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ORIGINAL ARTICLE

Dynamic analysis of eco-environmental changes based on remote sensing and geographic information system: an example in Longdong region of the Chinese Loess Plateau

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Abstract The Chinese Loess Plateau is suffering from severe soil erosion. The eco-environmental changes of the plateau are believed to have an important influence on global eco-environmental sustainability; hence, this problem has attracted considerable attention from scientists around the world. This study has two purposes; application of remote sensing (RS) and geographic information system (GIS) techniques in the dynamic analysis of eco-environmental changes in the semiarid zone; and using the Longdong region of the Chinese Loess Plateau as an example, to make dynamic analysis of the eco-environmental changes of the region during the 1986–2004 period and identify controlling factors. Landsat Thematic Mapper (TM) data at a spatial resolution of 30 m were used for analysis. Two training areas were selected in Jingning and Qingcheng counties for analysis using 10-m resolution SPOT and Landsat TM data. The satellite RS images were obtained from the Institute of Remote Sensing Application (IRSA), Chinese Academy of Sciences (CAS). Each images was rectified by Albers Equal Area Conic projection based on 1:50,000 scale topographic maps after spectrum preparation of the images. To make the precision within 1 or 2 pixels, the accurate coordinative control points of the two systems were identified. Then the interpretation key was established based on the land use/cover survey in the study area. The images were classified into six primary environmental types (farmland, forest, grassland, water, construction area, and desert) and 25 sub-types using a visual image interactive interpretation method to obtain vector and attribute data. The resultant accuracy of the land use/cover classification reached 95%. Finally, the transformation areas and ratios of various eco-environmental types in the region were calculated to obtain the transition matrixes of eco-environmental types in the two training areas, Jingning and Qingcheng. This study demonstrates that satellite RS and GIS techniques are effective tools to monitor and analyze the eco-environmental changes in the semiarid region. Visual image interactive interpretation based on GIS technique provides comprehensive information on the direction, rate, and location of eco-environmental changes. The transition matrix model can be used to precisely analyze the variation and rates of the eco-environmental types and their spatial distribution. Great land use changes have taken place Longdong during the 1986–2004 period. These eco-environmental changes were driven by natural and human factors. Natural factors influencing the Longdong region of the Chinese Loess Plateau mainly include temperature, water condition, terrain, soil, and erosion; while human activities include over-cultivation, overgrazing, and fuelwood cutting. As viewed from the extent and severity of the influences, human activities play a very important role in altering the eco-environment of the semiarid region. The study results indicate a need for future research and observation in the semiarid region.

Keywords Remote sensing · Geographic information system (GIS) · Eco-environmental change · The Longdong region of the Chinese Loess Plateau

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Introduction

The Chinese Loess Plateau has a fragile ecosystem (Fu et al. 2000, 2006) and monsoon climate (Xu 1994; Zhang and Liu 2005). At present, more than 60% of the plateau's land is undergoing severe soil erosion, with an average annual soil loss of 2,000–2,500 t km^{-2} (Tang et al. 1993). The fragile ecosystem has a very low resistance to natural disasters, such as soil erosion, vegetation degeneration and desertification. Once damaged, it is very difficult to restore (Meng 1997; Li et al. 2001; Zhao et al. 2004).

Human demand on the region's resources and environment system are increasing. Therefore, the studies of the relationship between human activities and natural systems are needed to for scientific and rational development programs to better manage and use natural resources. Enhanced public awareness of eco-environmental protection is essential (Chen et al. 2001; Apan et al. 2002; Chen 2002; Li et al. 2004; Yadav and Gupta 2006).

In recent years, great changes have taken place in the Longdong region. Better study methods of eco-environmental change in the semiarid region may help reduce natural disasters such as drought, vegetation degradation, severe soil erosion, and desertification (Zhu 1992; Wang et al. 2001; Huang et al. 2005; Li and Shao 2006).

Materials and method

Study area

The Longdong region is located in the northwestern part of the Chinese Loess Plateau, between 35°15′–37°10′N and 106°20′–108°45′E (Fig. 1), and covers an area of 38,297.6 km^2. Lying between Ziwuling Mountain and Liupanshan Mountain, it has a temperate semiarid climate. Annual precipitation is 450–600 mm and decreases from south to north, from east to west, and from mountainous areas to river valley regions due to the influence of the East Asian monsoon and the topography, but the annual evaporation varies from 1,500 to 3,000 mm (Committee of Qingyang's Chorography 1997; Committee of Pingliang's Chorography 1998). The region's terrain is complex, its northern part is hilly, the southern part has loess ravine landforms, the eastern part is the Ziwuling Mountains, and western part is earthy-rocky mountain terrain. The Jingning training area is located in the third hill region of the loess plateau, with a land area of 297.93 km^2, while the Qingcheng training area lies in the second hill region of the loess plateau, with a land area of 420.43 km^2. Main soil types are loessial soil (accounting for 62.8%), Heilu soil (accounting for 17.2%), entisol and sierozem. Natural vegetation is sparse and only a few areas are covered by natural forest. Owing to dense ravines and fragmentized landform, gully erosion, gravity, and engineering-induced erosion are prevalent; this has long been a main ecological problem of the region.

