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RESEARCH ARTICLE

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Optimization of land use pattern reduces surface runoff and sediment loss in a Hilly-Gully watershed at the Loess Plateau, China

Yini Han[1], Jianzhi Niu[1]*, Zhongbao Xin[1], Wei Zhang[2], Tielin Zhang[3], Xilin Wang[1],Yousong Zhang[1]

[1] *Key Laboratory of Soil and Water Conservation and Combating Desertification, School of Water and Soil Conservation, Beijing Forestry University, Beijing, China* [2] *Department of Plant, Soil and Microbial Sciences; Environmental Science and Policy Program, Michigan State University, East Lansing, Michigan, United States* [3] *Department of Water Resources Engineering, Lund University, 221 00 Lund, Sweden*

Abstract

Aim of study: The aim is to find a way increasing gain yield and lessen area of farmland, and then increasing vegetation cover, improving environment and alleviating soil erosion.

Area of study: The Hilly-Gully region at the loess plateau of China.

Material and methods: In this study, an adjusted and optimized land use pattern was developed in Luoyugou watershed in the Yellow River valley based on the gradient distribution of land use types, and its effect on water and sediment transport was simulated using the SWAT model and GIS, with remote sensing images, land use maps and hydrologic data.

Main results: The results indicate: average simulated runoff and sediment for the period 1986-2000 under conditions of the three land use pattern (2011, 2008 and optimized land use) reduced by 0.002-0.013 m^3/s (2.7-17.6%) and 0.66 million tons, respectively. The runoff and sediment data obtained were compared with observed data from 2008, which showed that runoff and sediment production would be reduced by 467625 m^3 and 22754 tons, respectively.

Research highlights: The adjustment of the land use pattern in comprehensive consideration of vegetation and geography have a positive effect on water and sediment transport which will be important for decision making and water resources management, and provides a reference for future environmental management and ecological construction in the loess plateau Hilly-Gully region.

Keywords: Land use pattern optimization; Luoyugou watershed; runoff and sediment transport; SWAT.

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Correspondence should be addressed to Jianzhi Niu: nexk@bjfu.edu.cn

Introduction

Globally, areas of soil erosion resulting from changes in land use are increasing (Bakker *et al.*, 2008; Deng *et al*., 2004; Fu *et al.*, 1999; LUCC, 1996). The main causes of watershed hydrologic features change are climate change and human activity (Asbjornsen *et al.*, 2011; Hörmann *et al.*, 2005; Huisman *et al.*, 2009; Kezer & Matsuyama, 2006). Climate change influences evapotranspiration form of underlying surface by changing atmospheric temperature and precipitation, and then, severe impacts internal water circulation. Anthropogenic influenced land use and land cover change transfer surface roughness and soil infiltration characteristics of underlying surface and then impact surface runoff and sediment, the formation of groundwater and space-time distribution of water resource. In summer, torrential rain occurs frequently at the loess area and the unreasonable exploitation makes soil erosion even worse. The global warming might significantly increase the soil erosion, and the regions with mismanaged land use pattern might face much more serious problems related to soil erosion (Yang *et al.*, 2003).

The Loess Plateau is the main sediment source of the Yellow River. 90% of the annual average 1.6 billion tons sediment is come from the Loess Plateau. The third sub-region of the Loess Plateau not only has the particularity of Hilly-Gully region, but also possesses its own characteristics. It is the most populous regions among all the Hilly-Gully regions, which caused huge demand of food and housing. Crop production and inhabitants' livelihood is as important as water and soil conservation. Slope cropland causes more serious soil erosion in any slope from the grading index of soil erosion intensity SL190-2007.

Studies on managemental practices in many regions have shown that adjustment of land use patterns is an approach to reducing losses of soil and water (Yang *et al.*, 2003). In 1995, two major international research programs (Chen & Yang, 2001), the IGBP (International geosphere biosphere) and the IHDP (International Human Dimensions Program) included studying of land use and land cover change (LUCC).

The relationship between landscape patterns and functions plays an important role in research of the effect of land use structure on water and sediment transportation (Wu, 2003). Small watersheds are often used as study areas for investigating the relationships between land use patterns and runoff and sediment deposition (Bi *et al.*, 2009; Wang *et al.*, 2008; Zhang, 2012) .

