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Landscape change detection in Yulin prefecture

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Abstract: Landscape is a dynamic phenomenon that almost continuously changes. The overall change of a landscape is the result of complex and interacting natural and spontaneous processes and planned actions by man. However, numerous activities by a large number of individuals are not concerted and contribute to the autonomous evolution of the landscape in a similar way as natural processes do. There is a well-established need to detect land use and ecological change so that appropriate policies for the regional sustainable development can be developed. Landscape change detection is considered to be effectively repeated surveillance and needs especially strict protocols to identify landscape change. This paper developed a series of technical frameworks on landscape detection based on Landsat Thematic Mapper (TM) Data. Through human-machine interactive interpretation, the interpretation precision was 92.00% in 1986 and 89.73% in 2000. Based on the interpretation results of TM images and taking Yulin prefecture as a case study area, the area of main landscape types was summarized respectively in 1986 and 2000. The landscape pattern changes in Yulin could be divided into ten types.

Key words: landscape; remote sensing data; Yulin prefecture

1 Introduction

Landscapes are dynamic features which evolve almost continuously. Landscape changes can be distinguished into conversions from one land cover type into another one and transformations within a given land cover type (Yue *et al*., 2003). These changes are seen and evaluated by man as improvement or deterioration of the previous or existing state. However, this judgment is mainly based upon a particular view of utility or in relation of achieving a particular goal or situation. Consequently, changes are not always perceived all in the same way and positive and negative evaluations may be conflicting for the same type of change (Antrop, 1998). Landscape ecologists recognize that landscapes are heterogeneous in nature and complex so that the design of a fully integrated system is difficult to achieve (Bunce and Heal, 1984). In this context, Landscape researchers are expected to have set up detection systems for landscapes and their components. However, literature searches of academic journals reveal that landscape monitoring is a little reported subject (Brandt *et al*., 2002).

Satellite imagery is a principal way by which landscape change can be surveyed. A major step forward in the application of remote sensing data to landscape change detection is land-cover mapping (Oetter *et al*., 2001). In 2000, a land-cover and land-use database was completed by Multi-Resolution Land Characteristics Program. There is an international effort underway to map land cover of most continents by the year 2002 (Yue *et al*., 2003; Harms *et al*., 2000). Satellite imagery has the advantage of synoptic coverage but usually at a relatively low level of detail (Brandt *et al*., 2002). The new Land-sat TM images do however contain much greater details and their increased definition are currently being assessed.

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Landscape pattern represents spatial and temporal distributions of landscape ecological factors, and it is the result of landscape ecological process (Forman and Godron, 1986; Turner *et al*., 1995; William, 1989; Fu *et al*., 1999; Shi *et al*., 1999). Keeping the basic patterns of landscape ecology, such as conserving large-scale natural vegetation, maintaining green-corridors along wide rivers, is important to biodiversity protection, water conservation and the ability of ecological system anti-disturbance and restoration (Kazunobu Nomura, Nobukazu Nakagoshi. 1999). As the economic development and intensified human activities, the landscape pattern had changed conspicuously in China during 1986-2000 (Liu *et al*., 2002). In this context, studies on the process and patterns of landscape change in this period are of paramount significance to the decision-makings of local government in rational utilization, protection and renovation of land resources.

Yulin prefecture is located in the northern part of Shaanxi Province (Figure 1), where the Loess Plateau and Mu Us Desert intercrossed, and its topography consists of loess hilly-gully area and desert area. From southeast to northwest, the vegetation transits from forest-grassland, arid-grassland to hungriness-grassland. Located in the center of five provinces' (or autonomous region) conjunct boundaries, Yulin has abundant coal, natural gases, oil and kaoline resources, which provide a reliable basis for economic development. However, exploitation of those resources had resulted in some severely environmental problems in this area, especially soil and water loss and desertification. In this context, there is a well-established need to detect land use and ecological change so that appropriate policies for regional sustainable development can be formulated. With the help of landscape ecological models, this paper develops a series of landscape change detection methods based on remote sensing data.

