Land-use change in a small catchment of northern Loess Plateau, China

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Abstract

In China, the new land policy “household responsibility system”, implemented since late 1970s and early 1980s, has advanced China’s agriculture and led to some changes in land-use structure. In this study, land-use change due to this land policy in a small catchment of the Loess Plateau, northern Shaanxi province, China, was studied by an interpretation of two aerial photographs (1975 and 1997). The land-use pattern in 1975 and 1997 was studied by various pattern measures: areal percentage, patch number per unit area, mean patch area, landscape diversity, fractal dimension and relative land-use suitability index. The results indicated that after implementation of the new land policy, the area percentage of terrace farmland, slope farmland, sparse woodland and bushland decreased obviously, while the area and the percentage of dense woodland, orchard and sparse wild grassland increased. Mean patch size of terrace farmland, dense woodland, bushland and sparse wild grassland became larger, while mean patch size of slope farmland, sparse woodland and orchard became smaller. Fractal dimension analysis indicated that, compared with 1975, the patch shape of orchard and slope farmland was becoming complex, while the patch shape of dense woodland, sparse woodland, bushland terrace farmland and sparse wild grassland was becoming more regular. Based on land-use suitability evaluation by calculating the *R*-value, the present land-use structure appears to be suitable. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Land-use change; Land policy; Household responsibility system; Loess Plateau; China

1. Introduction

Land-use and land cover change can play a pivotal role in environmental changes and contribute to global change (Dale, 1997; Imbernon, 1999; Li, 1996; Meyer and Turner, 1991). Changes in land-use and land cover have important consequences for natural resources through their impacts on soil and water quality, biodiversity, and global climatic systems (Houghton et al., 1991; Houghton, 1994; Turner et al., 1995).

Land-use and land cover change are particularly related to increase of population and intensive agriculture (Verburg et al., 1999). Land cover modification and conversion are driven by the interaction in space and time between biophysical and human dimensions (Turner et al., 1993, 1995; Skole et al., 1994). With the awareness of the importance of land-use change on global change, the study of regional or global land-use and land cover change has become the focus of much scientific endeavor and international organizations (Turner et al., 1993; UNEP-EAPAP, 1995). Since 1995, several projects have been carried out on land-use/cover change and its driving force (e.g. US-SGCR/CENR, 1995; Otsubo, 1994).

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The Loess Plateau, as one of the areas of the most serious soil erosion in the world, receives a lot of attention from the Chinese government and international society (Yang and Yu, 1992; Lu et al., 1997; Jiang, 1997; Wu and Yang, 1998; BREST-CAS, 1992). Soil loss in most areas of the Loess Plateau reaches 5000–10,000 Mg km⁻² per year, and in some areas, it is even higher than 20,000 Mg km⁻² per year (Chen and Luk, 1989; Jiang, 1997; Wu and Yang, 1998). The most important reason for soil erosion on the Loess Plateau is irrational land-use and low vegetation coverage (Fu, 1989; Fu and Gulick, 1994; Jiang, 1997). However, about 2000 years ago, the population density in Loess Plateau was only about 13 persons per kilometer square, most areas were covered by forest and grassland and little soil erosion was induced (COSTLOP-CAS, 1991). With the increase of population in China, many people moved to the Loess Plateau and forest cover was reduced rapidly, which resulted in increasing soil erosion. The present name of ‘yellow river’ did not appear until 1400 years ago when the river water becoming turbid (COSTLOP-CAS, 1991). The serious soil erosion causes land to be less fertile and therefore, more areas need to be reclaimed to sustain the population growth. At present, the population density of the Loess Plateau is about 144 persons per kilometer square (Wu and Yang, 1998) and the forest coverage is only 9.47% and many areas are used for agricultural purposes (Jiang, 1997).

The objectives of this study were: (1) to identify land-use change within two typical periods in a small catchment in northern Loess Plateau by aerial photograph interpretation; (2) to analyze the relationships between land-use and natural landscape factors and (3) to analyze the influence of land policy on land-use structure.