Land use can increase or reduce runoff and soil erosion (Fu *et al*., 2000; Trimble, 1999). In Europe, the relationships between the land use patterns and water and soil transportation at watershed scale under different conditions were investigated, such as erosion rates changed by 28% during a 50-year period in the Belgian Loam Belt, but with decreases as well as increases occurring (Van Oost *et al*., 2000). Although there were many uncertainties, differences in the land use pattern had a clear effect on runoff and sediment transportation; at the same time, the adjustment of land use plays an important role in controlling soil erosion events in small watersheds (Van Oost *et al*., 2000). The importance of land use pattern at a watershed scale was also illustrated in flood responses. The influence of land use change on storm-runoff was related to vegetation coverage, although it largely depended on the characteristics of rainfall events and their spatial scales (Niehoff *et al.*, 2002). It is considered that a decrease in forest cover that followed an increase in grassland amplified the peak flow rate, and thus increased the risk of flooding (Fohrer *et al.*, 2001). The difficulty in investigating the influence of land use on floods is highlighted in a study at a watershed scale in southwest England and pointed out that small-scale land use decisions could result in large-scale hydrological changes (Sullivan *et al.*, 2004).

In China, studies have been conducted on the relationships between land use patterns and runoff and sediment loss to search for an optimized structural configuration that would reduce soil erosion and conserve water resources. Hao showed that forest and grassland were able to increase runoff and reduce soil erosion in a downstream area of the Yellow River, while an increase of farmland area increased sediment yield (Hao *et al*., 2004). This result provided a base for future land use adjustment (Hao *et al.*, 2004). Wu attempted to adjust the type of land use at a landscape scale to achieve sustainable development of soil and water resources in the middle-upper Yangtze River (Xing & Zhenyao, 2007). Gao achieved a relatively optimized configuration by adjusting a characteristic index of land use based on GIS (Gao *et al.*, 2010). Chen took economic factors into consideration, using the iCLUE model in research into land use adjustment in North China (Chen *et al.*, 2008). Li introduced a land use structure characteristic index (e.g., SI) as a means of optimizing land use structure based on the response of water and sediment (Li *et al.*, 2004).

In recent years, the Soil and Water Assessment Tool (SWAT) has been widely used by global scientists and technical workers (Arnold & Allen, 1996; Eckhardt & Ulbrich, 2003; Panagopoulos *et al.*, 2011; Qiu *et al.*, 2012; Stolte *et al*., 2005; Zhang *et al.*, 2007). SWAT was developed by Dr Jeff Arnold of the Agricultural Research Service of the United States Department of Agriculture. The SWAT model is a distributed hydrological model based on physical processes. Integrating remote sensing (RS) and geographic information system (GIS) technology, the SWAT model has a friendly operational interface, with input data including a Digital Elevation Model (DEM), land use, soil type, climate, hydrology and nutrients, even simulating missing data. Hence it can be used to assess watershed hydrological processes, as well as non-point-source pollution with changes in land use patterns. It can also be used to conduct scenario design and analysis by adjusting the input data to set different land use or climate scenarios to simulate the influence of changing climate and land use on runoff, sediment and pollution loads (De Girolamo & Porto, 2012; Maximov, 2003).

Long-term irrational land use has led to water shortages, water and soil loss, poor soil quality, low agricultural production rates and low-income levels in the Loess Hilly-Gully Region of China (Wang & Jiao, 1996). There is an urgent need to find a reasonable and optimized land use pattern. Analyzing the relationship between this land use pattern optimization and runoff and sediment transport can help to improve the local land use management and living standards.

The objectives of this study include (i) applying an adjusted and optimized land use with its gradient distribution and the policy of the returning farmland to forest at a typical small watershed (the Luoyugou watershed in the Loess Hilly-Gully Region of China (Figure 1); (ii) using SWAT model to simulate the relationship between this land use pattern optimization and water and sediment reduction; and (iii) providing implications for future environmental management in the Hilly-Gully area at the Loess Plateau.

Material and methods

Study area

This study was conducted at the Luoyugou watershed in the third subplot of the Hilly-Gully region at the Loess Plateau of China. Luoyugou is a tributary of the Ji River that flow into the Wei River, and is located at east longitude of 105°30' – 105°45' and northern latitude 34°34' –34°40' in Tianshui of Gansu Province, China (Figure 1). Luoyugou watershed is relatively small and pinnate, with a drainage area of 72.79 km^2, a high symmetry coefficient of 0.9, and a low watershed development index of 1.49. The 21.81 km long main channel has 293 branches, with 96 on one side and 97 on the other side. The total length of the branches at all levels above the medium gully is 395.35 km. The cutting density is 3.54 km per km^2, and channels with a length of more than 1 km reach a total length of 107.28 km. The gully density at this watershed is 1.47 km per km^2, and the average gradient of the main channel is 2.5% (Han, 2011; Wang *et al.*, 2008; Zhang, 2012).

