

Analysis of the landscape change at River Basin scale based on SPOT and TM fusion remote sensing images: a case study of the Weigou River Basin on the Chinese Loess Plateau

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Abstract Eco-environmental changes which generally manifest as the ecological landscape changes are mainly affected by natural and human factors. Through complex interaction, natural factors and human activities alter the landscape structure and decide the service function of regional ecosystem. With the development of geographical information system (GIS) and satellite remote sensing (RS) techniques, the researches on quantitative analysis of landscape changes have made great strides forward. In this paper, the landscape change dynamics in the Weigou River basin have been investigated by the combined use of high-resolution RS images and GIS techniques. The objectives are to determine the landscape transition rates among landscape types and to quantify changes of various landscape indexes using FRAGSTATS, one of the spatial pattern analysis programs for categorical maps. Under man-machine interactive interpretation method, all of the 10-m resolution SPOT + TM images are classified into six primary types (farmland, forest, grassland, water,

construction area and desert) and 12 sub-types based on the interpretation key which was established based on 1947 filed pictures in the Weigou River basin. A field check on the data accuracy shows that the total interpretation accuracy approaches 97.53%. Significant land-use change has taken place in the Weigou River basin over the six years from 1998 to 2004 due to rehabilitation measures. The results show that there has been a notable decrease in farmland mainly due to conversion to forest and grassland, the landscape heterogeneity and evenness has increased, and there is a greater connectivity. The dominance of farmland patch has decreased. And hence the ecological environment has started to develop in a reversing direction. The study of the integration of high-resolution RS images and GIS technique is an effective approach to analyze the landscape changes at river basin scale.

Keywords Landscape change · SPOT + TM image · Remote sensing and GIS · FRAGSTATS · Weigou river basin

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Abbreviations

ha	Hectares
km	Kilometer
GIS	Geographical information system
RS	Remote sensing
HRV	High resolution visible
TM	Thematic mapper
FRAGSTATS	Spatial pattern analysis program for categorical maps
CA	Class area
PLAND	Percentage of landscape
NP	Number of patches
LPI	Largest patch index

MPS	Mean patch size
AWMSI	Area-weighted mean shape index
AWMPFD	Area-weighted mean patch fractal dimension
MPI	Mean proximity index
MNN	Mean nearest-neighbor distance
IJI	Interspersion and juxtaposition index
CONTAG	Contagion index
SHDI	Shannon's diversity index
SHEI	Shannon's evenness index
RUSLE	Revised universal soil loss equation

Forman 1990; Turner and Gardner 1991; Forman 1995; Naveh and Liberman 1994; Xiao 1996; Frohn 1998). There have been some academic reports (Li and LI 2004; Zhan and Deng 2006) on landscape change analysis of the Chinese Loess Plateau, but very few reports (Liu and Dong 2007) on landscape change analysis at river basin scale based on GIS and high-resolution RS images can be found. This paper has a double purpose: first, to present the methods to quantify landscape change at river basin scale using GIS and RS images; and second, to apply the methods to the Weigou River basin on the Chinese Loess Plateau to analyze the landscape change during the period from 1998 to 2004.

Introduction

The research on regional landscape change has been one of the hottest fields, which draws general interest of the geographers and ecologists all over the world (Forman and Godron 1986; O'Neill and Gardner 1988). Landscape change and eco-process are interrelated and interact on each other (Forman 1995; Xiao and Bu 1997). Studying on eco-process takes quantitative analysis of landscape change as preexisting. The methods of quantitative analysis of landscape pattern structure and its change based on landscape indexes have been the core of landscape ecology researches (Roy 1999; George and Perry 2002).

With the development of geographical information system (GIS) and remote sensing (RS) technique, quantitative analysis of landscape change has been getting in greater depth (Forman and Godron 1986; Zonneveld and

Materials and methods

Study area

The Weigou River basin, located in Jingning county, Gansu province, China, between 105°29'–105°48'E and 35°25'–35°38'N (Fig. 1), has a population of 43,690 inhabitants and covers an area of 29,444 ha. It is one of the sub river basins of the Huluhe River, which is a tributary of the Weihe River water system. Lying at the west piedmont of Liupanshan Mountain in the third hill region of the loess plateau, it has a temperate semi-arid climate. The average annual precipitation is 450 mm, with a maximum of 690 mm and a minimum of 228 mm. The precipitation from June to September accounts for 69% of the total annual precipitation. The average annual temperature is

Fig. 1 Study area

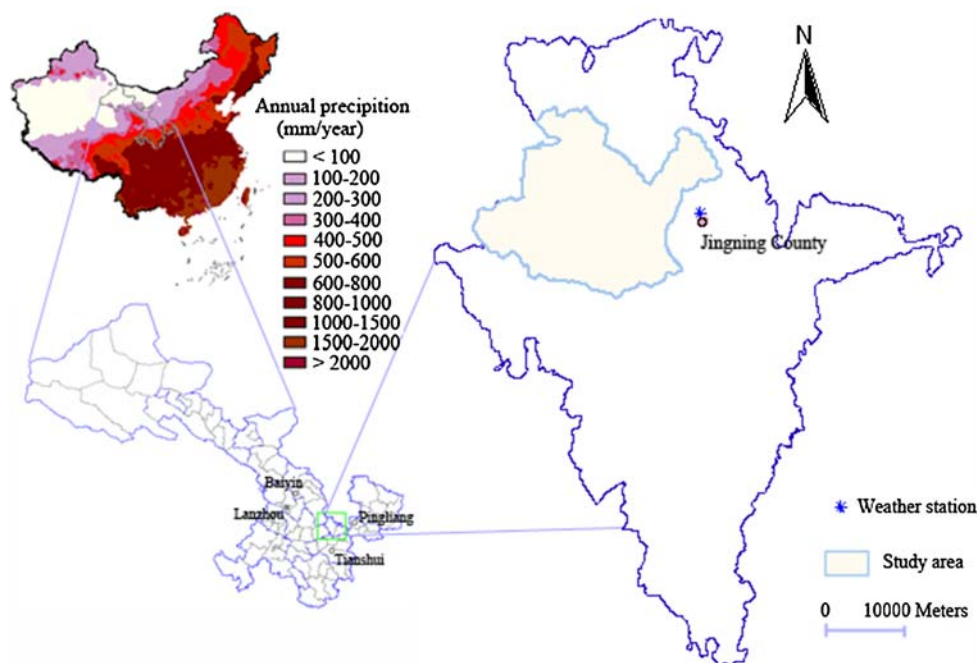


Table 1 Data

Data	Date ^a	Description
SPOT2	19980702	HRV (high resolution visible)
SPOT2	20040914	HRV
Landsat 5	19980617	TM (thematic mapper)
Landsat 5	20040815	TM
Topographic maps	1987	five topographic maps
Meteorological data	1960–2003	Recorded at Jingning weather station