2. Materials and methods

2.1. The study area

Danangou catchment, the case study area, is located in An'sai county, Yan'an area, Shaanxi province in the northern part of the Loess Plateau, within 36°54'–36°56'N and 109°16'–109°18'E geographically and covering about 3.9 km². Mean annual

precipitation is about 522 mm (1956–1990) and the maximum annual rainfall recorded is about 958 mm (1964), while the minimum precipitation recorded is about 297 mm (1974). Around 75% of the rainfall occurs during summer (June to September) and annual variation rate is up to 74.5%. Annual average temperature is 9°C and it is –8°C in January and +22°C in July. The study area belongs to the loess hilly area where soil erosion is much higher than that in the southern part of the Loess Plateau. Due to serious soil erosion, the ground surface has been incised strongly with rill and gully erosion. Soil in the study area has been developed from loess, and is characterized by a loose texture and high erodibility. Based on the soil map of the world (FAO-UNESCO, 1974), the soils in this part of the Loess Plateau, orientated in a southwest/northeast belt, are classified as calcic cambisols. Land-uses in this area comprise slope farmland, terrace farmland, orchard, bushland, woodland, traffic land, residential land and sparse wild grassland. Crops cultivated in this area are millet (*Panicum miliaceum*), maize (*Zea mays* L.), sorghum (*Sorghum* spp.), beans (*Vigna angularis* Wight.), potato (*Solanum tuberosum* L.) and bucket wheat (*Avena* spp.). Little natural vegetation can be observed and most of the area is covered by secondary vegetation under human influence. There is very little run-off during the dry season but a high run-off during the rainy season.

There are two villages in the study area, named Danangou and Leipingta. Leipingta village is situated in the upper part with 85 inhabitants in 15 families, and Danangou village is located at the outset of the catchment with 105 inhabitants in 23 families. The residential areas for local farmers are usually dispersed on a gentle hill-slope and cannot be delineated on a land-use map with an individual polygon. Apart from many small tracks spotted in field, there is only one road connecting Leipingta and Danangou villages (Fig. 1).

The history of the catchment can be broadly divided into three periods: before the liberation in 1949, after the liberation until the introduction of the “household responsibility system” in 1981, and after 1981. In the first period before 1949, a limited number of people lived in this area and most land was in the hand of landlords, from whom the local farmers had to rent land. Due to low yields, many areas were reclaimed as farmland.

Fig. 1. Location and general situation of the study area (shadow map) in the northern Loess Plateau, China.

The second period is characterized by the communal *farms*, when the land of individual farmers was collected as common land of the community. All the land was managed by the community and used based on state policy. The establishment of a commune was a process of increased collectivization through cooperation, which happened in 1956. This can be called the first land reform in the catchment.

At the end of 1978, it was decided at the national level to resolve the communes and again distribute land-use rights to individual farmers. This is called the “household responsibility system” (the second land reform). The introduction of this system in China started in 1979 and was completed in 1984. In study area, this system was introduced in 1981. After the second land reform, two minor reallocations of land ownership were undertaken in 1992 and 1995 due to the emigration of people. Because of data limitations for the first period, this study is mainly focused on the influence of land policy on land-use structure within the second and the third period.

In the study area, woodland coverage was the largest in history before 1958 and dropped to a minimum in

1958 due to the “great leap forward” movement. In early 1960s, it rose again by community activities after the establishment of communes, however, during late 1960s and 1970s, it declined due to wood harvesting during the “cultural revolution”. After the second land reform in 1981, the woodland area increased steadily. This was attributed to the land policy change. During the commune period, all the trees belonged to the community and nobody took care of them. In many cases, the local farmers were reluctant to report the occurrence of woodland destruction since it would not benefit themselves. After the second land reform, most trees were assigned to farmers and a new policy, “who plants, who owns” was adopted. To plant new trees in sparse wild grassland is encouraged.

2.2. Data source

In this study, two sets of aerial photographs (1975 and 1997) are collected for studying land-use change that reflects the consequences of two land reforms carried out in 1956 and in 1981, respectively. A hard copy of the aerial photographs with scale of

1:10,000, taken in October, 1975 with a camera focus of 114 mm, and a hard copy of the aerial photographs with scale of 1:35,000 taken in October, 1997 with a camera focus of 153.17 mm were available for study.