Data

Using geographic information system (GIS) software, dynamic data reflecting the eco-environmental changes, such as vegetation degeneration, soil erosion and loess land form evolution, can be extracted from satellite images (Turner 1989; Wang and Feng 1991; Germino et al. 2001; Ayad 2005). The satellite remote sensing (RS) images used were provided by the Institute of Remote Sensing Application (IRSA), Chinese Academy of Sciences (CAS) and consisted of 30-m resolution Landsat Thematic Mapper (TM) data (1986 and 2000) composed of band 4, 3, and 2; 10-m

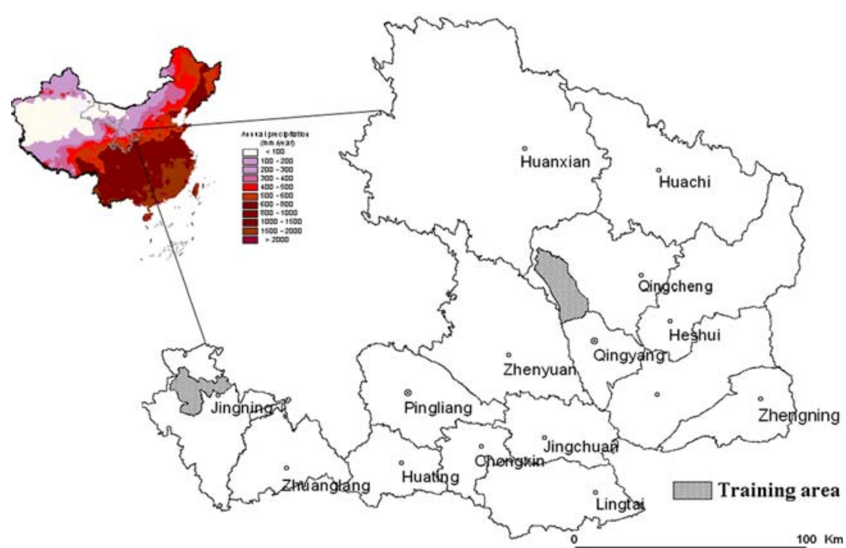

Fig. 1 Location of the study area and annual precipitation

resolution SPOT and TM fusion images (1998 and 2004) composed of band 4, 3, and 2 (Dong et al. 1997; Li et al. 2002; Kamel et al. 2006). These space and spectral information met the demand of this study (Wang and Feng 1991; Wang et al. 2003). The TM images taken in two time intervals (1986 and 2000) cover 15 counties in the Longdong region (Fig. 1); while the SPOT and TM fusion images (1998 and 2004) cover the two training areas (Fig. 1). Other data used include 1:50,000 scale topographic maps of the region and climate data recorded at ten weather stations (Jingning, Pingliang, Zhenyuan, Qingyang, Qingcheng, Huachi, Huanxian, Zhengning, Chongxin, and Changwu) from 1960 to 2004.

Method

Data processing

Data processing is very important for obtaining accurate data (Baret and Guyot 1991; Brivio et al. 2001; Bricaud et al. 2002; Qin et al. 2006; Masoud and Koike 2006). To identify ground control points, all of the images were enhanced by linear contrast stretching and histogram equalization methods. Each of these images was rectified by Albers Equal Area Conic projection based on 1:50,000 scale topographic maps. To keep the precision within 1 or 2 pixels, the accurate corresponding points on the images and the 1:50,000 scale topographic maps were identified to conduct geometric rectification. In the geometric rectification of these images, the quadratic polynomial model, principal component transformation model and nearest neighbor resampling model were used so that the original brightness values of pixels were kept unchanged (Wang and Feng 1991; Wang et al. 2003; Li et al. 2004). The resultant root-mean-squared errors (RMS) was 0.73 pixel (18.6 m) for 1986 TM images, 0.58 pixel (17.4 m) for the 2000 images, 0.46 pixel (4.6 m) for the 1998 SPOT and TM fusion images, and 0.51 pixel (5.1 m) for the 2004 images.

Data extraction

To obtain accurate information on the eco-environmental types and their spatial distribution, an understanding of spectrum and radiation information and geometric features, and to establish an unified classification system with local variance is needed (Carper et al. 1990; Chavez et al. 1991; Bocco et al. 2001). Vegetation communities, ground slope, microtopographic conditions and other environmental factors must be investigated.

Based on land use/cover types, the interpretation key for images was developed for this study. All images were classified into six primary environmental types (farmland, forest, grassland, water, construction area, and desert) and 25 sub-types. The primary environmental types were developed based on their regional characteristics, and the principles utilized are: spatial heterogeneity, joint features of regionalization and classification, coordination of dominant factors, and comprehensive factors. The sub-types were developed based on the differences of land use/cover types, vegetation coverage, and underlying layers. Farmlands were classified into sub-types based on cultivating conditions, forestlands based on forest coverage, grasslands based on grass coverage, water areas based on water bodies. Construction areas were classified into urban areas, rural residential areas, industrial, and traffic construction areas. When the vegetation coverage of a vacant land tract dropped to 5% or less, it was classified as desert.

The man–machine interactive interpretation method was used to obtain the vector and attribute data. This research employed the Grid and ArcTools module of Arc/Info Version 7 and ERDAS IMAGINE Version 8.5. The demonstrated results showed that the classification accuracy approached 95%.

In the extraction process, the minimum patches of undeveloped land were maintained to 3×3 pixels. The minimum patches of strip residential areas were maintained to 2×4 pixels. The narrowest valley width was controlled at 2 pixels. Linear objects (roads and rivers) were controlled at a minimum of 2 pixels. All other features were controlled at 5×5 pixels.