^a The RS data was provided by the Institute of Remote Sensing Application (IRSA), Chinese Academy of Sciences (CAS), based on the satellites' scan periodic date, wiping off the data recorded under cloudy days

7.37°C. More than 10°C accumulated temperature is 2551.2°C. There are 160 frost free days a year. The altitude is between 1,700 and 2,100 m above the sea level. The density of ravines is 3–5 km/km². The main soil types are loessial soil (about 78%), heilu soil (about 18.9%), red clay, and entisol. The natural vegetation is sparse due to the dense ravines and fragmented landform. Gully erosion, gravity and engineering-induced erosion are prevalent, with an erosion modulus of 9348.3 t km⁻² a⁻¹ in 2004. And these have long been the main ecological problem of the region (Committee of Jingning's Chorography 2005).

Data

In this paper, 1:50,000 scale topographic maps, SPOT HRV (high resolution visible) images and Landsat TM (thematic mapper) composed of band 4, 3, and 2 images from 1998 to 2004 have been adopted to establish the 10-m resolution SPOT + TM images. All the Weigou River basin has been completely covered (Fig. 1). These space information and spectral information of SPOT images and TM images can entirely meet the demand of this study (Wang and Feng 1991; Wang and Qi 2003). Other data used in the study include the climatic information recorded at Jingning weather station from 1960 to 2003 (see Table 1; Fig. 1).

Methods

The three key links of landscape changes analysis using RS images and GIS techniques are satellite remote sensing monitoring, data processing, indoor man–machine interactive interpretation, integration issues and comprehensive analysis (see Fig. 2). Firstly, a collection of related data or program records, including RS data, land form data, climate data, etc., should be executed. Secondly, data processing is

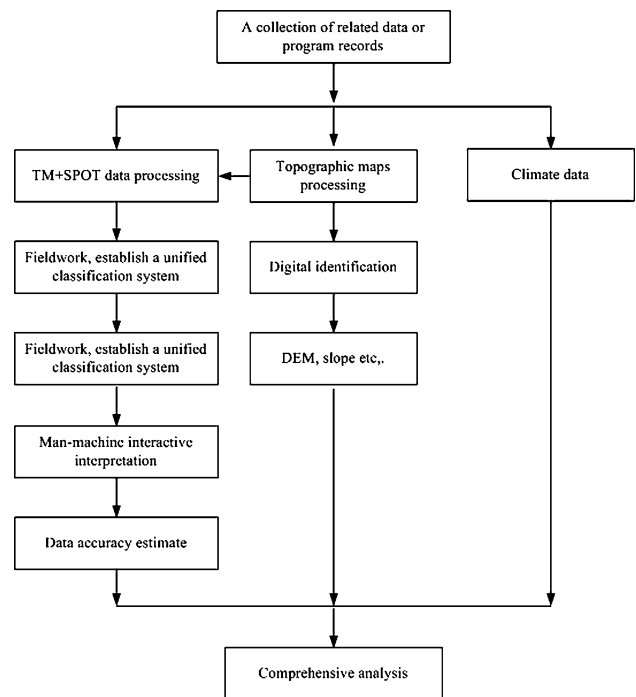


Fig. 2 Workflow figure

requested, including data standardization, data classification, accuracy estimation, checking and so on. Thirdly, the changes of landscape are quantified and a comprehensive analysis is conducted.

In this study, the land use/cover in the Weigou River basin has been investigated. The RS images have been studied completely, so as to get an overall understanding of the spectrum information (see Table 2), radiation information and geometric features, to establish a unified classification system in the light of local condition, and to establish the interpretation key (Carper et al. 1990; Chavez et al. 1991; Bocco et al. 2001).

Data processing

Data processing is very important for obtaining accurate data (Baret et al. 1991; Brivio et al. 2001; Bricaud et al. 2002; Qin et al. 2006; Masoud 2006). ERDAS IMAGINE has been used for the process of image radiometric

Table 2 Data spectrum information

Satellites	Sensor	Spectral bands (µm)	Spatial resolution (m)
Landsat 5	TM2 green	0.52–0.60	30
	TM3 red	0.63–0.69	30
	TM4 near IR	0.76–0.90	30
SPOT2	HRV	0.51–0.73	10

enhancement, geometric rectification and merging images (Dang and Wang 2003).

To identify ground control points, all images have been enhanced by linear contrast stretching and histogram equalization methods, so that the original brightness values of pixels could be kept unchanged (Wang and Feng 1991; Wang and Qi 2003; Li and Li 2004). To keep the precision within one or two pixels, the accurate corresponding points between images system and topographic maps (65 for each SPOT image and 42 for TM) have been carefully identified and geometric rectification has been conducted. The quadratic polynomial model and nearest neighbor resampling model have been used in the geometric rectification of these images. The former, which perform coordinate transformation to the images directly, is widely used for geometric rectification of various images of satellite sensors. However, the complicated high order exponent may lead to the unexpected changes in length, hence, the quadratic polynomial model was selected. The latter, keeping the DN (digital number) of pixels unchanged without smoothing, was considered effective in the landscape classification (Dang and Wang 2003). Each image has been rectified by Albers Equal Area Conic projection based on 1:50,000 scale topographic maps.

