertaken an innovative gully land consolidation project (GLCP) which is characterized by adapting gullies for farmland purposes, thus making full use of the land resources of gullies and ensuring continuity in agricultural development. The project seeks to make best use of cultivated land reserves and promote ecological restoration by returning farmland to forest in mountainous regions and at the same time adapting and consolidating the gullies in the valleys to farmland, so as to optimize the fragile human-environment system and the ecological environment of the region (Liu and Li, 2017; Liu *et al*., 2017).

Land is a fundamental necessity for human survival and land use is a reflection of the natural and socio-economic status of a certain region. Consequently, land use development may be considered as a direct reflection of the transformation and management of the earth's surface by human activities (Long *et al*., 2007; Chen *et al*., 2012). Landscape patterns refer to the spatial structures of landscapes, which can reflect the spatial distribution of landscape types and quantities (Chen and Fu, 1996; Chen *et al*., 2008). Land use may not only change the surface structures but also impact directly on the evolving nature of landscape patterns, thereby affecting the safety of the entire ecosystem (Tuan *et al*., 1971; Zhao *et al*., 2004). At present, many studies have been carried out on the dynamic evolution of land use and landscape patterns at home and abroad (Lausch and Herzog, 2002; Liu *et al*., 2008; Long *et al*., 2009; Lambin and Meyfroidt, 2011; Liu *et al*., 2014), and the research directions have tended to shift from large-scale comprehensive research to small-scale in-depth studies (Fu *et al*., 1999; Deng *et al*., 2009; Hu *et al*., 2011; Zhou *et al*., 2011; Chen *et al*., 2014). Such in depth studies on the impact of the GLCP on land use and landscape patterns may contribute to a better understanding of the GLCP and assist in a comprehensive evaluation of the effectiveness of the GLCP.

To date, some research has been performed on the principles and technologies of the GLCP, and the impact of the GLCP on the development of soil, water resources and agriculture in watersheds. Liu and Li (2017) suggested that the GLCP should follow the concept of "landscape harmony, stable structure, sustainable utilization and efficient function", and proposed zoning, classification standards and key techniques for the GLCP. Lei *et al*. (2017) analyzed the formation mechanism for subsurface flow under the influence of a GLCP in Yan'an, presenting a comprehensive unpowered subsurface flow-adjusting irrigation technology system based on the subsurface flow characteristics. Liu *et al*. (2017)

conducted research on the cultivation and industrialization of forage rape in a typical region of a GLCP for the purposes of promoting sustainable agricultural development and improving farmers' livelihoods. However, few studies have been carried out on the impact of a GLCP on local land use and landscape patterns, and comprehensive awareness of the impact of the GLCP on the local land and the ecological system has yet to be realized.

Given the above, this paper aims to analyze systematically the dynamic changes of land use and landscape patterns in a study area which has experienced a GLCP. Specifically, remote sensing, GIS technology and landscape pattern analysis methods are used to gain a better understanding of the impact of a GLCP on local land and ecological systems, thus providing scientific reference for the optimization of the GLCP, and improvement of the ecological environment together with sustainable development of the watershed and the Loess Plateau.

2 Methodology

2.1 Study area

The S watershed was selected for the case study. This watershed, located in the Baota District of Yan'an City in Shaanxi Province, is 46 km east of Yan'an City (Figure 1). The length of the main gully is about 12 km and the total area of the watershed is 24.87 km^2. The study area, characterized by typical loess hills and gullies and at an altitude of 900–1200 m with a ground height difference of 100–200 m, is dominated by a semi-arid continental monsoon climate. The geomorphology consists of ridges, gully slopes and the gully bed and the gully slope is the main landform. There are ravines, ridges, deep valleys and tattered landforms in this region, and the surface is covered with Quaternary loess. There are four villages in the watershed, with a total of 606 households and a population of 2191. To reduce soil and water erosion and ensure food security, the watershed has benefited from a variety of ecological restoration projects. In the 1960s and 1970s, check dam projects were mainly implemented; in the 1980s and 1990s, smaller watershed management projects were undertaken. The GGP has been implemented since 1999 and the GLCP has been underway since 2013. The research team has carried out extensive observations and investigations in this region since 2012.