Estimation of data accuracy

A field check was carried out to verify data accuracy of various eco-environmental types in July 2000. The GVG system (Car GPS combined with digital Video system and GIS) was adopted to obtain the ground truth data along the intersected linear routes in the typical loess plateau areas (plateau, the second hill region, the third hill region, and the forth hill region of the Chinese Loess Plateau). About 30,243 photographs were obtained. Then superposition analysis was conducted on the interpreted results and the error matrix established. The total error (vector and attribution data from TM images) approximated to 5% and interpretation accuracy of the eco-environment-related data was 95%. In 2004, the same methods were adopted to obtain 2,152 photographs in the two training areas in Jingning County and Qingcheng County and the error matrix established. The total error (vector and attribution data from SPOT and TM fusion images) approximated to 2.5% and the total interpretation accuracy was 97.5%. Therefore, the total interpretation accuracy in this study approached 95%.

Results

Distribution of various eco-environmental types

The Longdong region of the Chinese Loess Plateau has a typical loess terrain (Wang et al. 2001; Zhang et al. 2004; Kimura et al. 2005). Grassland and farmland are the largest and two most widely distributed types in the study area. Grasslands mainly occur on mountain tops, hills, tableland slopes, gully floors, and gully heads. Farmlands are mainly distributed in the piedmont belts in basins, alluvial and deluvial plains, loess plains, hilly valleys terraces, and shoaly lands. Natural forests mainly occur in the Ziwuling and Liupan mountain areas, on the west slope of Long Mountain, and on other mountains in Kongtong, Mawu, Machuan, Huating, and Chongxin. Artificially established forests mostly occur on the residual loess plain, weir and mound slopes, and both sides of canals and roads. Shrub forests and sparse forests are generally distributed at the gully heads and ravine areas. Construction lands are dominated by dwelling land in countryside and are scattered on loess plain, loess slopes, gully areas, weirs, mesa and both sides of roads.

Eco-environmental changes during the 1986–2004 period

Considerable changes have taken place in the eco-environment in the region during the 14-year period from 1986 to 2000 (Table 1, Fig. 2). Farmland decreased from 16,353.36 Km^2 in 1986 to 16,275.37 Km^2 in 2000, a decrease of 77.98 Km^2, or a mean annual decrease ate of 0.03%. Forest land decreased by 188.79 km^2; this is equivalent to 4.58% of the total forest land area in 1986. Grassland area increased by 213.13 km^2, accounting for 1.25% of the total grassland area in 1986. Construction area increased about 57.57 km^2, a mean annual increase rate of 0.76%. Water body area decreased about 2%. Desert area decreased about 6.6%.

The analytical results of the eco-environmental changes at subtype level are presented in Table 2. Hilly dryland, plain dryland, shrub forest and sparse forest decreased by 23.90, 49.08, 102.8, and 97.84 km^2, respectively, while the areas of thick grassland and moderate grassland increased by 62.47 and 156.85 km^2, respectively.

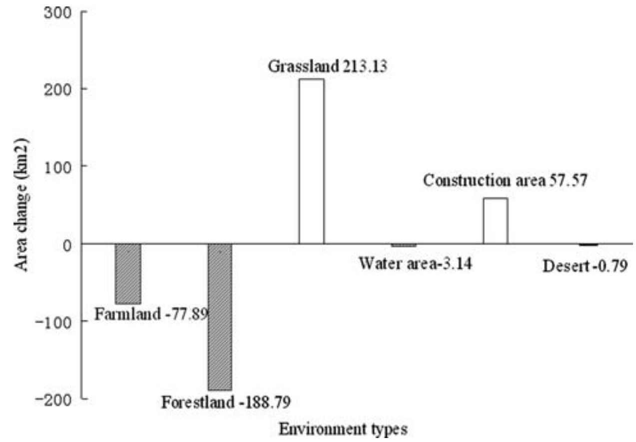

Fig. 2 Area changes of the primary eco-environment types

Table 2 The eco-environment changes of the sub-types (km^2)

	1986	2000	Area change
Monotonic dryland	955.54	950.56	–4.98
Hilly dryland	11,914.34	11,890.44	–23.9
Plain dryland	3,460.49	3,411.41	–49.08
Steep dryland	15.6	15.68	0.08
Arbor forest	595.05	594.35	–0.7
Shrub forest	1,952.64	1,849.8	–102.84
Sparse forest	1,515.6	1,417.76	–97.84
Other forest	55.72	68.33	12.6
Thick grassland	2,158	2,220.47	62.47
Moderate grassland	13,018.48	13,175.33	156.85
Thin grassland	1,938.81	1,932.62	–6.19

A transition matrix can give the information on ecological types and their variation direction (Li et al. 2001, 2004; Liu et al. 2002). Tables 3 and 4 represent the dynamic transition matrixes of eco-environmental types extracted from the SPOT and TM fusion images (1986 and 2004) in the two training areas, Jingning and Qingcheng. Where artificial ecological rehabilitation projects were implemented, local vegetation was being restored and the eco-environment was improved. As can be seen in Tables 3

Table 1 The eco-environment changes of the primary types

	Farmland	Forestland	Grassland	Water area	Construction area	Desert
1986 (km^2)	16,353.36	4,119.02	17,115.30	157.03	540.08	12.83
2000 (km^2)	16,275.37	3,930.23	17,328.43	153.89	597.65	12.03
Area change (km^2)	–77.98	–188.79	213.13	–3.14	57.57	–0.79
Percent (%)	–0.48	–4.58	1.25	–2.00	10.66	–6.19
Dynamic rate (%)	–0.03	–0.33	0.09	–0.14	0.76	–0.44