Luoyugou watershed is located at beam-shaped hilly terrain, has a high elevation and steep slopes, and is cross-cut by numerous ravines and gullies. Given a high surface runoff potential with an annual runoff modulus of 3.069×104 m^3/km^2, gully and gravity erosions are serious, with an annual soil erosion modulus of 3300–9500 t/km^2 (Zhang, 2012). It is one of most vulnerable areas on the Loess Plateau for soil loss and one of the main sources for sediment loads to the lower Yellow River, thus eliciting serious consequences in downstream ecosystems. As a result, the Luoyugou watershed was managed through 3-year planning of agriculture and forestry production and water and soil conservation under the guidance of China's Ministry of Water Resources as early as 1956. In August 1983, it was listed as a pilot watershed at the middle Yellow River and a key comprehensively managed watershed in Gansu Province. Detailed hydrological, soil, climate and land use data have been collected for the Luoyugou watershed since 1950s, therefore it is a suitable small watershed for the research of the relationship between land use change and water and sediment transportation.

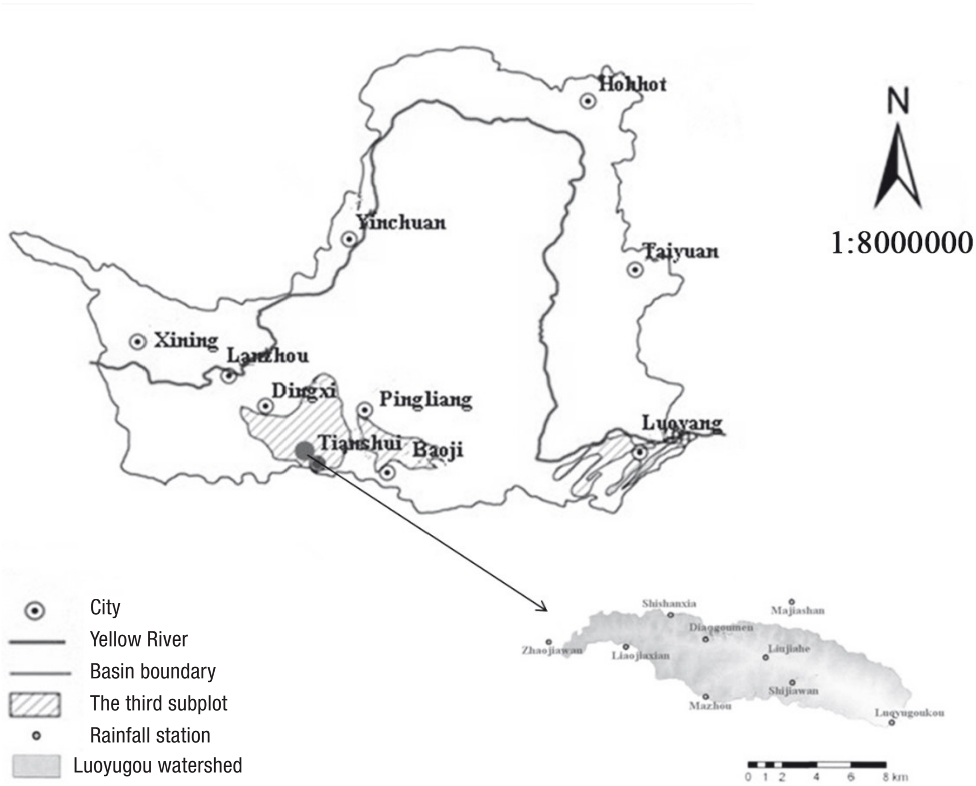

Figure 1. Geographic location and rainfall stations of the Luoyugou watershed.

Input data

In order to optimize the land use pattern and subsequently its impact on surface runoff and sediment loss in the watershed, we have collected the following input data, including rainfall, stream flow, sediment data, climate data and Digital elevation model (DEM) data. Annual runoff and sediment data from 1986 to 2000 were recorded at the outlet station of the watershed (i.e., the Luoyugoukou station, Figure 1), and accessed from the monitoring data Tianshui hydrology and water resources survey. Rainfall data from 1986 to 2000 were obtained from nine stations within and adjacent to the Luoyugou watershed (Figure 1) from Tianshui hydrology and water resources survey. Tianshui county weather station provided detailed relative humanity, wind speed and temperature data at the same time (Wang *et al.*, 2008). DEM data for the area was downloaded from the Service Platform of the International Science Data. The slope map of the watershed was obtained from the DEM data (Liu *et al.*, 2011). Briefly, the DEM of the watershed was analyzed through the gradient tool in the ArcGIS9.3 (ESRI, America) to generate the slope data. The resolution of the DEM at 30 m×30 m was transformed into 5 m×5 m overlaid by remote sensing data through the data conversion tool of ArcGIS9.3 after projection conversion. According to the grading index of soil erosion intensity in the Luoyugou watershed (Zhang, 2012), the slopes in the watershed were reclassified into six classes, including 0^o–5^o, 5^o–8^o, 8^o–15^o, 15^o–25^o, 25^o–35^o, and > 35^o. This slope data is critical for generating the map of land use gradient distribution.