2.2 Data

To fully reflect the changes of land use and landscape before and after the GCLP, and considering practical accessibility issues and the clarity of remote sensing images for the study region, this research selected high resolution (resolution 2 m) satellite images as the main data source, the images being acquired in 2010 and 2016 from Google Earth. Based on the land use classification criteria of China, combined with the actual land use characteristics of the study area, the lands were divided into the following types: cropland, forest, shrub land, grassland, industrial and mining land, rural residential land, rural roads, and water and bare land. In addition, the croplands were subdivided into check dam land, terraces and sloping fields according to their geographic locations. Random sampling and field verification showed that the overall accuracy of image interpretation was over 95%. To gain more comprehensive information on the land consolidation project, land use and landscape change, four special field surveys were also conducted. Remote sensing images and records of interviews constituted the main data and the materials used.

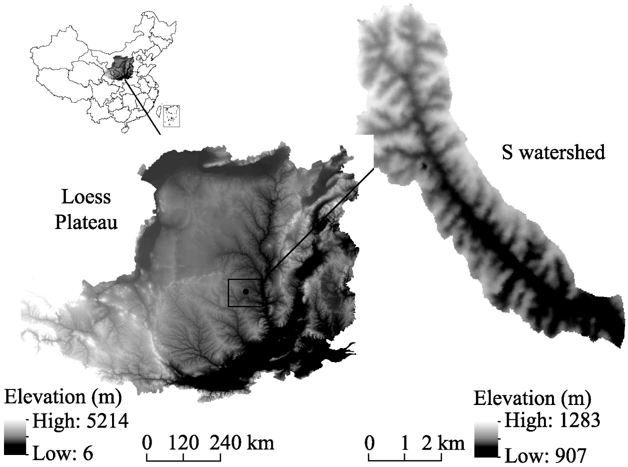

Figure 1 Location and DEM of the study area

2.3 Methods

The methods employed to analyze land use and landscape pattern change in the watershed are based on quantitative research on the high-resolution remote sensing images and field investigations. ArcGIS was used to perform geometric rectification, coordinate registration, visual interpretation and vectorization of the images, and through field investigations, verification and correction of the interpreted data from remote sensing images was performed. The land use transfer matrix, which contained abundant information about the directions of land changes and the source and compositional information of various land types, has been widely used to study land conversion between different land use types (Long *et al*., 2007; Li *et al*., 2017). This method was also employed in this study. Based on the spatial overlap analysis of the two-stage land use map in ArcGIS10.3, the land use transfer matrix during the study period was obtained. Furthermore, the Sankey diagram was employed to visualize the conversions of different land use types. A Microsoft Power BI Desktop was used to prepare the Sankey diagram.

The landscape index highly condenses the landscape pattern information, and may be used for analyzing various ecological processes at different scales to reflect the ecological characteristics of landscape structure and evolution (Chen and Fu, 1996; Gong *et al*., 2009; Zhang *et al*., 2009). According to the aims of this study and the characteristics of the watershed, three indicators were selected at the type level (Table 1), namely the average patch area (AREA_MN), the landscape shape index (LSI) and the patch cohesion index (COHESION); and eight indicators were selected at the landscape level, namely the number of patches (NP), the patch density (PD), the edge density (ED), the Shannon diversity index (SHDI), the Shannon evenness index (SHEI), the contagion index (CONTAG), the LSI and the average patch area (AREA_MN). These indicators can largely reveal the area advantage, shape, spatial layout or degree of aggregation of the landscape. FRAGSTATS, a widely used landscape pattern analysis package, was employed to compute the above landscape indices.