Table 3 The dynamic transition matrixes of ecological types in Jingning training area (km^2)

1998	2004						1998 total
	Farmland	Forestland	Grassland	Water area	Construction area	Desert	
Farmland	201.59	6.96	2.96	0.00	0.56	0.03	212.1
Forestland	0.04	14.80	0.00	0.00	0.05	0.00	14.89
Grassland	0.06	2.54	43.31	0.08	0.00	0.00	45.99
Water area	0.00	0.00	0.00	3.94	0.00	0.00	3.94
Construction area	0.00	0.00	0.00	0.00	14.74	0.00	14.74
Desert	0.32	0.03	0.00	0.03	0.00	5.89	6.27
2004 total	202.01	24.33	46.27	4.05	15.35	5.92	

Table 4 The dynamic transition matrixes of ecological types in Qingcheng training area (km^2)

1998	2004						1998 total
	Farmland	Forestland	Grassland	Water area	Construction area	Desert	
Farmland	223.99	21.11	0.16	0.00	0.00	0.00	245.26
Forestland	3.05	33.10	0.49	0.00	0.00	0.00	36.64
Grassland	1.69	0.00	104.72	0.00	0.00	0.00	106.41
Water area	0.00	0.00	0.00	1.86	0.00	0.00	1.86
Construction area	0.00	0.00	0.00	0.00	7.49	0.00	7.49
Desert	0.00	0.00	0.00	0.00	0.00	22.77	22.77
2004 total	228.73	54.21	105.37	1.86	7.49	22.77	

and 4, the total forest land transformed from farmland was 28.07 km^2, total grassland transformed from farmland was 3.12 and 0.56 km^2 of farmland was transformed into residential land due to population growth. On the other hand, about 3.09 km^2 of forest land and 1.75 km^2 of grassland were transformed into farmland and 0.49 km^2 of forest land was transformed into grassland. Patches of trees, shrubs, and economic forests were enlarged, and the farmlands transformed from forest land and grassland were mostly built into terraced fields (Figs. 3, 4).

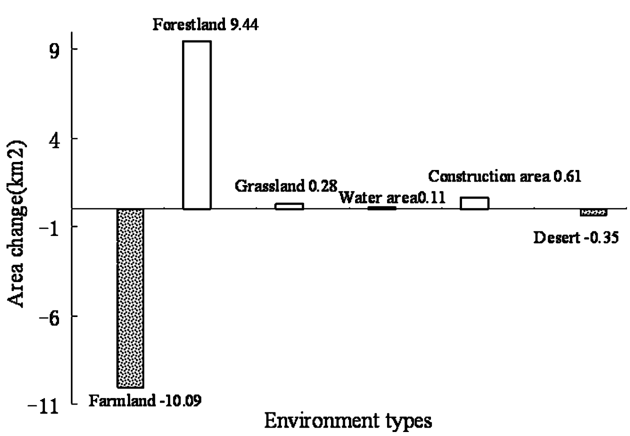

Fig. 3 Area changes of the environment types in Jingning training area

Analysis of eco-environmental changes

The transformations from forest land into grassland and from farmland into mid- to low-coverage grassland due to tree drying up and farmland abandonment were of the most striking changes in the eco-environmental types and affected a total area of 281.4 km^2. The third important change manifested as the variation of the second class of grasslands, i.e., high-coverage grassland changed into mid- to low-coverage grassland. All three show that the eco-environmental in the Longdong region has deteriorated.

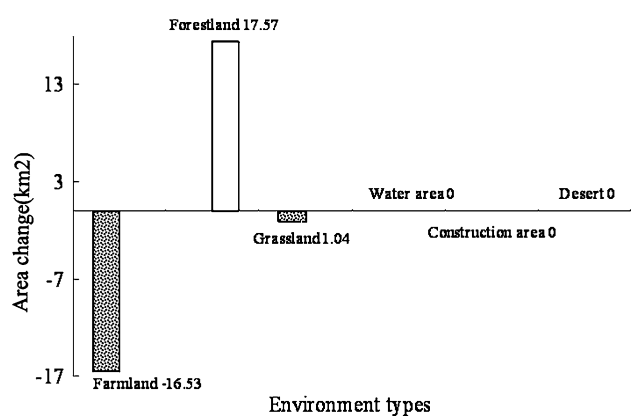

Fig. 4 Area changes of the environment types in Qingcheng training area

Water erosion created a deeply dissected terrain, with undercutting and lateral erosion and associated soil loss. Gully head erosion accelerated the development of dendritic erosion gullies in the region (Shi et al. 2002). For example, at the Dongzhi loess plateau, the head of ravines moved forward with a distance of 18 m during the monitoring period, that is, 1 m per year. Other factors that contributed to the rapid gully erosion are: vegetation degradation, flood washing, gravitational erosion, underground erosion, landslide, and irrational farming activities. See Fig. 5 for the gully erosions reflected by SPOT + TM images. Relatively perfect loess plain surface without undercutting only occupied 30–40% of the area, while residual loess plain surface accounted for 10–20% (Wei and Gao 1992; Liu et al. 1995; Dai and Wen 2000). The soil erosion rates in Jingning training area in 1998 and 2004 were calculated using the Revised Universal Soil Loss Equation (RUSLE) (Renard and Freimund 1994; Onori et al. 2006). The results showed that some 237 km^2 of land suffered from severe erosion in 2004. Severely and very severely eroded land (38% of the region's area) produced 76.6% of erosion sediments. The erosion modulus was larger than 15,000 t km^{-2} a^{-1}, as the ground slope was larger than 25°. Of all the land use/cover types, farmland had the largest soil erosion rate (Table 5). Table 6 shows that human land reclamation activities can significantly exacerbate soil erosion (Tang et al. 1994).