A topomap with scale 1:10,000 made in 1998 by the photogrammetry bureau of Shaanxi province, China was available. The digital form of this map was used to analyze the relationship between land-use and natural landscape factors.

Questionnaires and field investigations were carried out among the farmers in 1998 and 1999 for collecting data on land-use change, land policy, population and economic income. The major purpose was to have a general understanding on: (1) the change of farmland area and woodland area; (2) the history of land policy change; (3) the exact time and how the land reform was carried out during late 1970s and early 1980s; (4) the population dynamic and land reallocation after people emigration and (5) the community activities of the catchment, such as building terrace and dam. This survey was mainly carried out among the elder people and village leaders, since they are familiar to the history of the village and land-use change.

2.3. Interpretation of aerial photographs and data processing

Before the interpretation of the aerial photographs, a land-use reconnaissance was carried out in May 1998,

by which a general understanding of the land-use situation of the study area was obtained. Land-use within the study area was classified into eight domains: (1) slope farmland; (2) terrace farmland; (3) check-dam (flat land behind a dam, which is formed when a small reservoir is filled up with silt deposit and normally used for agriculture) farmland; (4) dense woodland (coverage is higher than 60%); (5) sparse woodland (coverage is about 30–60%); (6) bushland; (7) orchard and (8) sparse wild grassland. Based upon this land-use classification, an interpretation of the aerial photographs was made, which resulted in two draft land-use maps of 1975 and 1997, respectively. A field check was carried out in July 1999 to improve the accuracy of land-use map of 1997. Considering the scale difference of two aerial photographs, the two land-use maps were updated and transferred manually to the digital topomap of scale 1:10,000 (Fig. 2) for further data processing and analysis (ITC, 1999).

2.4. Statistical analysis

For comparing the land-use structure in this study between the two periods, measures such as area, areal percentage and patch number per land-use type were calculated using statistics. Based on these data, the following indicators are employed to analyze land-use change.

- Patch numbers per unit area (Pt, how many patches within 1 ha), is a simple parameter to describe landscape fragmentation from catchment scale.

Fig. 2. Land-use maps of the study area derived by aerial photo interpretation.

Table 1
Weight of different land-use types for relative land-use suitability evaluation

Slope section (°)	Check-dam farmland	Slope farmland	Terrace farmland	Orchard	Bushland	Sparse woodland	Dense woodland	Sparse wild grassland
0	1.0	1.00	1.00	1.00	1.00	1.0	1.00	0.50
0–3	1.0	1.00	1.00	1.00	1.00	0.75	1.00	0.50
3–8	0.75	0.75	1.00	1.00	1.00	0.50	1.00	0.50
8–15	0.50	0.50	0.75	0.75	1.00	0.50	1.00	0.50
15–25	0.25	0.25	0.50	0.50	1.00	0.50	1.00	0.50
>25	0.0	0.00	0.25	0.25	1.00	0.50	1.00	0.50

- Mean patch area of different land-use types (P_a), was used for studying change of patch size within different land-use types.
- Diversity (H): based on the information, Shannon and Weaver (1949) developed diversity dominance for describing information change. O'Neill et al. (1988) applied them for landscape pattern analysis. It has been widely used in landscape pattern analysis (Turner et al., 1987; Hobbs and Huenneke, 1992; McGarigal and Marks, 1994; Baskent and Jordan, 1995; Rescia et al., 1995; Fu and Chen, 2000). It can be calculated with the following formula

$$H = - \sum_{i=1}^m P_{c_i} \times \log(P_{c_i}) \quad (1)$$

where, H is landscape diversity, P_{c_i} the percentage of i th land-use types within the total area and m the number of land-use types. The more diverse the landscape is, the bigger the value.