The principal component transformation model has been adopted when merging the SPOT images and TM images (Pohl 1998; Li and James 2002; Dang and Wang 2003). Firstly, a spatial registration should be carried into execution to input multispectral image (TM image, with 30-m resolution), and then a principal component transformation. Secondly, the histogram of the panchromatic image (SPOT HRV images, with 10-m resolution) should be matched to the main principal component (PC 1) of the input multispectral image. Thirdly, the stretched panchromatic image takes the place of PC 1 and takes a reverse principal component transformation in the processing of images merged (see Fig. 3).

The resultant root-mean-squared errors (RMS) are 0.46 pixels (4.6 m) for the 1998 SPOT + TM images, and 0.51 pixels (5.1 m) for the 2004 images.

Data extraction

Satellite remote sensing and GIS techniques are efficient tools to monitor and quantify the landscape changes. By the use GIS software, dynamic data reflecting the landscape changes in the Weigou River basin, such as land use, land use changes, change area and change direction, etc., could be extracted from the satellite remote sensing images.

For extracting, processing and displaying vector- and grid-data, both the ArcTools model and the Grid model of ARC/INFO have been used (ESRI 1996, 1997).

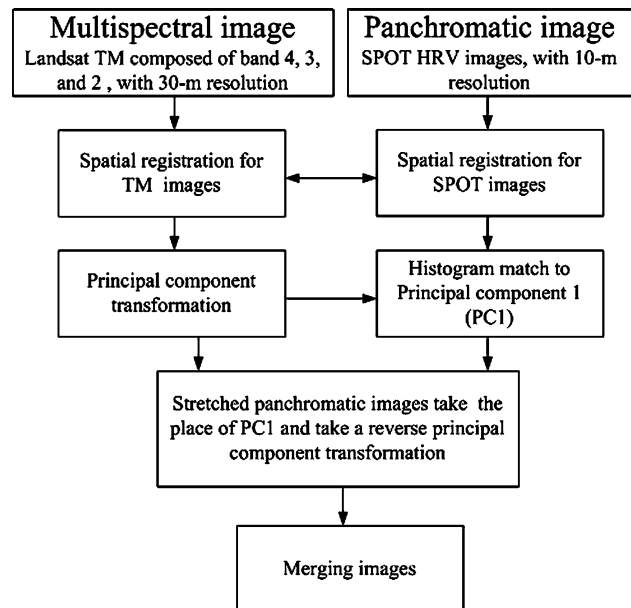


Fig. 3 RS data merging based on principal component transformation model

By the first-hand investigation of land use/cover in the Weigou River basin and in-door analysis, all the images have been classified into six primary landscape types (farmland, forest, grassland, water, construction area and desert). In more detail each image was classified into 12 sub-types (plain farmland, sloping farmland, terraced farmland, arbor forest, shrubbery forest, economic forest, natural grassland, artificial grassland, water, town construction area, rural residential area, and desert).

The vector and attribute data have been obtained under man–machine interactive interpretation method, with which the information of remote sensing images is extracted by veterans of landscape changes analysis and remote sensing application under GIS software. By this method, it has complementary advantages for data extraction, because the veterans and the software are so well coordinated. So it plays a unexchangeable role in remote sensing information extraction (Pu 1992). The precision of the vector has been kept within one or two pixels.

In July 2004, the fieldwork was carried out in order to check data accuracy of various landscape types. The GVG system (car global position system (GPS) combined with digital video system and GIS system) was adopted to obtain 1947 ground truth pictures along the intersected linear routes. Then superposition analysis was conducted on the interpreted results and thereby the error matrix was established. The results show that the total error rate is 2.47%, and therefore the total interpretation accuracy approaches 97.53% (see Table 3).

Table 3 Error matrix (m²)

Landscape types	Landscape types						
	Farmland	Forest	Grassland	Water	Construction area	Desert	Total
Farmland	172,798	28	2,058	0	0	0	174,884
Forest	3,456	124,687	387	0	0	0	128,530
Grassland	3,407	1,512	223,114	588	0	0	228,621
Water	0	0	402	17,318	0	0	17,720
Construction area	0	0	0	168	26,259	1,988	28,414
Desert	0	0	0	0	671	15,073	15,743
Total	179,661	126,227	225,961	18,073	26,930	17,060	593,912
error	0.0382	0.0122	0.0126	0.0418	0.0249	0.1165	0.0247

Landscape transition matrix and landscape indexes

Area change, change ratio and change direction of various landscape types can be shown up by the landscape transition matrix (Li and Lu 2001; Li and Li 2004). In this paper, the landscape transition matrix has been quantified by Grid data of all the landscape types in the Weigou River basin established by the Grid model of ARC/INFO.

To study the interrelation between landscape pattern and eco-process, it is necessary to monitor and analyze the landscape change at the accurately same scale of the landscape characteristics (Wu 2000). Landscape index has demonstrated its efficacy in researches on scale effects and scale characteristics of landscape pattern (Turner and O'Neill 1989; Jelinski and Wu 1996; O'Neill and Hunsaker 1996; Wu 2000; Turner and Gardner 2001). The structural characteristics of landscape can be pointed out by comparing landscape indexes at class level and at landscape level (Lu and Li 2001; Xiao and Li 2005). Nine landscape indexes at class level and eleven indexes at landscape level (Table 4) have been quantified by the use of the spatial pattern analysis program for categorical maps (FRAG-STATS) for monitoring the landscape change at river basin scale. The expressions of the indexes provided by FRAG-STATS have been adopted (McGarigalv and Marks 1994; McGarigalv et al. 2002). The landscape vector data have been converted to 10-m resolution grid under Grid model of ARC/INFO. The edge of the river basin and landscape has been treated as the edge of patches. The minimum search radius has been assigned to 2,000 m, respectively.

Results

Analysis of landscape transition matrix

As seen in Table 5 and Fig. 4, farmland dominates the study area. There has been a considerable change (1,390.30 ha, 4.72% of the total area) in the Weigou River

basin during the 6-year-period. Forest, grassland, construction area, and water have increased (by 63.93, 0.65, 4.04 and 2.75%, respectively).