In recent years with the implementation of ecological rehabilitation, eco-environmental conditions in the region exhibited some favorable changes. As can be seen from the transition matrix, some land use/cover types have changed from farmland into forest land and high-coverage grassland, or changed from grassland in to forest land, and from sloping farmland into terrace fields, with a total area of 79.48 km^2 reclaimed. The calculated results by RUSLE showed that the mean erosion modulus in the Jingning training area during the 6-year period from 1998 to 2004 decreased from 9,559.42 to 9,340.3 t km^{-2} a^{-1} and the erosion area decreased by 11.62%. The soil erosion severity changed from slight and moderate degrees to weak. Although the region's ecosystem exhibited some encouraging changed, on the whole, the ecological restoration process is not significant on a large scale. Much more restoration is needed.

Table 5 Water erosion states of different land use/cover types in Jingning in 2004

	Average erosion modulus (t km^{-2} a^{-1})	Maximum erosion modulus (t km^{-2} a^{-1})
Farmland	16,672	88,179
Grassland	6,079	25,383
Water area	1,091	3,703
Desert	6,394	26,423
Sparse forest	787	4,582
Shrubbery forest	663	1,826
Economic forest	13,112	69,026
Residential area	6,642	37,487
Industrial land and traffic area	7,318	37,427

The climatic background of the eco-environmental changes

From the end of the nineteenth century to the early twentieth century, the climate in the Longdong region experienced a persistent relatively warm-dry period and reached a peak in the 1940s (Deng 2000), and then entered a relatively cold-humid period. The minimum annual tempera-

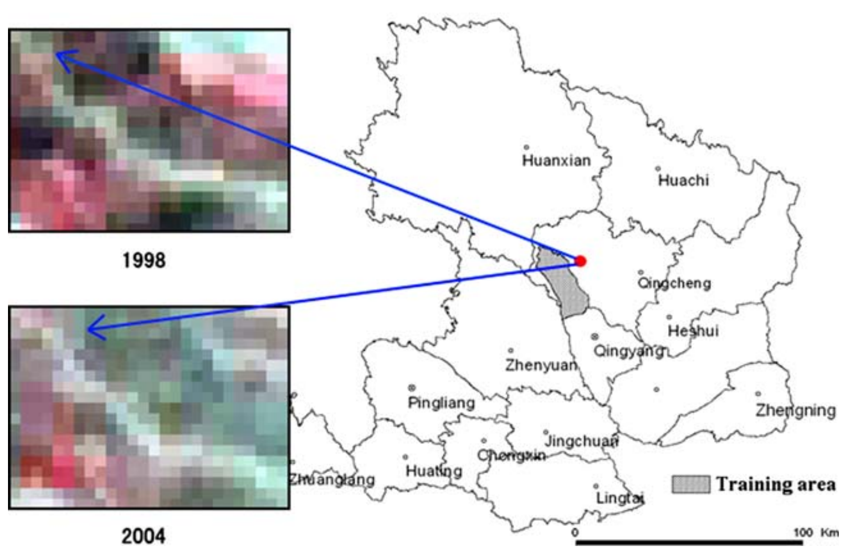

Fig. 5 Gully erosions visible on SPOT and TM fusion images

Table 6 Water erosion of forest, forest to farmland and forest to bareland in Ziwuling Mountain region from 1989 to 1991

	Land use types	Observation time	Observation times	Length (m)	Slope (°)	Area (m^2)	Erosion modulus ($t\ km^{-2}\ a^{-1}$)
Mound slope	Forest	1989–1991	22	80.2	14–32	965.8	1.29
	Forest to farmland	1990–1991	22	99.2	14–32	1,144.3	9,703.7
	Forest to bareland	1990–1991	22	86.3	5–34	995.2	10,324.5
Ravine slope	Forest	1989–1991	28	38.2	37–42	253.5	14.41
	Forest to farmland	1990–1991	24	41.0	38–41	406.5	13,179.35
	Forest to bareland	1990–1991	24	48.8	37–42	243.8	21,774.12

ture and the maximum annual precipitation recorded since the Xifeng weather station was established occurred in the mid-1960s, being 7.19°C and 805.2 mm, respectively. From the end of 1960s onwards, the climate exhibited an obvious warming and aridification tendency.

As can be seen in Table 7 and Fig. 6, the air temperature in the Longdong region in the 15-year period since 1960 continuously increased at a rate higher than the global warming level (IPCC 2001). The mean annual temperature-rising values in the 1976–1990 period and 1991–2004 period were higher than those in the 1960–1975 period and 1976–1990, respectively. Annual precipitation in the region significantly decreased during the same time period. Mean annual precipitation values in the 1976–1990 period and 1991–2004 period were smaller than those in the 1960–1975 period and 1976–1990 period, respectively (Table 7; Fig. 7). In the whole Longdong Loess Plateau, precipitation increased from its center to the borders. The increased temperature and decreased precipitation accelerated eco-environmental degradation such as aridification, vegetation degradation, soil erosion, moving sand encroachment and desertification (Xu 2005).