Table 1 Selected landscape indices used in the study

Index	Formula	Note	Brief description of index
Average patch area (AREA_MN)	$AREA\_MN = \frac{Ai}{Ni}$	*Ni*–number of patch type *i*; *Ai*-area of patch type *i*; *E*–total length of all patch boundaries; *A*–total landscape area; P_{ij}–total length of edge in landscape between patch types *i* and *k*; a_{ij}–area of patch *i* within specified neighborhood of patch *j*; *Ak*–total number of cells in the landscape; P_i–proportion of the landscape occupied by patch type *i*; g_{ik}–number of patch *i* within specified neighborhood of patch type *j*; *m*–number of patch types present in the landscape	AREA_MN describes landscape fragmentation. The larger average patch area represents the lower landscape fragmentation.
Landscape shape index (LSI)	$LSI = \frac{0.25E}{\sqrt{A}}$		LSI describes the complexity of landscape shape. The higher the LSI the more complex the shape of the landscape.
Patch cohesion index (COHESION)	$COHESION = \left[1 - \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} P_{ij}}{\sum_{i=1}^{m}\sum_{j=1}^{n} P_{ij} \cdot \sqrt{a_{ij}}}\right] \cdot \left[1 - \frac{1}{\sqrt{A\text{k}}}\right]$		COHESION describes physical connectivity of the corresponding patch type. The higher the COHESION the stronger the connectivity of the patches.
Number of patches (NP)	$NP=Ni$		NP describes landscape fragmentation, a landscape with a higher NP would be considered as more fragmented.
Patch density (PD)	$PD= \frac{Ni}{Ai}$		PD describes landscape fragmentation, a landscape with a greater PD would be considered more fragmented.
Edge density (ED)	$ED = \frac{1}{A_i}\sum_{j=1}^{M} P_{ij}$		ED describes landscape fragmentation, a landscape with a greater ED would be considered more fragmented.
Shannon diversity index (SHDI)	$SHDI = -\sum_{i=1}^{m}\left(P_i \; In \; P_i\right)$		SHDI describes landscape diversity. A larger SHDI indicates that the landscape has more diverse patch types.
Shannon evenness index (SHEI)	$SHEI = \frac{-\sum_{i=1}^{m}\left(P_i \cdot In \; P_i\right)}{In \; m}$		SHEI describes landscape evenness. A smaller SHEI indicates that the landscape is dominated by one or a few dominant patch types.
Contagion index (CONTAG)	$CONTAG = 1 + \frac{\sum_{i=1}^{m}\sum_{k=1}^{m}\left[(P_i)\left(\frac{g_k}{\sum_{k=1}^{m} g_k}\right)\right] \cdot \left[In(P_i)\left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right)\right]}{2In(m)}$		CONTAG describes landscape contagion. A larger contagion index indicates that the dominant patch types in the landscape form a good connection.

3 Results and analysis

3.1 Land use change

The implementation of the GLCP has caused significant changes in land use structure of the S watershed (Figures 2 and Table 2): (1) The area of croplands increased from 272.36 ha in 2010 to 355.31 ha in 2016, and share of total area increased from 10.95% to 14.29%. In line with local conditions, the terraces, sloping fields, shrub land and the grassland at the bottom and both sides of the gully were mostly converted into high quality check dam land. The area of terraces and sloping fields decreased by 59.06 ha and 17.05 ha, respectively; the area of check dam land increased by 159.06 ha, which represented the greatest increase for all land use types. (2) The area of shrub land was reduced by 112.37 ha, but it still remained the largest area for all land use types in the watershed, accounting for more than 45% of the total area. In comparison, forests increased by 69.75 ha. (3) The grassland and bare land decreased by 63.26 ha and 6.34 ha, respectively, and the areas for water and rural roads increased by 14.23 ha and 10.60 ha, respectively, due to the construction of dams and better roads. (4) The areas for rural residential land and industrial and mining land increased by 2.54 ha and 1.80 ha, respectively.