Figure 1 Location of Yulin prefecture in Shaanxi Province

2 Data processing

2.1 Data sources

Satellite remote sensing, in conjunction with geographic information systems (GIS), has been widely applied and been recognized as a powerful and effective tool in detecting landscape change (Liu *et al*., 2003; Li, 1996; Cai, 2001; Paul *et al*., 1992; Allen S Hope and Douglas A Stow, 1993; Anthony Gar-On Yeh and Li, 1999). A number of data users involved in landscape analysis were interested in updated and finer-scale land cover data. In the early 1990s, the Environmental Remote Sensing Center (ERSC) at the University of Wisconsin Madison had been investigating the use of Landsat Thematic Mapper (TM) data to derive land cover maps (Lillesand, 1992). The studies had proven promising enough to use satellite data for mapping land cover and monitoring landscape (Heather *et al*., 2002).

Study on the patterns of landscape changes cannot be conducted without the support of modern technologies. At present, the research methods of landscape change are mainly establishing suitable spatial analysis technology by combining remote sensing, map theory, GIS and mathematics methods, with which we can study the spatial structure and interior functions of landscape, and discuss the mechanism of landscape heterogeneity's occurrence, development and conservation. Provided by National Resource and Environment Data Center of Chinese Academy of Sciences, two-period images (1986/1987 and 2000) of autumn-seasonal Landsat

Thematic Mapper (TM) data set consisting of six images were used to characterize landscape changes in Yulin prefecture. The Orbit Number is 128-33, 127-33, 126-33, 128-34, 127-34 and 126-34.

2.2 Data handling

Post-classification comparison and multi-date composite image change detection are the two most commonly used methods in the landscape change detection. In this study, an efficient classification system (Table 1) was drafted and an effective research team was organized to work on remotely sensed data through human-machine interactive interpretation for guaranteeing classification consistency and accuracy.

Table 1 Land-use classification systems

Code	Name	Description
1	Farmland	Lands for agriculture
2	Forest	Lands growing trees including arbor, shrub, bamboo and lands for forestry use
3	Grassland	Lands covered by herbaceous plant with coverage greater than 5%, including shrub-grass for pasture and the woods with cover canopies less than 10%.
4	Water body	Lands covered by natural water bodies or lands with facilities for irrigation and water reservation
5	Man-made built-up	Lands used for urban and rural settlements and factories and transportation facilities
6	Unused land	Lands having not been put into practical use or being difficult to use

Notes: Farmland is reclassified into paddy (11) and dry farming (12); forest is reclassified into natural or man-made forest (21), shrub (22), woods (23) and other forests (24); grassland is reclassified into dense grass (31), moderate grass (32) and sparse grass (33); water body is reclassified into rivers (41), lakes (42), reservoir and ponds (43) and bottomland (44); man-made built-up is reclassified into city built-up (51), rural settlements (52) and other built-ups (53); unused land is reclassified into sand (61), salina (62), wetland (63), bare soil (64) and bare rock (65).

According to the purpose of this study, this paper developed a working flow of data handling and landscape information interpretation (Figure 2). The Digital Terrain Model (DEM) could be derived from the 1:250,000 contour map, and the Digital Line Graphic (DLG) could be derived from relief map and thematic map. With the help of DEM and DLG, the background of landscape could be identified. As for Landsat TM/ETM images, only bands 2, 4, and 5 are used in this study because of their sensitivities to landscape changes. Each Landsat