A further analysis shows that all the sub-types of landscape, the area of terraced farmland have decreased most significantly (by 715.11 ha) and economic forest has had the largest increment in area (by 511.19 ha) (Fig. 5). Plain farmland, slope farmland and terraced farmland have decreased by 206.53, 117.72, and 715.11 ha, respectively. Arbor forest, shrubbery forest and economic forest have increased by 163.04, 271.23 and 511.19 ha, respectively. Natural grassland has decreased by 256.92 ha, while the artificial one has increased by 288.84 ha.

Table 6 presents the transition matrix of landscape change. The results indicate that, the two most prominent conversions are the conversion from terraced farmland to artificial grassland and the one from terraced farmland to economic forest (284.84 and 273.64 ha, respectively). Conversions from plain farmland to economic forest, from natural grassland to shrubbery forest, and from terraced farmland to shrubbery forest are also notable (137.79, 137.61, and 106.23 ha, respectively). Arbor forest has been transformed mainly from terraced farmland (40.95%) and natural grassland (39.34%). Of the area converted to town construction area, 88.93% were originally plain farmland. Of the area converted to rural residential, 65.89% were originally plain farmland, 34.11% were originally terraced farmland.

As shown in Tables 5, and 6, from 1998 to 2004, the primary type of grassland changed a little. However, to illuminate the remarkable changes among farmland, grassland and forest, the transformations related to sub-types of grassland cannot be ignored.

Analysis of landscape indexes at class level

The changes in landscape indexes at class level are shown in Table 7. The interspersion and juxtaposition index (IJI)

Table 4 FRAGSTATS metrics

Acronym	Metric name	Description	Units
CA	Class area	Total class area	Hectares
PLAND	Percentage of landscape	The percentage of the landscape comprised of the corresponding class; measuring component of landscape	Percent
NP	Number of patches	The number of patches of the corresponding class; reflecting landscape pattern	None
LPI	Largest patch index	The percentage of the landscape comprised by the largest patch; identifying the dominating landscape types	Percent
MPS	Mean patch size	Average size of patches in expected to decrease with increasing fragmentation; reflecting landscape fragmentation	Hectares
AWMSI	Area-weighted mean shape index	Mean patch shape complexity, weighted by path area; measuring edge effects of landscape patch	None
AWMPFD	Area-weighted mean patch fractal dimension	Patch shape complexity measure, weighted by path area; reflecting human disturbance to landscape	None
MPI	Mean proximity index	Average proximity index for all patches in a class; measuring the edge-to-edge distance for all patches	None
MNN	Mean nearest-neighbor distance	Sum of distances to the nearest neighboring patch of the same type; reflecting landscape scatter	Meter
IJI	Interspersion and juxtaposition index	The observed interspersion over the maximum possible interspersion for the given number of patch types; reflecting adjacencies of patch types	Percent
CONTAG	Contagion index	The observed contagion over the maximum possible contagion for the given number of patch types; reflecting clumping level and Spreading tendency of different patch types	Percent
SHDI	Shannon's diversity index	Minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion; measuring spatial heterogeneity of landscape	None
SHEI	Shannon's evenness index	Minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion, divided by the logarithm of the number of patch types; measuring spatial diversity of landscape	None

of all landscape types increased from 1998 to 2004, indicating more uniform landscape configuration and diversity landscape at class level in the Weigou River basin.

First of all, among landscape types, terraced farmland is the highest variable patch type: its percentage of landscape index (PLAND) decreased from 57.06% in 1998 to 54.63% in 2004, whereas its number of patches index (NP) increased from 90 to 111 and the mean patch size (MPS) declined. Both its area-weighted mean patch fractal

dimension (AWMPFD) and area-weighted mean shape index (AWMSI) decreased, indicating that the 2004 terraced farmland patches were more isolated and less uniform than the 1998 patches. That is also supported by the mean proximity index (MPI), which decreased from 6242.61 to 4093.02 and mean nearest-neighbors distance (MNN), which decreased from 54.48 to 51.03. Therefore, it shows that the landscape pattern, which was dominated by large terraced farmland patch, has changed to a certain degree.

Table 5 Landscape change in six primary types, 1998–2004 (ha)

	Farmland	Forest	Grassland	Water	Construction area	Desert area
1998	21,199.15	1,479.01	4,310.40	393.28	1,472.35	590.43
2004	20,159.79	2,424.47	4,338.32	404.08	1,531.79	586.17
Change area	-1,039.36	945.46	27.92	10.80	59.44	-4.26
Percent (%)	-4.90	63.93	0.65	2.75	4.04	-0.72

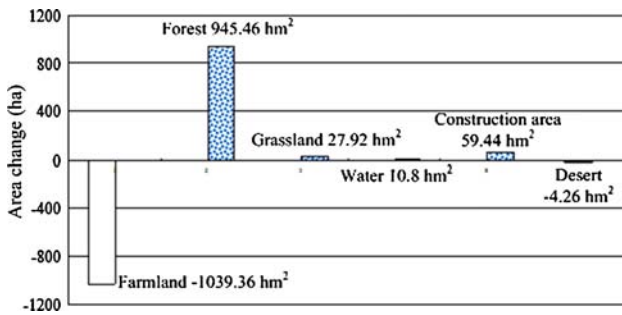
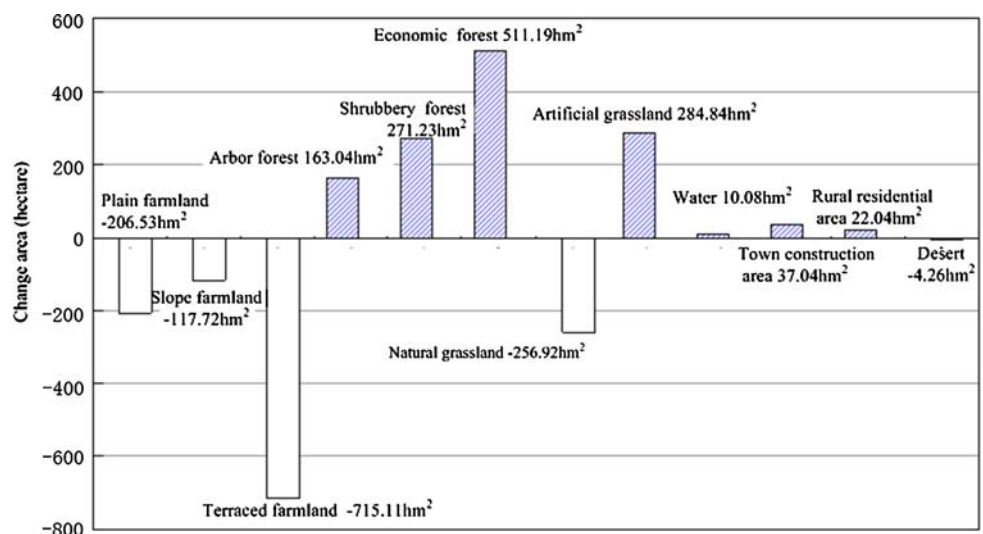