- Fractal dimension (S) was used as a measure of patch shape complexity (Mandelbrot, 1982). The fractal dimension has been employed widely in landscape studies (Lovejoy, 1982; Olsen et al., 1993; Turner and Ruscher, 1988; Leduc et al., 1994; Fu and Chen, 2000). It can be described by the following equation.

$$S = \frac{2 \ln(P_r/4)}{\ln(A_i)} \quad (2)$$

where S represents fractal dimension value, A_i and P_r the area and perimeter of i th land-use type.

- Relative land-use suitability index (R), which is mainly used to reflect the suitability of land-use structure. R will be higher if most current land-use types are situated in suitable place, otherwise it will be lower. In this study, the R -value was calculated

taking soil erosion into account. Suppose that, if the land-use type is in favor of reducing soil erosion, the weight of that land-use type will be higher when calculating the R -value. Since the slope degree is one of the important factors to influence soil erosion, it was used as a basis to evaluate land-use suitability. The weight for land-use suitability is given in Table 1 based on standards for classification and gradation of soil erosion published by Ministry of Water Resources of China (BOWASC-MOWR, 1997, China). The relative land-use suitability can be derived by using the following formula.

$$R = \frac{\sum_{j=1}^n \sum_{i=1}^m P_{c_{ij}} \times w_{ij}}{n} \quad (3)$$

where R is the value of land-use suitability, $P_{c_{ij}}$ the areal percentage of i th land-use type within j th slope sections, w_{ij} the weight of suitability of j th slope section to i th land-use type and varies among 0–1 (see Table 1), where 1 means most suitable and 0 means unsuitable, m the total number of land-use types and n the number of slope groups. The value of R will change within 0–1. The bigger the R -value is, the more suitable the land-use structure. When the value of R reaches 1, it implies the land-use structure reaches the best situation.

3. Results

3.1. Statistical results

Table 2 displays area, percentage, number of patches, mean patch area and fractal dimension of different land-use types in 1975 and 1997. Slope farmland and sparse wild grassland were the two

Table 2
Statistic of land-use types and landscape pattern analysis in 1975 and 1997

Land-use type	Patch number (Np)	Perimeter (Pr) (m)	Area (A) (ha)	Percentage (Pc) (%)	Mean patch area (Pa) (ha)	Fractal dimension (S)	Diversity ^a (H)	LFI ^b	R-value (R)
1975									
Dense woodland	6	3135.4	5.0	1.3	0.8	1.23	—	—	—
Sparse woodland	6	6888.3	21.9	5.6	3.6	1.21	—	—	—
Bushland	4	3391.7	6.8	1.8	1.7	1.21	—	—	—
Orchard	2	1810.2	4.4	1.1	2.2	1.14	—	—	—
Check-dam farmland	1	976.6	1.6	0.4	1.6	1.13	—	—	—
Terrace farmland	4	2895.3	13.3	3.4	3.3	1.12	—	—	—
Slope farmland	19	45560.8	155.5	40.1	8.2	1.31	—	—	—
Sparse wild grassland	6	36720.7	179.3	46.2	29.9	1.27	—	—	—
Total	48	101379	387.7	100	8.1		0.52	0.12	0.58
1997									
Dense woodland	8	7572.3	32.8	8.5	4.1	1.19	—	—	—
Sparse woodland	5	4154.4	15.4	4.0	3.1	1.16	—	—	—
Bushland	1	1202.3	3.9	1.0	3.9	1.08	—	—	—
Orchard	4	2518.5	6.9	1.8	1.7	1.16	—	—	—
Check-dam farmland	0	0	0	—	—	—	—	—	—
Terrace farmland	1	1425.0	6.7	1.7	6.7	1.06	—	—	—
Slope farmland	31	47939.0	137.2	35.4	4.4	1.33	—	—	—
Sparse wild grassland	2	24290.5	184.7	47.7	92.4	1.21	—	—	—
Total	52	89102.0	387.7	100	7.5		0.54	0.13	0.60

^a Landscape diversity is only used to describe the richness and diversity of land-use types from catchment scale other than for individual land-use type.

^b LFI represent landscape fragmentation index (patch number per unit area).