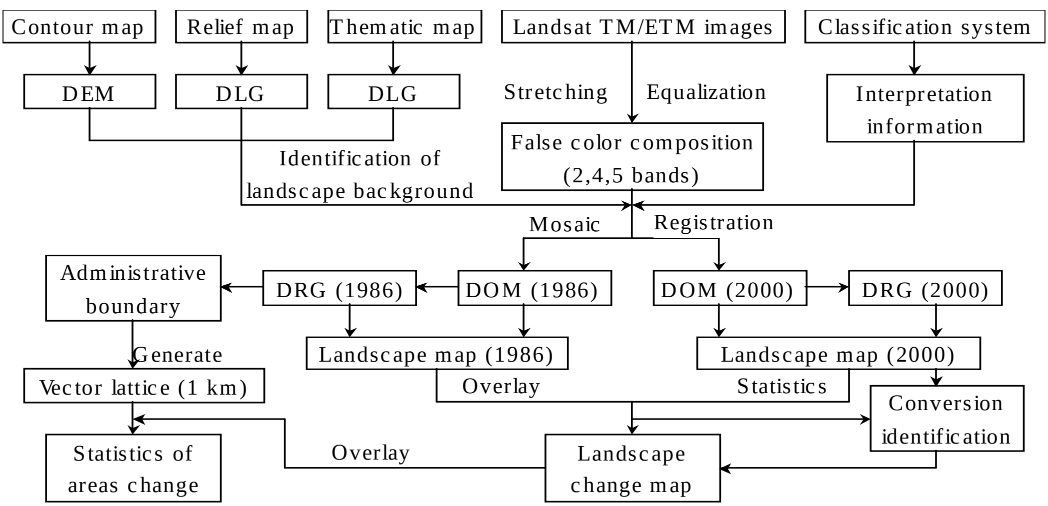


Figure 2 Flow chart of data handling and landscape interpretation

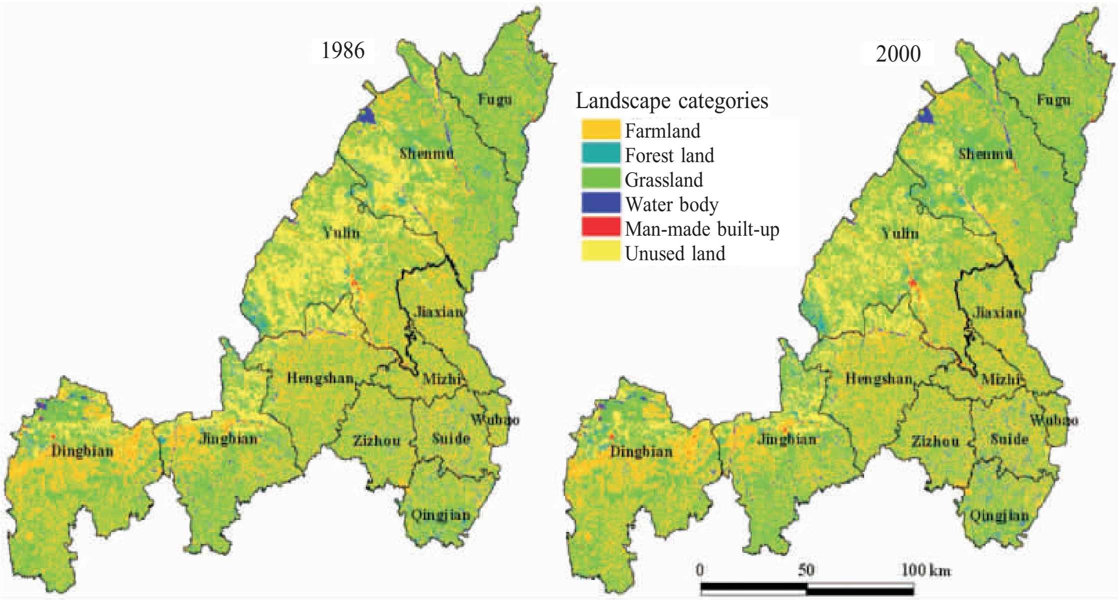


Figure 3 Landscape of Yulin prefecture in 1986 and 2000

image was enhanced using linear contrast stretching and histogram equalization to improve the image quality to help identify ground control points in rectification. The digital images were firstly rectified to a common ALBERS coordinate system based on 1:100,000 scale topographic maps. After geometric correction and mosaic, the geometrically registered was accomplished with the administrative boundaries of Yulin in the Image Analysis module of MGE. And then the Digital Orthophoto Map (DOM) and Digital Raster Graphic (DRG) could be developed to manifest the landscape structure of Yulin prefecture.