Fig. 4 Area change of primary landscape types

The area of slope farmland and NP index decreased, while the MPS index increased. The AWMPFD index decreased while the MNN index increased. This indicates that the slope farmland was regulated to a certain degree.

Secondly, PLAND index and NP index of forest increased. Economic forest changed most significantly among the sub-types of forest, from 2.78 to 4.48% and 761 to 834, respectively. All of its MPS index, AWMSI index and AWMPFD index increased, while MNN index decreased, indicating that distribution of forest changed from fragment to clumped, and the inner-connection were further strengthened.

Fig. 5 Area change of 12 sub-types



Besides farmland and forest, grassland is another flexible patch type. PLAND index of artificial grassland increased, while natural grassland decreased. Therefore the total area of grassland changed a little. All MPS index, AWMSI index, AWMPFD index, and MNN index of the two sub-types of grassland decreased, indicating that artificial grassland protected the grassland ecosystem in the situation of natural grassland degradation.

At last, the changes in landscape indexes of construction area indicate that: the construction area has been expanded, more clumped and more regulated, and the inner-connection has been strengthened. Additionally, indexes of water and desert changes point out that water area increased and clumped. Desert decreased little, but has been regulated and changed to uniform.

Analysis of landscape indexes at landscape level

From 1998 to 2004, in the Weigou River basin, the NP index increased and MPS index decreased, showing a trend towards increasing fragmentation and fine-grained landscape (Table 8). Both Shannon’s Diversity Index (SHDI) and Shannon’s Evenness Index (SHEI) became

Table 6 Landscape change matrix, 1998–2004 (ha)

	2004										1998 Total		
	Plain farmland	Sloping farmland	Terraced farmland	Arbor forest	Shrubbery forest	Economic forest	Natural grassland	Artificial grassland	Water	Town construction area		Rural residential area	Desert
1998	2274.51	0.00	0.00	16.51	4.53	137.79	0.00	0.00	0.00	32.94	14.76	0.00	2481.04
Plain farmland	0.00	1777.85	35.92	9.87	27.15	54.94	11.27	0.00	0.00	0.00	0.00	0.00	1917.00
Sloping farmland	0.00	16.43	16045.57	66.76	106.23	273.64	0.00	284.84	0.00	0.00	7.64	0.00	16801.11
Terraced farmland	0.00	0.00	0.00	131.44	0.00	1.57	0.00	0.00	0.00	0.00	0.00	0.00	133.01
Arbor forest	0.00	0.00	0.00	6.01	533.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	539.37
Shrubbery forest	0.00	3.63	0.00	1.32	0.00	797.58	0.00	0.00	0.00	4.10	0.00	0.00	806.63
Economic forest	0.00	1.37	4.51	64.14	137.61	52.30	4012.92	0.00	8.26	0.00	0.00	0.00	4281.11
Natural grassland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	29.29	0.00	0.00	0.00	0.00	29.29
Artificial grassland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	393.28	0.00	0.00	0.00	393.28
Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	257.62	0.00	0.00	257.62
Town construction area	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1214.73	0.00	1214.73
Rural residential area	0.00	0.00	0.00	0.00	1.72	0.00	0.00	0.00	2.54	0.00	0.00	586.17	590.43
Desert	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	404.08	294.66	1237.13	586.17	29444.62
2004 Total	2274.51	1799.28	16086.00	296.05	810.60	1317.82	4024.19	314.13	404.08	294.66	1237.13	586.17	29444.62
Change area	-206.53	-117.72	-715.11	163.04	271.23	511.19	-256.92	284.84	10.80	37.04	22.40	-4.26	1390.30
Percent (%)	-8.32	-6.14	-4.26	122.58	50.29	63.37	-6.00	972.48	2.75	14.38	1.84	-0.72	4.72

larger. Thus, the landscape heterogeneity and evenness increased. Furthermore, landscape dominated by large patches of farmland became subdued. The spatial context of landscape had significant changes. For instance, the MNN index and the MPI index declined, displaying that the spatial distribution of patched became more continuous. In addition, the IJI index increased and the contagion index (CONTAG) became smaller, illustrating that the spatial distribution of main patches (terraced farmland, natural grassland, plain farmland and slope farmland) in the landscape became less clumped, and the dominance of one or several patch types decreased and had an even greater connectivity. That also supported that the landscape became more uniform and more continuous.

Drive factors of landscape pattern

Climate factor

The Weigou River basin has a temperate semi-arid climate. The climate data recorded at Jingning weather stations from 1960 on (Figs. 1, 6; Table 9) shows that the average annual precipitation is 450 mm with a disparate time distribution (from June to September, accounting for 69% of annual total precipitation) and mainly in the form of rainstorm, which is the effect of general circulation of atmosphere (west wind). The average annual temperature is 7.37°C and more than 10°C accumulated temperature is 2,551.2°C. The climate condition caused an asynchronous incidence of solar radiation, solar heat and water condition. The quality and condition of vegetation is not so good. Soil erosion is severe and ecological environment is broken up. These are the climatic reasons for the current situation of landscape pattern and structure.