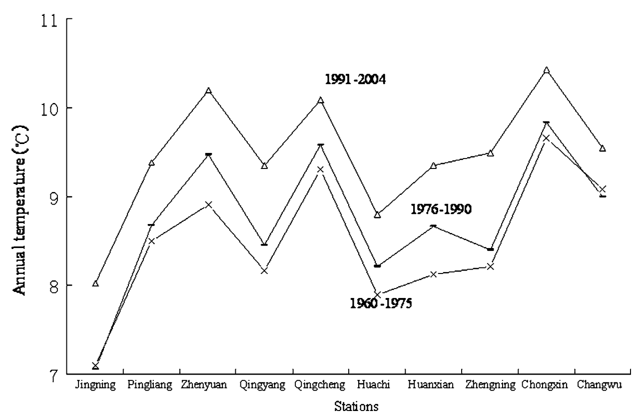

Fig. 6 Annual temperature at ten stations

Driving factors of eco-environmental changes

Eco-environmental changes, are affected by landform, soil, climate, and water conditions, as well population and socioeconomic development. The continuously increasing temperature and decreased precipitation (Table 7, Figs. 6,

Table 7 Temperature and precipitation at ten stations

	1961–1975		1976–1990		1991–2004	
	Average annual temperature (°C)	Average annual precipitation (mm)	Average annual temperature (°C)	Average annual precipitation (mm)	Average annual temperature (°C)	Average annual precipitation (mm)
Jingning	7.10	491.4	7.06	449.6	8.03	402.8
Pingliang	8.50	547.1	8.67	495.5	9.38	481.4
Zhenyuan	8.91	568.7	9.47	492.8	10.20	463.6
Qingyang	8.17	597.7	8.45	548.3	9.35	514.8
Qingcheng	9.30	562.6	9.58	507.4	10.08	499.2
Huachi	7.89	504.6	8.21	491.4	8.80	476.4
Huanxian	8.12	466.0	8.66	430.7	9.35	415.4
Zhengning	8.21	645.7	8.40	625.5	9.49	593.7
Chongxin	9.66	580.6	9.83	515.5	10.43	476.1
Changwu	9.08	611.0	8.99	594.5	9.54	548.7

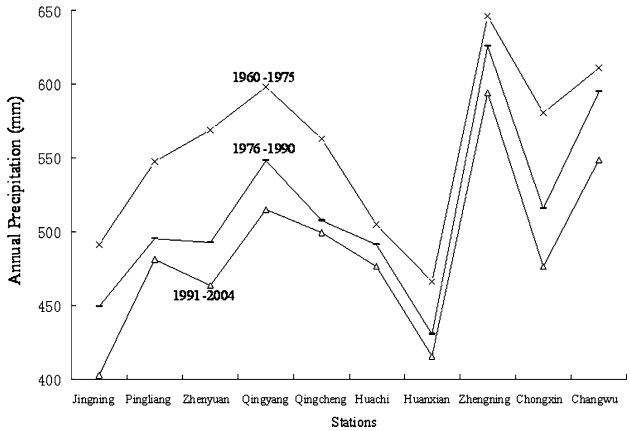

Fig. 7 Annual precipitation at ten stations

7), together with severe soil erosion, have led to ecological deterioration in the study area. Drought, vegetation degradation, soil erosion, topographic dissection, moving sand encroachment, and densification are increasingly exacerbated.

Rapid population growth (Table 8), intensified development of agriculture and animal husbandry. Severe deforestation and overgrazing of grassland led to the desertification of impoverished land (Wang et al. 2006). Unmonitored water resource allocation altered the local hydrological balance and engineering construction destroyed land vegetation (Wang et al. 2006). All these processed increased regional environmental deterioration. With the implementation of ecological restoration projects, some changes favorable to the eco-environment also occurred. Some farmlands were transformed into forest land and grassland, grasslands were transformed into forest land, and sloping croplands were transformed into terrace fields. When surface vegetation is restored to some degree, erosion intensity of heavy rain is reduced, soil loss is decreased, and a reversing trend occurs.

The combined actions of natural factors and human activities work together to control the regional ecological landscape.

Table 8 Human activities and socioeconomic developed level

	Total population (10^4)	Density of population (per km^2)	Rural population (10^4)	Urban population (10^4)
1984	369.45	96.43	349.85	19.60
2004	479.08	125.05	418.44	61.18
Change	109.63	28.62	68.59	41.58
Percent (%)	29.67	29.68	19.61	212.14

Discussion and conclusions

The use of satellite RS and GIS techniques to detect and analysis the eco-environmental change in the Longdong region was generally successful. The man-machine interactive interpretation method coupled with GIS technique has demonstrated its ability to provide comprehensive information on eco-environmental changes. The transition matrix of eco-environmental changes proved useful in monitoring and analyzing the dynamic eco-environmental directional changes in the semiarid area of the Chinese Loess Plateau.

Under the effects of regional warming and decreased precipitation, the region's eco-environment has been getting worse since the mid-1980s. Environmental aridification and vegetation degradation have been exacerbated. Already broken terrain became even more fragmentized due to water erosion- induced dissection and gulling. The arid-climate boundary moved southward, and land desertification increased. Due to lack of environmental awareness, seeking instant benefits, developing economy at the expanse of the environment, uncontrolled removal of vegetation in the economic construction, over-cutting, and over-reclamation, the erosion of loose loessial soil in the region accelerated.