After the reference interpretation signs were developed, the image interpretation was done by human-computer interaction in Image Analysis environment according to image characters and field survey data, and the interpretation results were saved as DXF file. In the ARC module of ARC/INFO, the DXF files were converted into coverage files, and the landscape type codes were converted and saved in the coverage files' attribute tables together. Following the spatial fustian structure of 1 km vector lattice (Liu *et al*., 2002), the landscape maps of 1986 and 2000 could be converted into multi-thematic landscape map (Deng *et al*., 2002) (Figure 3).

In ArcGIS environment, the landscape change maps were generated through overlay and spatial statistics of the landscape maps of 1986 and 2000. Landscape change maps from 1986 to 2000 are the statistic background for the following area change analyses.

Precision assessment was important for any remote sensing interpretation and cartographic process. In this study, sampling analysis method was used. Sampling scheme was designed as follows: referred to the administrative boundaries of Yulin, created 1 km vector grid that covered the whole area; and marked the interpreted landscape plots' location with the coordinates of vector grid. The un-integrated grids located in the border were eliminated when sampling. The total number of integrated grids was 44,099. 440 grids (accounting for 10% of the total grids) were selected as sampling sites. The total number of verified patches was 2814 in 1986 and 2975 in 2000. We defined the ratio of accurately judged patches to total sampling patches as the total precision of the two-period images, therefore, the interpretation precision was 92.00% in 1986 and 89.73% in 2000 respectively.

3 Change of landscape indexes

Measuring the features of landscape pattern and its index system is the basis of landscape pattern structure study (Qiu, 2000; Yue *et al*., 1998a, 2001; Oneill *et al*., 1988). In this study, based on interpretation results of two-period TM images, we calculated the following landscape pattern indexes: ecological diversity (Yue *et al*., 1998a, 2001), evenness index, dominance index, fragmented index, isolation index and fractal dimension (Table 2).

Table 2 Main landscape ecological indexes

Indicators	Formulae	Meanings
Ecological diversity	$H = -\ln(\sum_{i=1}^{m(\varepsilon)} (P_i(t)^{1/2})^2)/\ln(\varepsilon)$	The number of patch types and the proportional abundance of patch types
Evenness index	$E = (H/H_{max}) \times 100\%$ $H_{max} = \mathrm{Log}_2 m$	The evenness of various landscape type
Dominance index	$D = H_{max} + \sum[(P_i(t))\log_2(P_i(t))]$	A measure of dominance in a landscape
Fragmented index	$FN_1 = (N_p - 1)/N_c$ $FN_2 = MPS \times (N_f - 1)/N_c$	The degree of division in the landscape
Isolation index	$F_i = D_i / S$ $D_i = 1/2\sqrt{n/a}$ $S_i = A_i / A$	The isolation of every different patch distribution in a certain landscape type
Fractal dimension	$D = 2\log_2(P_i(t)/4)/\log_2(A)$	A measure of patch shape complexity

Notes: $P_i(t)$ is the proportion of the landscape type i and m is the number of landscape types at time t; H is ecological diversity; H_{max} is the maximum diversity when all landscape types are present in equal proportion; FN_1 is landscape fragmented index of the whole study area and FN_2 is Landscape Fragmented index of each landscape type in the study area, FN_1, $FN_2 \in (0, 1)$, 0 represent un-damaged and 1 absolutely damaged; N_c is the landscape total area of the study area presented by grid number (the size of grid is decided by the minimum patch area so as to decrease the error resulted from different grid sizes and make the classification system in a study area stable, that is, N_c = total area/the minimum patch area). N_p is total number of patches of every patch type in landscape; MPS is every patch type's average patch area presented by grid number (MPS = average patch area/the minimum patch area); N_f is total patch number of a certain landscape type; F_i is isolation of landscape i, D_i is distance index of landscape i, S_i is area index of landscape i, n is patch number of landscape i, A is landscape total area, A_i is area of every landscape type; P is the perimeter of patch i, A is the area of patch i. The fractal dimension theoretically range from 1 to 2, with 1 representing a square with the simplest shape and 2 representing a patch with the most complicated perimeter encompassing the same area.