Terrain factor

The Weigou River basin is an offshoot of the Huajialing Mountain range, located in the third hill region of the loess plateau and at the west piedmont of the Liupan-shan Mountain. As shown in Table 10, only 9.34% of the area has slopes below 5°; 32.14%, 5°–15°; 39.72%, 15°–25°; 18.8%, above 25°. Due to dense ravines and fragmented landform, gully erosion, gravity and engineering—induced erosion are prevalent, with a mean erosion modulus of $9,360 \times 10^4 \text{ t km}^{-2}$ and a ravines density of 3–5 km/km². These are the topographic reasons for the current situation of landscape pattern and structure.

Table 7 Landscape matrix change at class level, 1998–2004

Type	CA	PLAND	NP	MPS	AWMSI	AWMPFD	MPI	MNN	IJI
1998									
Plain farmland	2481.04	8.43	184	13.49	2.38	1.13	449.44	241.24	85.02
Sloping farmland	1917.00	6.51	343	5.59	2.56	1.14	32.15	199.65	74.60
Terraced farmland	16801.11	57.06	90	186.66	6.38	1.22	6242.61	54.48	80.17
Arbor forest	133.01	0.45	88	1.51	1.74	1.11	0.85	624.14	70.95
Shrubbery forest	539.37	1.83	351	1.54	1.75	1.11	6.10	230.78	69.63
Economic forest	806.63	2.74	761	1.06	1.48	1.08	2.54	180.08	69.72
Natural grassland	4281.11	14.54	610	7.02	3.30	1.18	188.88	90.94	73.06
Artificial grassland	29.29	0.10	6	4.88	2.03	1.12	0.02	2541.05	55.03
Water	393.28	1.34	13	30.22	23.82	1.43	210.74	727.55	73.33
Town construction area	257.62	0.87	6	43.04	15.00	1.38	1166.94	31.52	76.32
Rural residential area	1214.74	4.13	475	2.56	1.60	1.09	15.28	133.31	73.80
Desert	590.43	2.01	207	2.85	6.12	1.29	3.65	214.17	63.63
2004									
Plain farmland	2271.8	7.72	184	12.36	2.47	1.13	407.93	236.04	85.56
Sloping farmland	1799.28	6.11	321	5.61	2.58	1.14	30.64	208.94	77.18
Terraced farmland	16086	54.63	111	144.92	5.91	1.21	4093.02	51.03	82.68
Arbor forest	296.05	1.01	114	2.60	1.81	1.11	2.76	480.28	74.22
Shrubbery forest	810.6	2.75	378	2.15	1.97	1.12	10.62	206.40	72.28
Economic forest	1317.82	4.48	834	1.58	1.59	1.09	6.82	156.26	74.09
Natural grassland	4233.09	14.38	607	6.97	3.17	1.17	149.94	90.83	76.44
Artificial grassland	105.23	0.36	22	4.78	1.88	1.11	2.29	1385.57	66.66
Water	404.08	1.37	12	33.63	23.71	1.43	79.57	814.85	75.46
Town construction area	294.67	1.00	8	36.49	14.11	1.37	1158.98	31.75	82.75
Rural residential area	1237.13	4.20	475	2.62	1.61	1.09	16.29	132.20	76.05
Desert	588.88	2.00	201	2.92	6.13	1.29	3.56	223.35	65.80

Soil condition factor

As shown in Table 11, the main soil types in the Weigou River basin are loessial soil (accounting for about 78%), heilu soil (18.9%), red clay (2.1%), and entisol (1%). Loessial soil, with visible vertical joint, lower anti-erosion capacity, shallow ripe layer, strong collapsibility, and the lower fertility characteristics, often occurs on slopes of residual loess plain, mid and top of weir and mound slopes,

and in gully areas. The soil distribution pattern causes the severe soil and water losses.

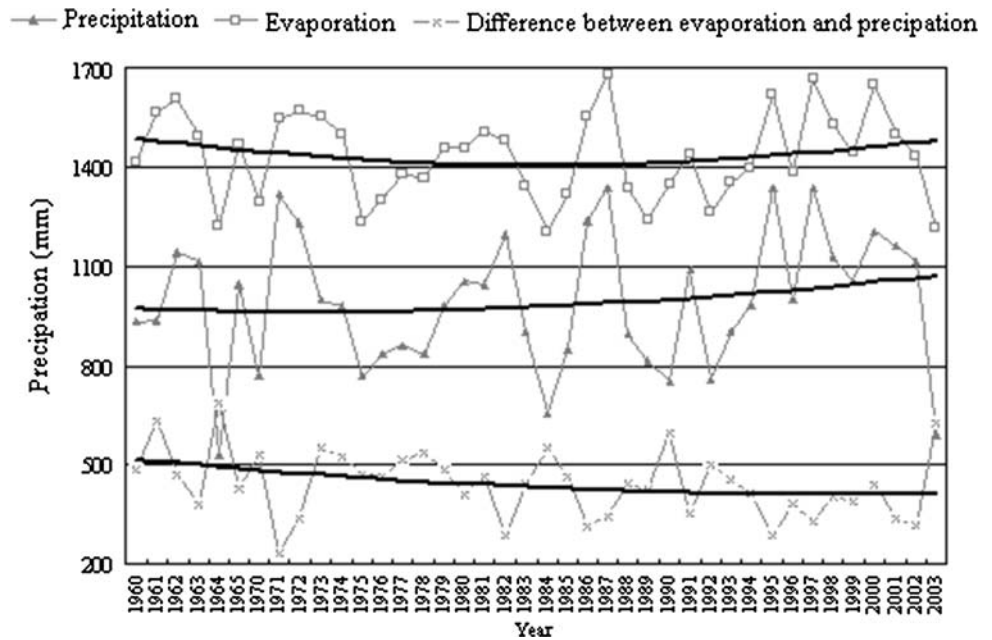
Human activities factor

The Weigou River basin is located in the agro-pasture zig-zag zone. The population density is 148 inhabitants per km². The intensified land reclamation for the development of