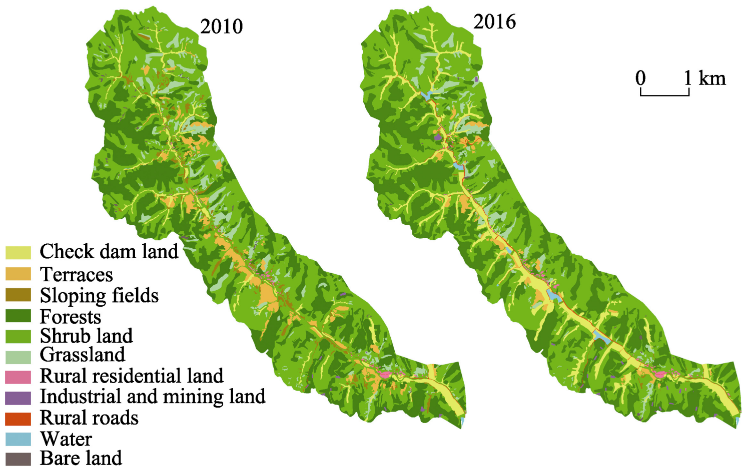

Figure 2 Land use change for the S watershed in 2010 and 2016

Table 2 Change matrix of each LULC type for the S watershed in 2010 and 2016 and changes in 2016

		2010 (ha)												
Type		Check dam land	Terraces	Sloping fields	Forests	Shrub land	Grassland	Industrial and mining land	Rural residential land	Rural roads	Water	Bare land	Sum	Percentage (%)
2016	Check dam land	72.78	0.01		0.02	1.60			0.04	0.75	1.16		76.36	3.07
	Terraces	45.03	54.63		3.65	15.83	10.29	0.05	0.25	2.47	3.68		135.88	5.46
	Sloping fields	26.93	3.41	1.06	4.18	16.12	3.41	0.28	1.07	1.43	2.23		60.12	2.42
	Forests	1.15	0.14		764.01	0.83	0.04	0.57	0.01	0.02		0.05	766.82	30.83
	Shrub land	84.54	41.96		55.44	1063.51	3.36	2.35	1.50	11.33	6.52	0.65	1271.16	51.11
	Grassland	1.43	18.27		8.65	53.05	62.14		0.34	0.02	0.01	0.02	143.93	5.79
	Industrial and mining land				0.51	0.59	0.35	2.75					4.20	0.17
	Rural residential land	0.25				0.20			10.48	0.20	0.02		11.15	0.45
	Rural roads	2.98	0.01			1.63	0.26			3.69	0.77		9.34	0.38
	Water	0.15				0.01					0.80		0.96	0.04
	Bare land	0.18	0.40		0.11	5.42	0.92			0.03		0.15	7.21	0.29
Sum		235.42	118.83	1.06	836.57	1158.79	80.77	6.00	13.69	19.94	15.19	0.87	2487.13	
Percentage (%)		9.47	4.78	0.04	33.64	46.59	3.25	0.24	0.55	0.80	0.61	0.03		100.00

In terms of the mutual conversion of different land use types, significant land use conversion in the S watershed may be largely characterized by the mutual transformation of shrub land, grassland, terraces, sloping fields, check dam land and forests (Table 2 and Figure 3): (1) 207.65 ha of shrub land was converted to check dam land, forests and terrace, which accounted for 40.71%, 26.70% and 20.21% of the loss of shrub land, respectively. (2) 81.79 ha of grassland was converted to other land use types, especially shrub land and terrace. (3) In the case of terrace, the amount converted into terrace (64.20 ha) was of similar magnitude to that lost (81.25 ha), and 45.03 ha of terrace was converted to check dam land. (4) The amount being converted to check dam land was the most significant, with 162.64 ha of other land use types being converted to check dam land, specifically, shrub land, terrace and sloping fields accounting for 51.98%, 27.69% and 16.56% of the newly increased check dam land, respectively.