Table 3

The percentage of different land-use types in different slope sections in 1975 and 1997

Slope degree (°)	Dense woodland	Sparse woodland	Bushland	Orchard	Slope farmland	Terrace farmland	Check-dam farmland	Sparse wild grassland
1975								
0	0.5	0.9	0.7	0.9	1.4	0.8	10.2	0.9
0–3	2.6	3.0	2.0	12.3	3.0	28.7	6.7	1.6
3–8	17.4	11.6	5.7	21.7	13.4	36.6	15.7	4.2
8–15	35.2	26.7	24.0	38.2	33.5	25.6	32.2	19.0
15–25	29.6	30.5	38.5	17.0	32.4	7.4	19.9	34.7
>25	14.8	27.2	29.2	10.0	16.3	1.0	15.3	39.6
1997								
0	0.3	0.1	0.1	0.3	1.7	1.1	0	1.1
0–3	1.8	0.7	0.2	7.1	3.5	46.0	0	1.8
3–8	11.2	4.1	1.7	16.3	14.8	34.8	0	4.6
8–15	23.2	17.6	31.4	32.5	36.2	13.7	0	18.7
15–25	32.6	37.3	46.1	26.7	31.3	3.5	0	33.9
>25	30.9	40.2	20.5	17.2	12.5	0.9	0	40.0

largest land-use types in this area, both in 1975 and in 1997. Slope farmland took up 40.1 and 35.4% of the total area, and sparse wild grassland was 46.2 and 47.7%, respectively, of the total area in 1975 and 1997. Significant difference for mean patch area remained for different land-use types and the largest patch size was found for sparse wild grassland both in 1975 and 1997. However, the smallest one for mean patch area was woodland in 1975 and orchard in 1997. The fractal dimension for slope farmland was the largest, while it was the least for terrace farmland both in 1975 and 1997.

Table 3 shows the relationship between land-use types and slope degree. Dense woodland, sparse woodland and bushland were mainly distributed in the area above 8°, where these land-use types take up 79.6, 84.5 and 91.7% in 1975; and 86.7, 95.1 and 98% in 1997 of the total area. Apart from an increase in orchard in the area above 8°, there are also many orchards distributed in areas with slope degree between 0 and 8°. Most slope farmland was located in the area above 3°, but the area percentage of farmland above 25° was much lower compared with sparse woodland and bushland. Most terrace farmland was distributed in the slope area within 0–15°. As the largest land-use type in this area, the area of sparse wild grassland increased with increasing slope degree.

Some land-use types were distributed randomly in regard to slope aspect, for example, dense woodland,

sparse woodland, slope farmland, check-dam farmland and sparse wild grassland. In both periods, orchard, terrace farmland and bushland had some preference to slope aspects.

There were some changes on land-use structure. Landscape fragmentation (patch number per unit area) of the study area increased from 0.12 in 1975 to 0.13 in 1997, and landscape diversity index increased from 0.52 to 0.54. The relative land-use suitability index increased from 0.58 in 1975 to 0.60 in 1997.

4. Discussion

4.1. Land-use change from 1975 to 1997

Compared with 1975, the area of slope farmland in 1997 decreased (Table 2), especially in the steep areas above 8° where a large reduction was found. In both years, the slope farmland was distributed randomly regardless of slope aspects. This was greatly affected by the local farmers' preference. Crops planted on the sun-facing slopes produce well in wet or normal years but not in dry years. However, in dry years, the crops planted in the sun-shading slope are usually more productive than that in sun-facing slope. Therefore, the local farmers were willing to spread crops on both sides of the hills to ensure adequate production under unpredictable weather conditions.

An interesting phenomenon is that terrace farmland decreased 6.6 ha from 1975 to 1997. Before the second land reform, the community leaders were able to organize the village (or communities) labors-force for some large agricultural projects, such as constructing dams and reservoirs, building terraces and planting trees. After that, most lands were contracted by individual farmers and most agricultural activities were undertaken in small groups. Even though the local farmers would like to build more terraces for agricultural use, it was difficult for them due to budget and labor deficits. With the destruction of old terraces by soil erosion, or by livestock and human activities, the area of terrace farmland decreased quickly. Due to this, there was an absence of check-dam farmland in 1997. A disrepaired dam was observed. This dam was built in 1960s and destroyed in late 1970s by flooding. After the second land reform, no more new dams are built.