The results showed that the average fragmentation index and landscape isolation index of the patches with smaller area, such as lake, urban areas, transportation, swamp, naked soil and rock land, etc., were quite high (more than 1.5), which indicated the shape of these landscape types was simple and regular, and patches were distributed dispersedly. As to dryland, middle-density-grassland, low-density-grassland and sand-land, the landscape isolation index was low (less than 0.003), which indicated the patch shape was complex and patches distributed more aggregate. The patch number of these four types was 8570, 4221, 4241 and 1486 respectively; the fragmentation index of them was higher, the ratios of total patch area to the entire study area were 38.52%, 24.25%, 16.92% and 13.26% respectively; because these landscape types are mainly in valley region, their landscapes were complex and fragmented relatively. From 1986 to 2000, ecological diversity of the whole landscape decreased from 2.307 to 2.337, evenness index decreased from 0.532 to 0.525, dominance index increased from 2.055 to 2.085, which indicated the heterogeneity degree of landscape increased.

As to patch area, the percentage of dryland, middle-density-grassland, low-density-grassland

and sand-land was higher than that of other types in 1986, up to 2000, the percentage of dryland and middle-density-grassland increased by 1.289% and 1.438% respectively, but that of sand-land decreased by 2.99%. Mean patch size of sand-land and grassland decreased 36.4% and 25.5% respectively; urban, other forestland and low-density-grassland increased 44.26%, 20.83% and 23.27% respectively. These changes showed that sand-land decreased gradually and the patches became more fragmented due to the reclamation of wasteland.

As to fragmentation index changes, the average value was 5.89×10^{-6} in 1986. Swamp had the minimum value 1.57×10^{-7}, and the maximum type was dryland with the value of 0.3852. By 2000, the average value was 3.39×10^{-6}, swamp had the minimum value 4.56×10^{-8} and the maximum type was dryland with the value of 0.3976. Fragmentation index declined 42.34%, of which the main types were woodland, sand land and swamp. The type with increased fragmentation index was paddy field, which meant that the local people had strengthened the development of suitable reclaimed water area (mainly bottomland), swamp and wetland. Restricted by terrain, these areas had not been developed on successive patches. As a result of "returning farmland to forestland or grassland" policy, a large amount of land suitable for forestry had been afforested, consequently, the fragmentation index of forestland decreased. The decrease of sand-land and swamp fragmentation index indicated their distribution tended to concentration.

The difference of isolation index of every landscape type was quite large. The average value was 0.5396 in 1986, the minimum value was 0.00093 (dryland) and the maximum was 3.6766 (swamp); by the year 2000, the average value was 0.6084, the minimum value was 0.00089 (dryland) and the maximum was 6.3579 (swamp). Isolation index decreased 12.76%, main types included urban areas and transportation; types with increased isolation index included sand land, swamp and saline-alkali land. These changes indicated that the human activities had great impacts on landscape.

Due to the topographical characters, physical environment of the study area and intensified human activities, the change of fractal dimension wasn't very evident. The average value was 1.3488 in 1986, the minimum was 1.1843 (swamp) and the maximum was 1.4792 (middle-density grassland); by 2000, the average value was 1.3472, the minimum was 1.1623 (swamp) and the maximum was 1.4883 (middle-density grassland). The average value of fractal dimension declined 0.09%; the increased types included middle-density grassland, sand land and naked-soil; the declined types included low-density grassland, saline-alkali land and swamp.