It is important to weigh the contradictions between resource use and the harmonious development of society and environment to protect the function of the regional ecosystem. Restoration of the ecosystem and elimination of poverty in the region with such a fragile ecosystem are a long-term process. Some plans to solve the conflicts may inhibit the region's economic development in a short period of time or even cause rebound of poverty, but considered from a long-term point of view, preserving the regional ecosystem and maintaining its functions are the only sure foundation for the region's long-term sustainable development.

Following implementation of ecological rehabilitation projects, including reestablishing vegetation, and building terrace fields in Jingning County and Qingcheng County, local eco-environmental conditions were preliminarily improved, vegetation restored, water erosion, and gravitational erosion were brought under control. To encourage prevention and amelioration, public awareness of eco-environment conservation must be increased, proper management plans developed, wise use of natural resources increased, and eco-engineering analysis used to decrease land use disasters. Scientific monitoring and forecasting systems for eco-environmental planning, dynamic analysis, and environmental protection should be encouraged to find methods for restoration of ecosystems in the semiarid region.

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References

Apan AA, Raine SR, Paterson MS (2002) Mapping and analysis of changes in the riparian landscape structure of Locker Valley catchment, Queensland, Australia. Landsc Urban plan 59(1):43–57

Ayad YM (2005) Remote sensing and GIS in modeling visual landscape change: a case study of the northwestern arid coast of Egypt. Landsc Urban Plan 73(4):307–325

Baret F, Guyot G (1991) Potentials and limits of vegetation indices for LAI and APAR assessment. Remote Sens Environ 35(2–3):161–173

Bocco G, Mendoza M, Velázquez A (2001) Remote sensing and GIS-based regional geomorphological mapping-a tool for land use planning in developing countries. Geomorphology 39(3–4):211–219

Bricaud A, Bosc E, Antoine D (2002) Algal biomass and sea surface temperature in the Mediterranean basin: intercomparison of data from various satellite sensors, and implications for primary production estimates. Remote Sens Environ 81(2–3):163–178

Brivio PA, Giardino C, Zilioli E (2001) Determination of chlorophyll concentration changes in Lake Garda using an image-based radiative transfer code for Landsat TM images. Int J Remote Sens 22(2–3):487–502

Carper WJ, Lilesand TW, Kieffer RW (1990) The use of intensity-Hue-Saturation transformation for merging SPOT panchromatic and multispectral image data. Photogramm Eng Remote Sens 56(4):459–467

Chavez PS, Sildes SC, Anderson JA (1991) Comparison of three different methods to merge multiresolution and multispectral data: landsat TM and SPOT panchromatic. Photogrammetric Eng Remote Sens 57(3):295–303

Chen L, Wand J, Fu BJ, Qiu Y (2001) Land-use change in a small catchment of northern Loess Plateau, China. Agric Ecosyst Environ 86(2):163–172

Chen X (2002) Using remote sensing and GIS to analysis land cover change and its impacts on regional sustainable development. Int J Remote Sens 23(1):107–124

Committee of Pingliang's Chorography (1997) Chorography of Pingliang. Lanzhou University press, Lanzhou (in Chinese)

Committee of Qingyang's Chorography (1998) Chorography of Qingyang. Lanzhou University press, Lanzhou (in Chinese)

Dai YL, Wen TM (2000) Study on soil and water conservation and ecological environment construction in Loess Plateau. Sci Tech Inf Soil Water Conserv 2:32–35 (in Chinese with English abstract)

Deng ZY, Qiu HM, Li HD (2000) Climate and agricultural development in Longdong District. Meteorologic, Bejing (in Chinese)

Dong YH, Forster B, Ticehurst C (1997) Street orientation detection and recognition in Landsat TM and SPOT HRV imagery. Pattern Recognit Lett 18(8):759–769

Fu BJ, Chen LD, Ma KM Zhou HF, Wang J (2000) The relationships between land use and soil conditions in the hilly area of the loess plateau in northern Shanxi, China. Catena 39(1):69–78

Fu BJ, Hu CX, Chen LD, Honnay O, Gulinck H (2006) Evaluating change in agricultural landscape pattern between 1980 and 2000 in the Loess hilly region of Ansai County, China. Agric Ecosyst Environ 114(2–4):387–396

Germino MJ, Reiners WA, Blasko BJ, McLeod D, Bastian CT (2001) Estimating visual properties of rocky mountain landscapes using GIS. Landsc Urban Plan 53(1–4):71–83

Huang Z, Liu N, Zhou T, Ju B (2005) Effects of environmental factors on the population genetic structure in chukar partridge (Alectoris chukar). J Arid Environ 62(2):427–434

IPCC (2001) Climate change 2001. In: Houghton JH et al (eds) The scientific basis, contribution of working Group I to the third assessment report of the interginnmental panel on climate change. Cambridge University Press, Cambridge

Kamel S, Christophe F, Guerric le M Dantec LV, Dufrêne E (2006) Comparative analysis of IKONOS, SPOT, and ETM+ data for leaf area index estimation in temperate coniferous and deciduous forest stands. Remote Sens Environ 102(1–2):161–175

Kimura R, Liu Y, Takayama N, Zhang X, Kamichika M, Matsuoka N (2005) Heat and water balances of the bare soil surface and the potential distribution of vegetation in the Loess Plateau, China. J Arid Environ 63(2):439–457