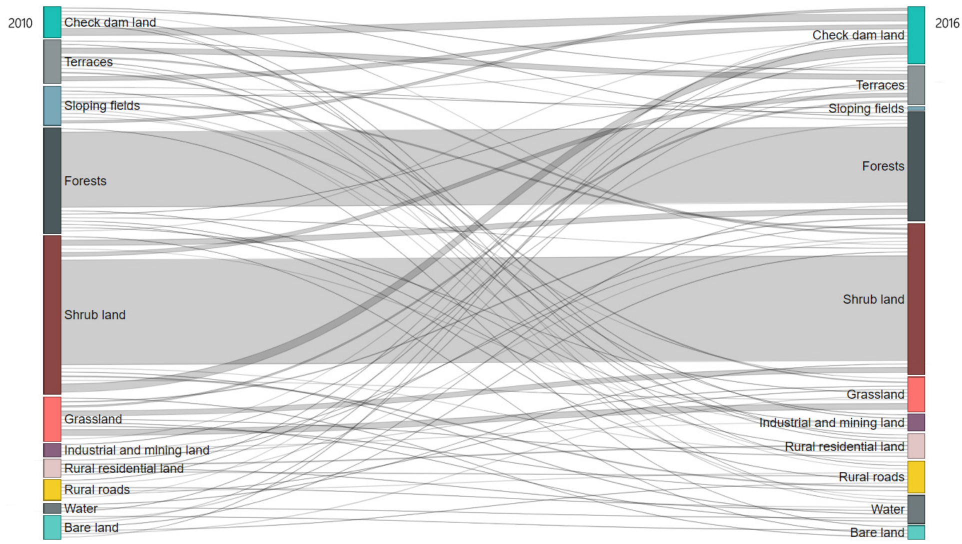

Figure 3 Flow chart of land use change in the S watershed from 2010 to 2016

The significant transformation processes between the different land use types were the result of the combined effects of natural factors and human activities. In the study area and for the study period, the engineering measures promoted by human factors played a leading role: (1) The GLCP turned the shrub land, the terraces and sloping fields on both sides of the gully into check dam land, and some of the shrub land and grassland were converted to high quality terraces. (2) Due to construction of farmland shelterbelt networks and ecological protection engineering, some shrub land, grassland and sloping fields were converted to forest. (3) Also due to the continuous implementation of a prohibition order for grazing for the purposes of improving the natural conditions, some grassland evolved naturally into shrub land.

3.2 Landscape pattern change

3.2.1 Landscape pattern change at the type level

The changes of landscape pattern were explored from both the type level and the landscape level. At the type level, in terms of the average patch area (Figure 4a): (1) The average patch area of high-quality production land such as check dam land and terrace increased, which was reflected in an increase in new croplands, and this would be of benefit to large-scale farming. (2) The average patch area for important ecological land such as forests, grassland and water also increased, which contributed to an improvement in ecological function. (3) The average patch area for sloping fields, shrub land, and industrial and mining land decreased.

In terms of the patch cohesion index (Figure 4b): (1) Shrub land was the main landscape type having the largest area in the S watershed, so the cohesion index was the highest, but it declined slightly from 99.00 in 2010 to 97.78 in 2016. (2) Sloping field, industrial and mining land, bare land and grassland were affected by engineering measures, and their spatial decentralization and fragmentation intensified, and the cohesion index also decreased. (3) The average patch area and the plaque cohesion index for check dam land, terrace, forestland, rural residential land, rural roads and water increased significantly, which indicated that influenced by human factors especially the GLCP, those landscape types tended to concentrate in the watershed. In particular, the increase in the cohesion index of the check dam land was most noticeable, rising from 78.96 to 92.77, highlighting the direct impact of the GLCP on the improvement of production conditions.