4 Characteristics of landscape change

4.1 Patterns of landscape change

Based on interpretation results of TM images, we summarized the area of main landscape types in 1986 and 2000 (Figure 4). From 1986 to 2000, arable land increased 56,709.76 ha, forestland increased 9961.14 ha, grassland increased 61,677.60 ha, water areas decreased 428.41 ha, build-up land increased 2633.04 ha, and unused land decreased 130,553.07 ha. The landscape pattern changes in the second-level classification were described as follows:

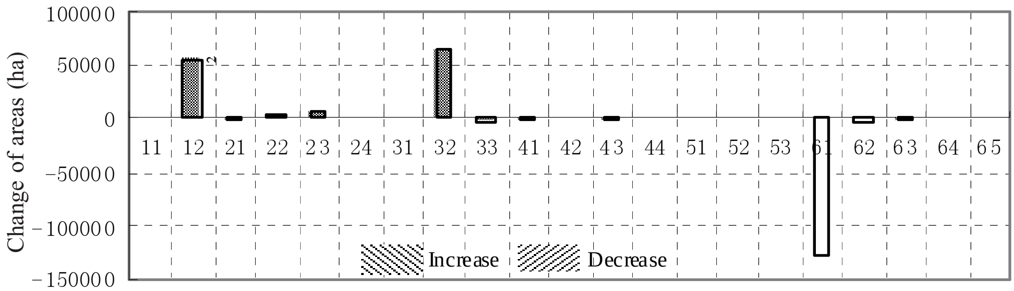
(1) Arable land: Paddy field and dryland increased 1271.44 ha and 55,438.32 ha respectively, in which increase of dryland was conspicuous.

(2) Forestland: Forested-land decreased 963.02 ha; shrubbery land, sparse-forested land and other forestland increased 4409.24 ha, 5675.37 ha and 839.55 ha respectively.

(3) Grassland: High-density grassland and low-density grassland decreased 42.56 ha and 2017.99 ha respectively; middle-density grassland increased 63,738.15 ha.

(4) Water bodies: Trench, reservoir-pool largely decreased with the area of 503.07 ha and 1684.62 ha respectively; the area of lakes increased 221.99 ha; bottomland expanded largely in the 10 years, with an increase of 1537.29 ha.

(5) Build-up land: Build-up land expanded obviously, especially rural resident. Urban areas,



Note: Numbers marked in the x axis are the codes of landscapes identified in Table 1

Figure 4 Area of main landscape types of Yulin prefecture in 1986 and 2000

rural residential sites and transportation increased 795.97 ha, 1347.42 ha and 489.66 ha respectively.

(6) Unused land: The decrease of unused land was an obvious character of landscape pattern change in Yulin, especially sand land and saline-alkali land, with area of 128,682.94 ha and 2742.54 ha respectively; swamp, naked-soil and naked-rock land increased 268.27 ha, 999.88 ha and 140.79 ha respectively.

4.2 Characteristics of landscape change

Conversion matrix is an effective method to describe the mutual conversion between different landscape types in a certain period. To take full advantages of the information derived from Landsat TM image and master the general characters of landscape transition, a landscape conversion matrix that contained landscape type, conversion ratio and conversion amount proportion was designed. The landscape conversion matrix of Yulin between 1986 and 2000 was drawn through programming computation (Table 3).

In Table 3, row represents landscape type i in time p, column represents landscape type j in time $p+\Delta t$, the bold part represents the conversion amounts (a certain landscape type in time p converted to every landscape type in time $p+\Delta t$), that is, the original conversion matrix A_{ij}; B_{ij} is defined as percentage of landscape type i in time p converted to landscape type j in time $p+\Delta t$, conversion amount proportion is defined as percentage of landscape type j in time $p+\Delta t$ converted from landscape type i in time p.

$$B_{ij} = A_{ij} \Big/ \sum_{j=1}^{6} A_{ij}$$

All the six first-level landscape types had mutual conversion with each other, of which conversion of unused land to grassland was most conspicuous. Based on conversion ratio, the conversion types ranked in the first ten places were listed below in sequence: conversion of unused land to grassland, modification of grassland, grassland to forestland, grassland to unused land, unused land to forestland, grassland to arable land, modification of water bodies, forestland to grassland, unused land to arable land and arable land to un-cultivated land, with the conversion area of 129,925.82, 16,981.38, 15,637.45, 8266.01, 3510.66, 3393.67, 3220.71, 3122.93, 2710.86 and 2618.27 ha respectively. According to the conversion amount proportion, the modification of water bodies and conversion of unused land to grassland were very conspicuous (conversion amount proportion higher than 80%), besides, conversion of grassland to forestland, grassland to unused land, grassland to arable land, arable land to built-up land, unused land to arable land, grassland to built-up land, unused land to built-up land and arable land to un-cultivated land ranked the successive places, with the conversion amount proportion of 71.77%, 69.92%, 43.50%, 38.62%, 35.29%, 35.29%, 23.99% and 23.99% respectively.