Recently, vegetation coverage has been widely obtained from the remote sensing images through the correlation analysis of vegetation coverage and the spectral index (Los *et al*., 2000; Sellers *et al.*, 1994) or using a regression model (Asrar *et al.*, 1992; Graetz *et al.*, 1988; North, 2002). Nonetheless, these methods are generally difficult to be implemented, require long-time observations, and have many limitations such as operation difficulty, longtime observation and low efficiency. Thus, the study chose normalized difference vegetation index (NDVI) to evaluate vegetation:

$$NDVI = \left(NIR - R\right)/\left(NIR + R\right) \qquad (1)$$

Vegetation coverage in the watershed was estimated by a Landsat Thematic Mapper (TM) remote sensing image with a 30-meter resolution taken in late August, 2001, when the cloud cover was almost zero. Radiometric, atmospheric and geometric correction were conducted on the image first, then the RS image of Luoyugou watershed was obtained by cropping the image along the watershed boundary. It is used to calculate NDVI through ENVI RS processing software. According to dimidiate pixel model, NDVI of a pixel can be expressed as $NDVI_{veg}$ (contribution information of vegetation) and $NDVI_{soil}$ (contribution information of bare soil), so vegetation coverage of any pixel can be express as:

$$F_c = \left(NDVI - NDVI_{soil}\right)/\left(NDVI_{veg} - NDVI_{soil}\right) \qquad (2)$$

The vegetation coverage map was collected in ArcGIS combining $NDVI_{veg}$, $NDVI_{soil}$ and function (2). The map use in this study was reclassification to 0-0.3, 0.3-0.45, 0.45-0.6, 0.6-0.75 and above 0.75 five levels.

The land use data of Luoyugou watershed were obtained from the Landsat images taken by the Thematic Mapper (TM) in 1986 and 1995 and Enhanced Thematic Mapper (ETM+) in 2001, as well as the SPOT image in 2008. Image preprocessing was conducted on the platform of ERDAS9.2 and ArcGIS 9.3. Supervised classification and artificial visual interpretation (Gong *et al.*, 2009) were used to classify the forth, third and second wave synthesis image and vectorization, generating the original land use map. The overall accuracy was determined around 85% through examining, repairing and establishing land use spatial database after field investigation and literature search. The land use was classified into seven types according to the national classification standard of China (GB/T21010—2007, 2007), namely, sloping farmland, terraces, forests, grassland, water, orchards and villages. At the same time, slope map and land use map overlaid to generate soil erosion intensity grading map according to different weight.

Overall, we have assembled yearly average rainfall, temperature, evaporation and wind speed in dBase as well as stream flow and sediment loads at the watershed outlet from 1986 to 2000. The vegetation coverage map, and the land use map and associated gradient distributions in 1986, 1995, 2001, and 2008 were also prepared. Considering our dataset, we have designed our experiment in the following manner: the period of 1986–2000 was used to establish our SWAT model; the land use of 2001 was used as the baseline land use on which the land use optimization was implemented as described below; the land use of 2008 was considered the future land use when no land use optimization was performed prior.

Land use optimization

Optimization of the land use pattern was mainly based on landform features, soil types and fertility, and severity of soil erosion in this area. When combined with the local social and economic development, this allows assessment of the key impact factors, and adoption of tillage measures, engineering measures and biological and other measures, and adjustment of the land use pattern in the watershed, with the purpose of reducing soil erosion and soil nutrient loss. In this study we will examine if a more elaborated scheme of land use optimization targeted at the most vulnerable areas to soil and water losses could reduce surface runoff and sediment transport in the watershed. This should enhance the sustainable use of soil natural resources, and promote sustainable development of the regional economy and the ecological environment. The land use in 2001 was intentionally chosen for the land use optimization, because severe soil erosion and surface runoff have occurred during this period. In order to optimize the land use in 2001, we prepared our own land use map (Figure 2), slope map, and gradient distribution of land use, soil erosion intensity, as well as obtained the spatial distribution of rainfall erosivity from Zhang *et al*. (2012), provided in the supporting information (Figures S1, S2, S3, S4, S5, S6 and S7 [online supplement]). As the main factors influencing surface runoff and soil erosion include the slope and vegetation cover conditions in the area (Li & Wang, 2007; Xu, 2002), we use land use gradient distribution map, rainfall erosivity map, and soil erosion intensity map combining with the national policy to optimize the land use with the following scheme: (1) the sloping farmland and terraces in the area with a slope above 25^o are returned to forest; (2) the sloping farmland with a slope between 5^o and 15^o are adjusted to terraces; (3) the orchards with slopes above 25^o are converted to forest; and (4) the areas with severe soil erosions on the slopes above 8^o are changed to forest, and other area of severe soil erosions on the slopes less than 8^o to terraces. Our primary focus is to make sure that wherever possible, the farmlands are changed to the terraces so that agricultural food production and the livelihood of rural communities could be protected. In responding to the China's national policy of "returning farmland to forest" (1999), in our scheme only the farmland on the slopes of greater than 25^o is changed to forests. In essence, the principal goal of the land use optimization is to reduce soil erosion in the watershed, which was verified by watershed-scale modeling using the Soil and Water Assessment Tool (SWAT) as described in detail in the next.