Table 8 Landscape matrix change at landscape level, 1998–2004

Year	NP	LPI	MPS	AWMSI	AWMPFD	MPI	MNN	CONTAG	IJI	SHDI	SHEI
1998	3134	7.31	9.40	5.21	1.20	252.93	184.67	64.29	76.87	1.50	0.60
2004	3267	7.24	9.01	4.84	1.19	201.71	178.33	61.99	79.54	1.60	0.64

Fig. 6 Difference between evaporation and precipitation



agriculture and animal husbandry, severe deforestation and overgrazing has led to the desertification of the impoverished land. These have caused the formation of the landscape pattern dominated by large farmland patches. Since 1980s, people have been aware of the fact that ecological environmental protection is important to social and economic development in the western regions. In recent years, with the implementation of ecological rehabilitation projects, including returning farmland to forest or grass, afforestation and building terrace fields in the Weigou river basin, the eco-environmental conditions have exhibited some favorable changes. For instance, the cooperation proportion values of farmland, grassland and forested rise from 27.28:3.77:1 in 1981 (Committee of Jingning’s Chorography 2005) to 14.33:2.91:1 in 1998 and to 8.32:1.79:1 in 2004 (see Table 12), calculated results by revised universal soil loss equation (RUSLE) shows that the mean erosion modulus in the Weigou River basin during the 6-year-period has decreased from $9559.4 \text{ t km}^{-2} \text{ a}^{-1}$ to $9348.3 \text{ t km}^{-2} \text{ a}^{-1}$ and the erosion area has decreased by

389.8 ha. The soil erosion severity has changed from weak and moderate degrees to slight degree.

Drive factors of landscape change

As seen in Fig. 7, the climate data recorded at Jingning Weather Station shows that, since 1960, the precipitation have been descending on the whole, while during the period from 1998 to 2004, the precipitation has been ascending on a partial scale. Because of the relatively favorable water condition, survival rate of vegetation moves upward. The implemented ecological rehabilitation projects expound the last paragraph. The land of total area of 1039.36 ha has retired from crop cultivation, with trees planted, tree-shielding systems established and small watersheds treated, covering an area of 697.42 ha. Artificially sown grass field and improved meadows have reached 296.11 ha (see Tables 5, 6). Therefore, the soil and water losses have been checked to a certain extent.

Table 9 Climate condition in Weigou river basin

Precipitation (mm)			Distribution in a year (%)			Maximum precipitation in 24 min	Strongest precipitation		
Average	Maximum	Minimum	March–May	June–September	October–December		60 min	30 min	
450	690	228	19	69	12	94.7	43.9	33.8	
Temperature (°C)				>10°C Accumulated temperature	Frost-free days (days)	Evaporation (mm)	Wind		Humidity (%)
Average	Maximum	Minimum	Wind direction				Wind velocity		
7.37	8.80	6.29	2551.2	160	1435.1	SE	2.2	65.96	

Table 10 Soil erosion intensity in Weigou river basin

Slope (°)	Percent in area (%)	Average erosion modulus (t/ha a ¹)	Erosion intensity
0°–5°	13.71	16.69	Slight erosion
5°–15°	42.06	59.88	Intense erosion
15°–25°	35.91	138.99	Severe erosion
25°–35°	7.92	193.50	Severe erosion
>35°	0.40	273.73	Heavy erosion

The landscape structure has been ameliorated. Landscape heterogeneity and evenness have increased.

Conclusions and discussion

This paper describes how the GIS analysis technology and satellite remote sensing images are combined to address the landscape change in the Weigou River basin, during the period of 1998–2004. The forest has been found increased notably, while farmland has decreased significantly due to the conversion to forest and grassland. The landscape heterogeneity and evenness have increased, with a greater connectivity. The dominance of farmland patch has decreased. The project of returning land from farming to forest and grassland and the development of supporting policies could be expected to benefit from the use of landscape information.

Located at a special geographic zone, the Weigou River basin has a rather fragile ecosystem and semi-arid climate

on Chinese Loess Plateau. Ecological landscape changes in this region are mainly affected by natural and human factors. Through complex interaction, the natural factors and human activities alter the landscape structure and decide the service function of regional ecosystem (Wang and Feng 1991; Zhang and Wang 2006).

The natural factors include climate, landform, soil and water condition, etc., the climate has become warmer and drier mainly by natural driving force. As a result, the environmental aridification and vegetation degradation have become exacerbated, and the already broken terrain has become even more fragmented due to the water erosion-induced dissection. The fluctuated arid-climate boundary has moved southward, and the land desertification (such as water erosion, wind erosion, gravitational erosion, soil salination and fertility reduction) become aggravated. Because of the relatively favorable water condition (expounded in “Drive factors of landscape change”), the survival rate of vegetation moves upward. The landscape structure has been ameliorated. And the landscape heterogeneity and evenness have increased.

The human activities, i.e. the rapid population growth and predatory economic activities, are also the important factors leading to the eco-environmental deterioration of the region. In the past, the erosion of loose loessial soil in the region was accelerated and the service function of regional ecosystem declined, which even caused serious conflicts. Such environmental degradations were caused by following factors: the lack of environmental awareness, the seeking of instant economic benefits at the expense of the environment, uncontrolled removal of vegetation,

Table 11 Soil condition in Weigou river basin

Type	Area (ha)	Percent (%)	Distribution	Characteristics	Soil bulk density (g/cm ³)	Soil pore density (%)
Loessial soil	22966.80	78	Occur at slopes of residual loess plain, mid and top of weir and mound slopes, and gully areas	Visible vertical joint, poor in water holding, lower anti-erosion capacity, shallow ripe layer, strong collapsibility, and the lower fertility	1.065	60.20
Heilu soil	5565.03	18.9	Occur at residual loess plain, mesa, and valley plain	Deep soil layer, good cultivation, poor in water holding, lower anti-erosion capacity, and good fertility	1.269	45.53
Red clay	618.34	2.1	Occur at the middle and backward of big river ditch valley	Heavy soil texture and bad cultivation, strong ability of sluice, higher anti-erosion capacity	1.410	36.20
Entisol	294.45	1	Occur at the flood land and the first river terrace	Uniform soil texture, long land ripping time, and higher fertility		