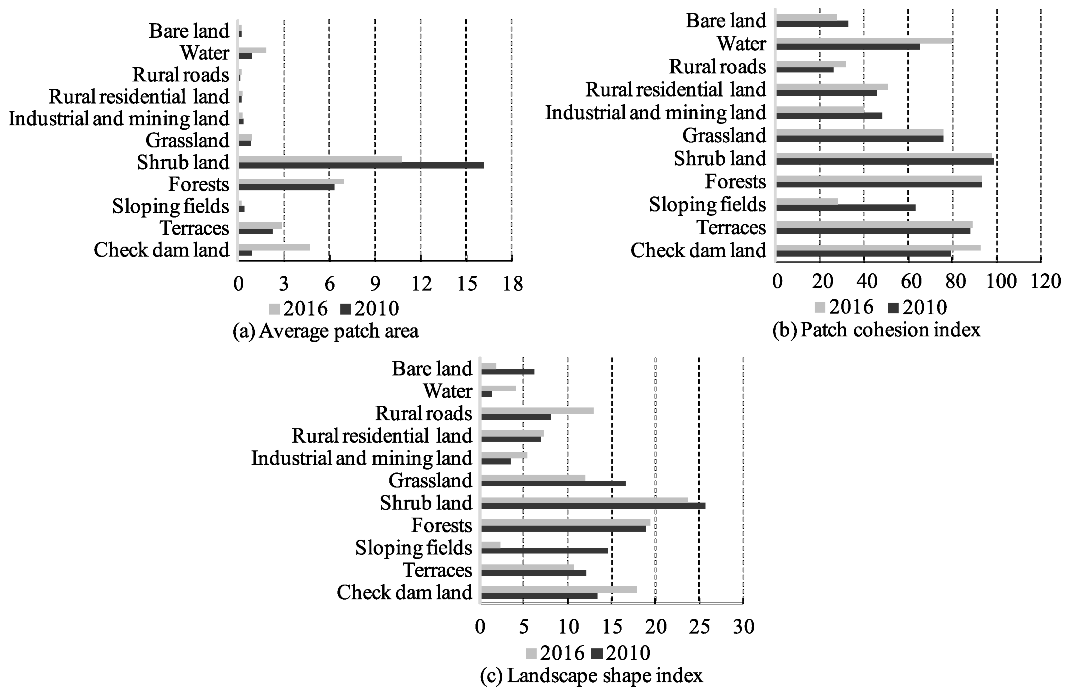

Figure 4 Changes of landscape structure in the S watershed during 2010 and 2016

In terms of the LSI (Figure 4c): (1) Over the entire study period, the shape index for shrub land was the highest, indicating that shrub land had the most complex shape and boundary for all landscape types. The LSI decreased from 25.66 in 2010 to 23.67 in 2016, indicating that the plaque shape of shrub land tended to be simplified under human disturbance. (2) The

LSI for terrace, sloping field, grassland and bare land also became more regular due to the influence of human activities as the LSI values decreased. (3) The LSI for forestland was relatively high and showed an increasing trend; the LSI for dam land, industrial and mining land, rural residential land, rural roads and water also showed a clear increasing trend, indicating that these six landscape types were also affected by human activities, the degree of shape irregularity increasing.

3.2.2 Landscape pattern change at the watershed level

At the watershed level (Figure 5): (1) During the study period, the number of landscape patches decreased from 807 to 618, the average plaque area increased from 3.08 to 4.02, the edge density decreased from 159.97 to 152.38, and the patch density decreased from 32.47 to 24.86, which indicated that the degree of fragmentation for the landscape decreased (Figures 5a–d). (2) The contagion index rose steadily, which indicated that the landscape elements formed a good connective link. The LSI decreased from 21.93 in 2010 to 21.00 in 2016, indicating that the various landscape elements had good linkability (Figures 5e and 5f). (3) The Shannon diversity index and the Shannon evenness index rose slightly from 1.30 and 0.54 in 2010 to 1.32 and 0.55 in 2016, respectively (Figures 5g and 5h). Thus the landscape tended to be more diversified and balanced, and the anti-jamming capability of the landscape and the stability of the local ecosystem were improved. In general, driven by the GLCP, the overall landscape pattern of the watershed became more acceptable.