Landscape pattern changes in Yulin from 1986 to 2000 could be summarized into ten types: (i) barren hill (hillside) reconstruction, characterized by conversion of unused land to grassland; (ii) grassland degradation, characterized by conversion of middle-density grassland to

Table 3 The landscape conversion matrix of Yulin district in 1986-2000 (unit: ha)

Landscape type	Farmland	Forest	Grassland	Water body	Built-up	Unused land
Farmland	791.00	1522.92	2056.47	121.54	1019.45	2695.35
Conversion ratio	9.64	18.56	25.06	1.48	12.42	32.84
Conversion amount proportion	10.14	6.98	1.34	3.02	38.62	22.80
Forest	486.46	662.39	3153.23	5.85	115.40	225.29
Conversion ratio	10.46	14.25	67.83	0.13	2.48	4.85
Conversion amount proportion	6.24	3.04	2.06	0.15	4.37	1.91
Grassland	3393.67	15650.96	16996.15	245.80	688.01	8266.01
Conversion ratio	7.50	34.59	37.57	0.54	1.52	18.27
Conversion amount proportion	43.50	71.77	11.09	6.11	26.07	69.92
Water body	376.82	89.77	858.05	3593.26	64.13	412.84
Conversion ratio	6.98	1.66	15.90	66.61	1.19	7.65
Conversion amount proportion	4.83	0.41	0.56	89.37	2.43	3.49
Built-up	0.00	255.93	226.05	19.86	119.30	222.33
Conversion ratio	0.00	30.34	26.80	2.35	14.14	26.36
Conversion amount proportion	0.00	1.17	0.15	0.49	4.52	1.88
Unused land	2752.82	3623.66	129925.82	34.13	633.24	0.10
Conversion ratio	2.01	2.65	94.86	0.02	0.46	0.00
Conversion amount proportion	35.29	16.62	84.80	0.85	23.99	0.00

low-density grassland; (iii) shelter-forest construction, characterized by conversion of grassland to forestland; (iv) grassland desertification, characterized by conversion of grassland to sand-land or other unused land types; (v) afforestation, characterized by conversion of unused land to forestland; (vi) wasteland reclamation, characterized by conversion of grassland and unused land to arable land; (vii) shrinkage of water areas, characterized by water bodies converted to dry bottomland; (viii) land laid un-cultivated, mainly arable land converted to unused land; (ix) returning farmland to forestland or grassland, mainly arable land converted to forestland or grassland; and (x) built-up land expansion, mainly other five land-use types converted to built-up land.

5 Conclusions

(1) With the development of remote sensing technologies, satellite imagery has become a principal way to monitor landscape change. The land-cover mapping, for example, is a major step forward in the application of remote sensing data to identify landscape change. In this paper, an effective working flow of data handling and landscape information interpretation was designed and experienced. Based on the data handling framework, the "zero-loss" of area information was insisted, which makes it possible to accurately detect the landscape at regional scale.

(2) The landscape pattern of Yulin prefecture had changed conspicuously from 1986 to 2000. Arable land, forestland, grassland and built-up land increased on a large scale, while water bodies and unused land declined. From the view of the type of landscape conversion, the most evident conversion was unused land to grassland, and next were the modification of grassland, grassland to forestland, grassland to unused land, unused land to forestland, grassland to arable land, modification of water bodies, forestland to grassland, unused land to arable land and arable land laid un-cultivated. The main landscape pattern changes of Yulin from 1986 to 2000 included: barren hill (hillside) reconstruction, grassland degradation, shelter-forest construction, grassland desertification, afforestation, wasteland reclamation, shrinkage of water areas, land laid un-cultivated, returning farmland to forestland or grassland and built-up land expansion.

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