From 1975 to 1997, the area of dense woodland increased from 5 to 32.8 ha and the area of sparse woodland and bushland declined. This was greatly related to the land policy change.

The area of orchard changed from 4.4 to 6.9 ha from 1975 to 1997. During the commune period, some off-farm works, such as fruit tree planting and livestock breeding were not encouraged even though they were helpful to raise income. Most land had to be used as farmland for planting crops. After the second land reform, most lands were distributed to the farmers and the lands were used according to farmers' choices. Since planting orchards could produce higher economic value than planting crops, many lands were converted into orchard. Furthermore, planting trees was encouraged by the government to avoid soil erosion.

Both in 1975 and in 1997, sparse wild grassland was larger than any land-use types. From 1975 to 1997, the area of sparse wild grassland increased about 5.5 ha. This reflects to some extent the influence of land policy change. Before 1980, the government reclaimed more land for agricultural use to produce more grain. But after the land was contracted to local farmers, the most important concern for farmers was economic benefits. Since planting crops on steep slope usually has a very low output, it was gradually discarded. Moreover, planting crops on sloping land was not welcomed by the government due to its high vulnerability to soil erosion.

4.2. Influence of landscape factors and policy on land-use

Slope degree has some impacts on human choices of land-use. For example, terrace farmland, slope farmland, check-dam farmland, and orchards which require more human input, were mostly distributed in the gentle sloping area. However, those land-use types that require little management, such as dense woodland, sparse woodland, bushland and sparse wild grassland were mostly distributed in steep areas (Table 3). On the other hand, there was no preference for slope aspect for the following land-use types: dense woodland, sparse woodland, slope farmland and sparse wild grassland. However, bushland, orchard, and terrace farmland showed a strong preference to slope aspect. This was probably caused by the soil moisture difference with slope aspect. For example, orchard was mostly distributed in the sun-facing slope since it requires more sunlight for good yield and high quality fruits.

It was found that the average patch area of terrace farmland, woodland, bushland and sparse wild grassland was larger in 1997 than in 1975, while it was smaller for slope farmland, sparse woodland and orchard (Table 2). After the second land reform, lands were divided into many small plots. This resulted in the mean patch area of those land-uses being closely associated with individual farmer's economic benefit, such as slope farmland and smaller orchards. The other land-use types had a larger patch size in 1997, than that in 1975. Additionally, it was found that the area of those land-use types which are favorable to soil erosion control increased. This was probably the consequence of environmental education and the improvement of public environmental awareness.

Fractal dimension reflected the change of patch shape. Its value changed from 1 to 2. Usually, a high fractal dimension means a complex patch shape, whereas a small value implies a regular patch shape. Compared with 1975, the value of fractal dimension of orchard and slope farmland was bigger in 1997, while the fractal dimension of dense woodland, sparse woodland, bushland, terrace farmland and sparse wild grassland was smaller than that in 1975 (Table 2). This implies that after the second land reform, the shape of slope farmland and orchard, which are more associated with human activities, was getting more complex and that the shape of the other land-use

Fig. 3. The relationship between relative land-use suitability and slope degree sections.

types which have been relatively less associated with human activities was getting regular.

At the same time, the patch number per unit area increased from 1975 to 1997, which infers that the study area was getting a bit more fragmented after the second land reform (Table 2). This may be because farmers had more free choices on land-use.

4.3. Evaluation on land-use suitability

Since the most important environmental problem on the Loess Plateau is soil erosion, an evaluation of relative land-use suitability was undertaken. Generally, a little improvement was made in land-use structure from 1975 to 1997 (Table 2). The *R*-value was small both in 1975 and in 1997. However, the *R*-value increased only 0.02 from 1975 to 1997 based on evaluation results. It indicates the land policy change and environmental propagation had produced some impact on land-use modification and conversion. Fig. 3 shows that the increase of relative land-use suitability index mainly resulted from the modification of land-use structure in the steep slope sections.