SWAT modeling

The SWAT model (version 2009, USDA-ARS, USA) was chosen for this study (Figure 3). We first verified the applicability of the SWAT model for the Luoyugou watershed. The calibration period was 1986–1994 and the input data for the model were included the land use in 1986, and observed rainfall, runoff, and sediment loads for the same period (Figures 4, 9 and S8 [online supplement]). The validation period was 1995–2000, and the model input included the land use in 1995, and observed rainfall, stream flow, and sediment loads for the same period. Other yearly climatic data such as temperature, potential evapotranspiration and wind speed in the dBase format were inputted in advance. 41 parameters such as ESCO (Soil evaporation compensation factor), EPCO (Plant uptake compensation factor), ALPHA_BF (Base flow alpha coefficient), (Table S1 [online supplement]) were adjusted automatically in the calibration period. A detailed list of calibrated parameters is provided in the supporting information.

Once the SWAT model for the watershed was calibrated and validated, three scenario analyses were performed to assess the influence of land use change on the surface runoff and sediment yields in the watershed, using the original land use in 2001, the optimized land use, and the land use in 2008, respectively. In order to assess the impact in a long period, these three scenario analyses were performed over a 15-year span using the input data from 1986–2000 while replacing the land use data with one of three above-mentioned land uses. The simulated surface runoff and sediment load in the SWAT calibration and validation were used a baseline values for comparison with the results of the above three scenario analysis. The objective was to assess the responses of surface runoff and sediment loads to the scenarios whether or not the land use optimization was implemented.

Because the change of surface runoff and sediment loads could also be influenced by climate change in addition to land use change, the last exercise dealt with the simulations with invariant climate input so as to exclude the effect of climate forcing. Because the similarity of annual rainfall in 1997 and 2008, the climate input in 1997, including rainfall, air temperature, potential evapotranspiration, etc., was used to simulate surface runoff and sediment loads using our developed SWAT model for the watershed with either the optimized land use or the actual land use in 2008. The simulated results were compared with each other and with the observed surface runoff and sediment load in 2008.

Results and discussion

Land use change and optimization

The land use patterns in 1986, 1995, 2001, and 2008 in the Luoyugou watershed are shown in Figure 2, and

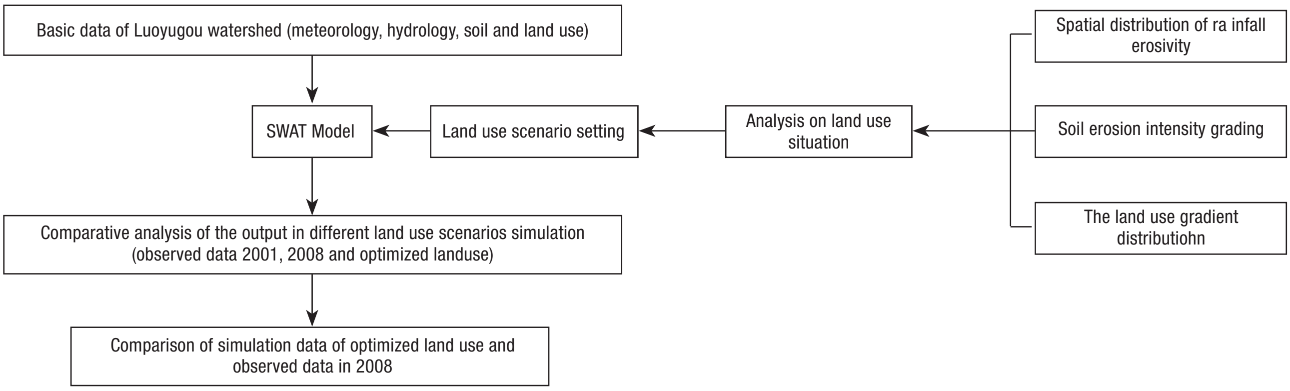

Figure 2. The method flowchart of this study.

the slope map of the watershed is shown in Figure S2 [online supplement] at the supporting information. Given that no major earthquakes or landslides able to significantly alter the terrain slopes were known to have occurred in the past 15 years, we overlaid the derived slope map (Figure S2 [online supplement]) and the land use map in each year to generate the land use gradient distribution maps in order to determine the terrain slope of a particular land use type (e.g., sloping farmland, terraces, orchards, and forests). A representative land use gradient distribution map and associated distribution in 2001 is shown in Figures 4 and 5, respectively, and similar maps for other years are provided in the supporting information.