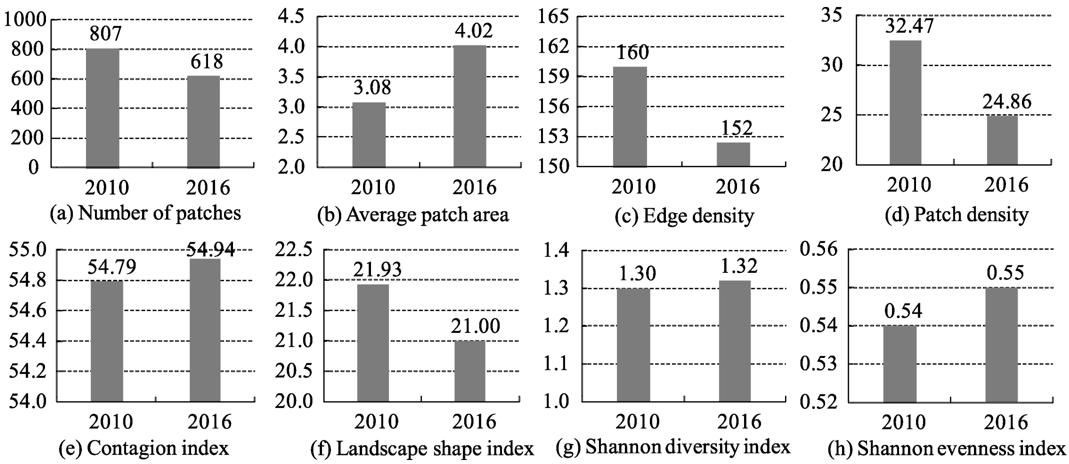

Figure 5 Changes in the landscape-level metrics from 2010 to 2016 for the S watershed

4 Conclusions and discussion

4.1 Conclusions

This paper has explored the change of land use and landscape pattern for the S watershed driven by a GLCP. The results showed that implementation of the GLCP has caused significant changes in the land use structure and landscape pattern in the watershed. In general, it may be concluded that implementing gully land consolidation in a rational manner can contribute to an improvement in local land use structure and landscape ecological pattern. From the perspective of land use and landscape pattern, gully land consolidation is conducive to the sustainable development of watershed systems.

4.2 Discussion

Latest research has shown that the annual accumulated temperature of ≥ 10℃ (AAT10) in the Loess Plateau has increased significantly, and the area of the warm temperate zone (AAT10 range 3,400–4,500℃ day) across the Loess Plateau increased from 21.0% to 50.3% in 2000–2015 due to climate change (Liu *et al*., 2018b). Thus, the local demand for a GLCP and agricultural structural adjustment is expected to increase significantly. Accordingly, GLCP should play a more important role in this region, and more detailed studies should be conducted to gain better understanding of the effects of GLCPs on the watershed.

Nonetheless, it is worth mentioning that both the watershed and the rural communities represent a complex system (Li *et al*., 2012; Cheng and Li, 2015), and the impact of gully land consolidation on the watershed and the local communities is also multidimensional and complex (Li *et al*., 2014). This paper has focused on just the impact of a GLCP on the change of land use and landscape pattern in a typical watershed. Hence more attention should be paid to evaluating the subsequent land use sustainability and agricultural and rural transition. In this context, if comprehensive investigation and evaluation of the impact of a GLCP on land use structure, landscape ecological patterns, ecosystem services, agricultural structure adjustment, farmers' livelihood status and sustainable community development is undertaken, the advantages and limitations of GLCP may be better understood, and approaches for optimization of the GLCP may be elaborated. Based on these knowledges, GLCP could become a more comprehensive and sound policy tool, then plays a more effective role in the sustainable evolution of rural human-environment systems, and boosts sustainable rural development.

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