5. Conclusions

The slope degree has strong impact on the land-use structure due to labors and input requirements, which causes agriculture to be found in the flat or gentle sloping area mostly. On the contrary, most land-use types had no preference on slope aspect. The impact

of slope aspect on land-use types was considered to be mainly due to differences in soil moisture.

The land policy had some impacts on land modification. The land-use structure was getting more suitable after the land was contracted to individual farmers in the study area. Some land-use types which had low input-output benefit were gradually decreased. From this point of view, the new land-use system was better than the old. However, with the land contracted by the individual farmer, the agricultural activities that require a high degree of labor, such as dam building and terrace construction, were ignored. With the decrease of these conservative works, soil erosion will probably increase. This is the drawback of the new land system compared with the old 'commune system'.

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References

- Baskett, E.Z., Jordan, G.A., 1995. Characterizing spatial structure of forest landscapes. *Can. J. Forest Res.* 25, 1830–1849.
- BOWASC-MOWR, China (Bureau of Water and Soil Conservation, Ministry of Water Resources of China), 1997. Standards for Classification and Gradation of Soil Erosion. China Hydroelectricity Press, Beijing (in Chinese).
- BREST-CAS (Bureau of Resource, Environmental Science and Technology, Chinese Academy of Sciences), 1992. Development and Comprehensive Treatment on Small Catchment in