From Figure 2, it was clear that a dramatic change in the land use patterns occurred during the period of 1986–1995 (Figure 2a and b). In 1986 the sloping farmland constituted the largest area of 49.28 km^2, representing 68.82% of the watershed area (Table S2 [online supplement]). Its main slope distribution was in the range of 8–15^o, which covered 28.24 km^2, representing 39.44% of the watershed area. The area with a slope greater than 25^o was 0.96 km^2, representing 1.35% of the watershed area. The combined area of terrace, forest and grassland was relatively small at 17.34 km^2 (i.e., 24.22% of the watershed area), which was only equivalent to 35.2% of the sloping farmland area. Consequently, the area was prone to severe soil erosion and rapid surface runoff. It concluded in previous study that runoff and sediment from 1960s to 1990s in Jing River basin that both loads reduced in 1970s, increased from 1981 then decreased in 1990s (Liu, 2011). The results were consistent with the available data in this study. The reason was probably the national police. Before 1980s, the people's commune collective ownership was executed in this region that developed large-scale construction of water conservancy works such as terraces; farmland contracted responsibility system took the place after 1981, many old terraces were out of repair or influenced by graze and farming which led to terraces reduction (Chen & Yang, 2001). After that, as a soil and water conservation practice, the conversion of sloping farmland to terraces (termed as terrace engineering) took place from the middle of 1980s (Jing, 2001; Jing & Jiao, 2010). As a result, the terraces became the largest land use type by 1995 (Figure 2b), with an area of 39.04 km^2 (i.e., 54.52% of the total watershed area) (Table S3 [online supplement]). Its main slope distribution was still in the range of 8–15^o, which covered 23.74 km^2, representing 33.16% of the watershed area. The area with a slope greater than 25° was 0.19 km^2, representing 0.27% of the watershed area. The combined area of sloping farmland, forest and grassland was relatively small at 27.4 km^2 (i.e., 24.22% of the watershed area).

From 1995 to 2001, the area of terraces remained relatively unchanged. In 2001, the terraces were mainly distributed in the slope range of 8–15^o, which covered an area of 23.73 km^2 or 33.14% of the total watershed. The area with a slope above 25^o was 0.19 km^2, covering 0.27% of the total watershed. The combined area of forest, orchards and grassland was 18.35 km^2, representing 25.63% of the watershed area, and less than half of the terraced area.

Nonetheless, by 2008 there were still some mismanaged areas of land use in 2008, with 0.68km^2 sloping farmland and 0.38km^2 terraces in regions where the slopes are greater than 25°, 0.96% and 0.54% of the total area. (Table S4 [online supplement])The area of sloping farmland was still large with an area of 9.83km^2, 13.45% of total area. Thus, despite the enormous improvement from the terrace engineering since the middle of 1980s (Jing, 2001; Jing & Jiao, 2010), in order to curtail the surface water and sediment loss, more targeted optimization of land use patterns is needed. According to the optimization scheme described previously, the land use pattern in 2001 was optimized, as shown in Table 1 and Figure 6.