Table 12 Soil erosion change

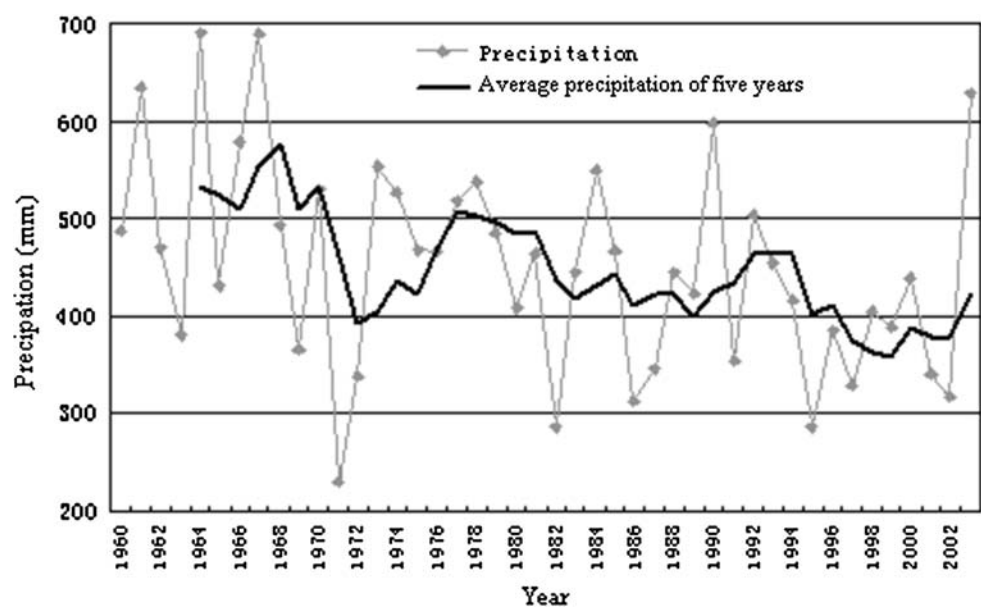
	Erosion modulus ($t\ km^{-2}\ a^{-1}$)	1998			2004			Change		
		Area (ha)	Erosion amount ($t\ a^{-1}$)	Average erosion modulus ($t\ km^{-2}\ a^{-1}$)	Area (ha)	Erosion amount ($t\ a^{-1}$)	Average erosion modulus ($t\ km^{-2}\ a^{-1}$)	Area (ha)	Erosion amount ($t\ a^{-1}$)	Average erosion modulus ($t\ km^{-2}\ a^{-1}$)
Slight erosion	<1,000	5,355.9	23,685.3	442.2	5,745.7	2,5241.4	439.3	-389.8	-1,556.1	2.9
Weak erosion	1,000–2,500	3,054.4	50,676.0	1,659.1	3,015.4	50,816.8	1,685.2	39.0	-140.8	-26.1
Moderate erosion	2,500–5,000	3,692.8	136,735.2	3,702.8	3,583.8	132,893.9	3,708.2	109.0	3841.3	-5.4
Intense erosion	5,000–10,000	5,945.3	439,816.1	7,397.7	5,940.9	440,055.6	7,407.2	4.4	-239.5	-9.5
Severe erosion	10,000–20,000	7,403.0	1,062,595.7	14,353.6	7,313.8	1,050,758.2	14,366.8	89.2	11,837.5	-13.2
Heavy erosion	>20,000	3,992.6	1,101,167.3	27,580.2	3,844.4	1,052,734.7	27,383.6	148.2	48,432.6	196.6
Total		29,444.0	2,814,675.6	9,559.4	29,444.0	2,752,500.6	9,348.3	0.0	62,175.0	211.2

over-cutting and over-reclamation. Since 1998, with the implementation of ecological restoration projects, some favorable changes to the eco-environment have occurred. For example, some farmlands have been transformed back into forestland and grassland, some grassland has been transformed into forest land, and some sloping croplands have been transformed into terrace fields. As a result, the surface vegetation has been restored to a certain degree, the erosion intensity of heavy rain has been reduced, the soil loss has been decreased, and hence the ecological environment has started to develop in a reversing direction.

However, the restoration of ecosystem structure and service function and the elimination of poverty in the region of a fragile ecosystem are a long-term process. Some schemes to solve the conflicts may slow down the region's economic development in a short period of time or even cause rebound of poverty, but in the long run, solving

the conflicts concerning the service function of regional ecosystem and maintaining its service function are the foundation for the region's sustainable development, modern civilization and human existence. Therefore, it is important to weigh the pros and cons and solve the conflicts, overcome the contradiction between resource use and the harmonious development of society and environment, and enhance the service function of regional ecosystem.

In Weigou River basin, farmland, forest, grassland, water, construction area and desert are not only major self-contained parts of the ecosystem, but also connected with each other. The natural and human activities made a weak service function of regional ecosystem. In the environmental and ecological systems engineering points of view, reestablishing vegetation and building terrace fields are just the beginning of the improvement of the local eco-environmental conditions. The vegetation is just restored,

Fig. 7 Precipitation in Weigou river basin

water erosion and gravitational erosion are just brought under control to a certain degree, and hence the ecological environment started to develop in a reversing direction.

The image interpretation coupled with GIS has demonstrated its ability to provide comprehensive information on the direction, rate, and location of landscape changes as a result of land management. Landscape metrics have proved useful in monitoring the dramatic landscape changes that have taken place in the Weigou River basin. Meanwhile, the transition matrix and the transition map of landscape patch types are helpful tools to the analysis of the changes in landscape structure and composition.

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