- Loess Plateau. China Science and Technology Literature Press, Beijing (in Chinese).
- Chen, Y.Z., Luk, S.H., 1989. Sediment sources and recent changes in the sediment load of yellow river, China. In: Rindwanich, S. (Ed.), *Land Conservation for Future Generations*. Proceedings of the 5th International Soil Erosion Conference, Ministry of Agriculture, Bangkok, Thailand, 18–29 January 1988. Department of Land Development, Bangkok, pp. 313–323.
- COSTLOP-CAS (Comprehensive Survey Team on Loess Plateau of Chinese Academy of Sciences), 1991. *The Natural Environmental Characteristics and Evolvement*. China Science and Technology Press, Beijing (in Chinese).
- Dale, V.H., 1997. The relationship between land-use change and climate change. *Ecol. Appl.* 7, 753–769.
- FAO-UNESCO, 1974. *Soil Map of the World (1:5,000,000)*. Food and Agricultural Organisation of the United Nations, UNESCO, Paris.
- Fu, B., 1989. Soil erosion and its control in the Loess Plateau of China. *Soil Use Manage.* 5, 76–82.
- Fu, B., Gulinck, H., 1994. Land evaluation in an area of severe erosion: the Loess Plateau of China. *Land Degradation Rehabilitation* 5, 33–40.
- Fu, B., Chen, L., 2000. Agricultural landscape spatial pattern analysis in the semi-arid area of the Loess Plateau, China. *J. Arid Environ.* 44, 291–303.
- Hobbs, R.J., Huenneke, L.F., 1992. Disturbance, diversity, and invasion: implications for conservation. *Conservation Biol.* 6, 324–337.
- Houghton, R.A., 1994. The worldwide extent of land-use change. *Bioscience* 44, 305–313.
- Houghton, R.A., Lefkowitz, D.S., Skole, D.L., 1991. Changes in the landscape of Latin-America between 1880 and 1985 I. Progressive loss of forests. *Forest Ecol. Manage.* 38, 143–172.
- Imbernon, J., 1999. Pattern and development of land-use changes in the Kenyan highlands since the 1950s. *Agric. Ecosyst. Environ.* 76, 67–73.
- ITC, 1999. *ILWIS 2.1 for windows — the integrated land and water information system (application guide)*. ILWIS Department, International Institute for Aerospace Survey and Earth Sciences (ITC), Enschede, The Netherlands.
- Jiang, D. (Ed.), 1997. *Soil Erosion and Control Models in the Loess Plateau*. China Hydroelectricity Press, Beijing (in Chinese).
- Leduc, A., Prairie, Y.T., Bergeron, Y., 1994. Fractal dimension estimates of a fragmental landscape: sources of variability. *Landscape Ecol.* 9, 279–286.
- Li, X., 1996. Core study area of global environmental change: perspective of land-use/cover. *Acta Geographica Sinica* 51, 553–557 (in Chinese).
- Lovejoy, S., 1982. Area–perimeter relation for rain and cloud area. *Science* 216, 185–187.
- Lu, Z., Liang, Y., Liu, G., 1997. *Ecological Agriculture in Loess Plateau, China*. Shaanxi Science and Technology Press, Xi'an (in Chinese).
- Mandelbrot, B.B., 1982. *The Fractal Geometry of Nature*. Freeman, New York.
- McGarigal, K., Marks, B., 1994. *FRAGSTATS: a spatial pattern analysis program for quantifying landscape structure v2.0*. Oregon State University, Corvallis (unpublished computer program user manual and guide).
- Meyer, W.B., Turner II, B.L., 1991. *Changes in Land-Use and Land Cover: A Global Perspective*. Cambridge University Press, Cambridge.
- Olsen, E.R., Ramsey, R.D., Winn, D.S., 1993. A modified factual dimension as a measure of landscape diversity. *Photogrammetric Eng. Remote Sensing* 59, 1517–1520.
- O'Neill, R.V., Krummel, J.R., Gardner, R.H., Sugihara, G., Jackson, B., DeAngelis, D.L., Milne, B.T., Turner, M.G., Zygmunt, B., Christensen, S.W., Dale, V.H., Graham, R.L., 1988. Indices of landscape pattern. *Landscape Ecol.* 1, 153–162.
- Otsubo, K., 1994. Towards land-use for global environmental conservation (LU/GEC) project. In: *Proceedings of the Workshop on Land-Use for Global Environmental Conservation*, Tsukuba, Japan.
- Rescia, A.J., Schmitz, M.F., Mattin de Agar, M.P., De Pablo, C.L., Pineda, F.D., 1995. Ascribing plant diversity value to historical changes in landscape: a methodological approach. *Landscape Urban Planning* 31, 181–194.
- Shannon, C.E., Weaver, W., 1949. *The Mathematical Theory of Communication*. University of Illinois Press, Urbana, IL.
- Skole, D.L., Chomentowski, W.H., Salas, W.A., Nobre, A.D., 1994. Physical and human dimensions of deforestation in Amazonia. *Bioscience* 44, 314–322.
- Turner, M.G., Ruscher, C.L., 1988. Changes in landscape pattern in Georgia, USA. *Landscape Ecol.* 1, 241–251.
- Turner, M.G., Billings, W.D., Golley, F., Lange, O.L., Olson, J.S., Remmert, H., 1987. *Landscape Heterogeneity and Disturbance (Ecological Studies 64)*. Springer, New York.
- Turner II, B.L., Ross, R.H., Skole, D., 1993. *Relating Land-Use and Global Land Cover Change (IGBP Report No. 24, HDP Report No. 5)*. IGBP of the ICSU and HDP of the ISSC, Stockholm and Geneva.
- Turner II, B.L., Skole, D., Sanderson, S., Fischer, G., Fresco, L.O., Leemans, R., 1995. *Land-Use and Land-Cover Change. Science/Research Plan (IGBP Report No. 35, HDP Report No. 7)*. IGBP of the ICSU and HDP of the ISSC, Stockholm and Geneva.
- UNEP-EAPAP, 1995. *Land Cover Assessment and Monitoring. Overall Methodological Framework and Summary, Vol. 1-A*. Bangkok, UNEP-EAPAP.
- US-SGCR/CENR, 1995. *Our Changing Planet, the FY 1995 US Global Change Research Program*. Washington, DC, USGCRIO.
- Verburg, P.H., Veldkamp, A., Bouma, J., 1999. Land-use change under conditions of high population pressure: the case of Java. *Global Environ. Change* 9, 303–312.
- Wu, Y., Yang, W. (Eds.), 1998. *Forest and Grassland Vegetation Construction and its Sustainable Development in Loess Plateau*. Science Press, Beijing (in Chinese).
- Yang, W., Yu, C., 1992. *Regional Treatment and Evaluation in Loess Plateau*. Science Press, Beijing (in Chinese).