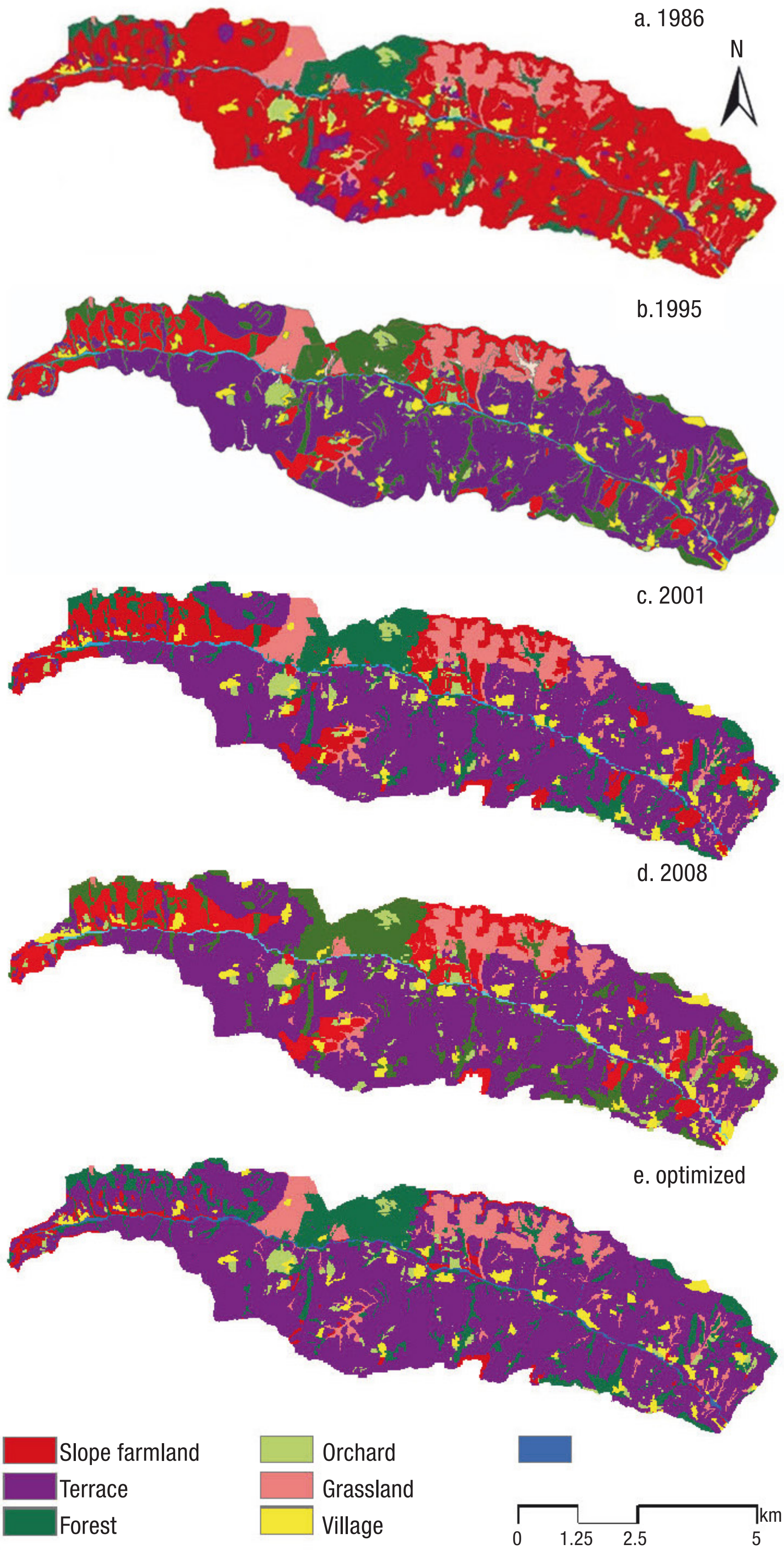

Figure 3. Land use patterns of the Luoyugou watershed in 1986, 1995, 2001, 2008, respectively and the optimized land use pattern.

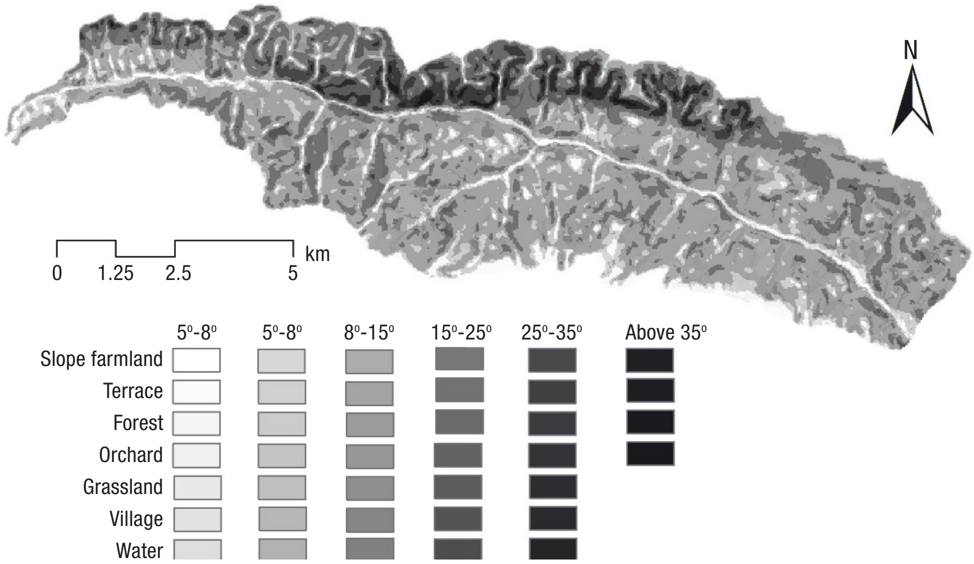

Figure 4. Land use gradient distribution in 2001.