Li ST, Kwok JT, Wang YN (2002) Using the discrete wavelet frame transform to merge Landsat TM and SPOT panchromatic images. Inf Fusion 3(1):17–23

Li X, Lu L, Cheng GD, Xiao HL (2001) Quantifying landscape structure of the north of Heihe River Basin, northwestern China using FRAGSTATS. J Arid Environ 48(4):521–535

Li YY, Shao MA (2006) Change of soil physical properties under long-term natural vegetation restoration in the Loess Plateau of China. J Arid Environ 64(1):77–96

Li Z, LI X, Wang Y, Ma A, Wang J (2004) Land-use change analysis in Yulin prefecture, northwestern China using remote sensing and GIS. Int J Remote Sens 25(2):5691–5703

Liu XM, Rolph T, Bloemendal J (1995) Quantitative estimates of palaeoprecipitation at Xifeng, in the Loess Plateau of China. Palaeogeogr Palaeoclimatol Palaeoecol 113(2–4):243–248

Liu Z, Huang F, Li L, Wan E (2002) Dynamic monitoring and damage evaluation of flood in north-west Jilin with remote sensing. Int J Remote Sens 23(18):3669–3679

Masoud AA, Koike K (2006) Arid land salinization detected by remotely-sensed landcover changes: a case study in the Siwa region, NW Egypt. J Arid Environ 66(1):151–167

Meng Q (1997) Soil and water conversation in Loess Plateau. Huanghe Hydraulic, Zhengzhou (in Chinese)

Onori E, Bonis PD, Grauso S (2006) Soil erosion prediction at the basin scale using the revised universal soil loss equation (RUSLE) in a catchment of Sicily (southern Italy). Environ Geol 50(8):1129–1140

Qin Z, Li W, Burgheimer J, Karnieli A (2006) Quantitative estimation of land cover structure in an arid region across the Israel–Egypt border using remote sensing data. J Arid Environ 66(2):336–352

Renard KG, Freimund JR (1994) RUSLE revisited: status, question, answer, and the future. J Soil Water Conversation 49(3):213–220

Shi ZH, Cai CF, Ding SW, Li ZX, Wang TW (2002) Soil conservation planning at small watershed level using GIS-Based revised universal soil loss equation (RUSLE). Trans Chin Soc Agric Eng 18(4):172–175 (in Chinese with English abstract)

Tang KL, Wang BK, Zheng FL, Zhang SL (1994) Effect of human activities on soil erosion in the Loess Plateau. Yellow River 2:13–17

Tang KL, Xiong GS, Liang JY (1993) Varieties of erosion and runoff sediment in Yellow River Basin. Chinese Sciences and Technique Press, Beijing (in Chinese)

Turner MG (1989) Landscape ecology: the effect of pattern on process. Annu Rev Ecol Syst 20:171–197

Wang J, Fu B, Qiu Y, Chen L (2001) Soil nutrients in relation to land use and landscape position in a semi-arid small catchment in the Loess Plateau in China. J Arid Environ 48(4):537–550

Wang JH, Feng YS (1991) The edit principle and denotation of remote sensing map in Gansu and Qinghai. Science press, Beijing (in Chinese)

Wang JH, Qi Y, Tang H (2003) Dynamic analysis of the eco-environment in Hexi Aisle based remote sensing and GIS. In: Pan X, Gao W, Glantz MH, Honda Y (eds) Ecosystem Dynamics, Ecosystem-Society Interaction, and Remote Sensing Application for Semi-Arid and Arid Land. Proceedings of SPIE, vol 4890. Bellingham, USA, pp 838–843

Wang MX, Liu GD, Wu WL, Bao YH, Liu WN (2006) Prediction of agriculture derived groundwater nitrate distribution in North China Plain with GIS-based BPNN. Environ Geol 50(5):637–644

Wei Z, Gao P (1992) A study on the relation between soil erosion and nutrients loss on cultivated land in the loess plateau. In: Wang FE (ed) Soil erosion management and GIS application in the Loess area of the Western Shanxi Province. Sciences Press, Beijing (In Chinese)

Xu JX (1994) The zonality characteristic of erosion and sediment yield on river basin in China. Chin Sci Bull 39(11):1019–1022 (in Chinese with English abstract)

Xu XM (2005) Current ecological environment situation of semi-arid area of the Loess Plateau in Longdong and countermeasure should be taken. Gansu Agric Sci Tech 1:18–20 (in Chinese with English abstract)

Yadav AS, Gupta SK (2006) Effect of micro-environment and human disturbance on the diversity of woody species in the Sariska tiger project in India. For Ecol Manage 225(1–3):178–189

Zhang QJ, Fu BJ, Chen LD (2004) Dynamics and driving factors of agricultural landscape in the semiarid hilly area of the Loess Plateau, China. Agric Ecosyst Environ 103(3):535–543

Zhang XC, Liu WZ (2005) Simulating potential response of hydrology, soil erosion, and crop productivity to climate change in Changwu tableland region on the Loess Plateau of China. Agric For Meteorol 131(3–4):127–142

Zhao CY, Nan ZR, Feng ZD (2004) GIS-assisted spatially distributed modeling of the potential evapotranspiration in semi-arid climate of the Chinese Loess Plateau. J Arid Environ 58(3):387–403

Zhu ZD, Wu Z, Liu S, Di XM (1992) Chinese desertification and its retrieval. Chinese environment science press, Beijing (in Chinese)