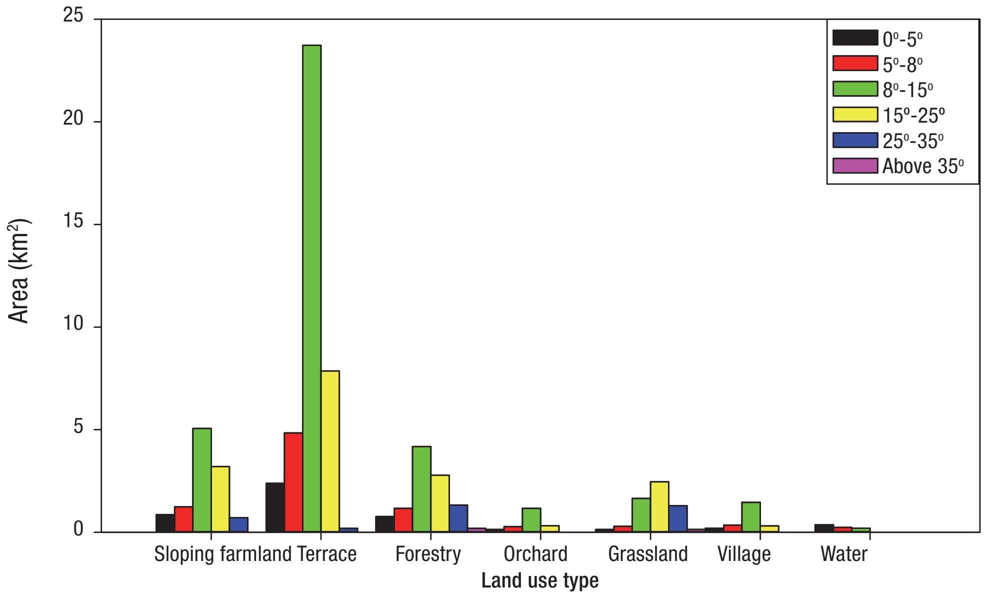

Figure 5. Land use gradient distribution in 2001.

After optimization, the slope farmland had a scope gradient of 0º–8º with a size of 2.10 km^2, i.e., 2.93% of the watershed area. All terraces with a total area of 47.08 km^2 were located at the regions with a slope less than 25º, which not only ensures food production but also reduces soil and water loss through small terrain changes of terraces. Compared with the land use in 2001 prior to optimization, the sloping farmland was reduced by 12.55%, the terraces increased by 11.29%, and the forests increased by 1.32%. The increased forest areas were mainly located mainly in the regions with a slope greater than 25º (Table 1 and Table S5 [online supplement]). There were minor changes in the sizes of orchards and grassland, whereas the sizes of villages and water remained unchanged (Figure 7). Obviously, the optimization was mainly involved the sloping farmland, the terraces, and the forests as these land uses are the major types in the watershed.

For the pure purpose of scenario analysis, we have chosen the land use pattern in 2001 as the current land use, while the land use in 2008 as the future land use. There was little land use change from 2001 and 2008, unless the optimization of the land use was implemented. Next we will examine how the optimization of land use patterns influences the surface runoff and sediment loads.

The optimization also corresponded to former researchers' results. It is indicated that land use changes had a deep influence on runoff and sediment (Xie, 2009). Tang studied sediment and runoff of a small watershed of Loess Plateau by using non-parametric Mann-Kendall test, Mov-

Table 1. Land use gradient distribution after optimization of the land use pattern

Land use type	Area/ proportion	0°–5°	5°–8°	8°–15°	15°–25°	25°–35°	Above 35°	Total
Sloping farmland	km^2	0.86	1.24	0.00	0.00	0.00	0.00	2.10
	%	1.20	1.73	0.00	0.00	0.00	0.00	2.93
Terrace	km^2	2.39	4.84	28.79	11.06	0.00	0.00	47.08
	%	3.34	6.76	40.22	15.45	0.00	0.00	65.77
Forest	km^2	0.77	1.17	4.18	2.78	2.26	0.20	11.36
	%	1.08	1.63	5.84	3.88	1.85	0.27	15.87
Orchard	km^2	0.14	0.28	1.17	0.32	0.00	0.00	1.91
	%	0.20	0.39	1.63	0.45	0.00	0.00	2.67
Grassland	km^2	0.14	0.29	1.65	2.46	1.29	0.14	5.97
	%	0.20	0.41	2.31	3.44	1.80	0.20	8.34
Village	km^2	0.20	0.35	1.46	0.31	0.02	0.00	2.34
	%	0.28	0.49	2.04	0.43	0.03	0.00	3.27
Water	km^2	0.36	0.24	0.20	0.02	0.00	0.00	0.82
	%	0.50	0.33	0.27	0.03	0.00	0.00	1.13
Total	km^2	4.86	8.41	37.45	16.95	3.57	0.34	71.58
	%	6.79	11.75	52.32	23.68	4.99	0.47	100.00

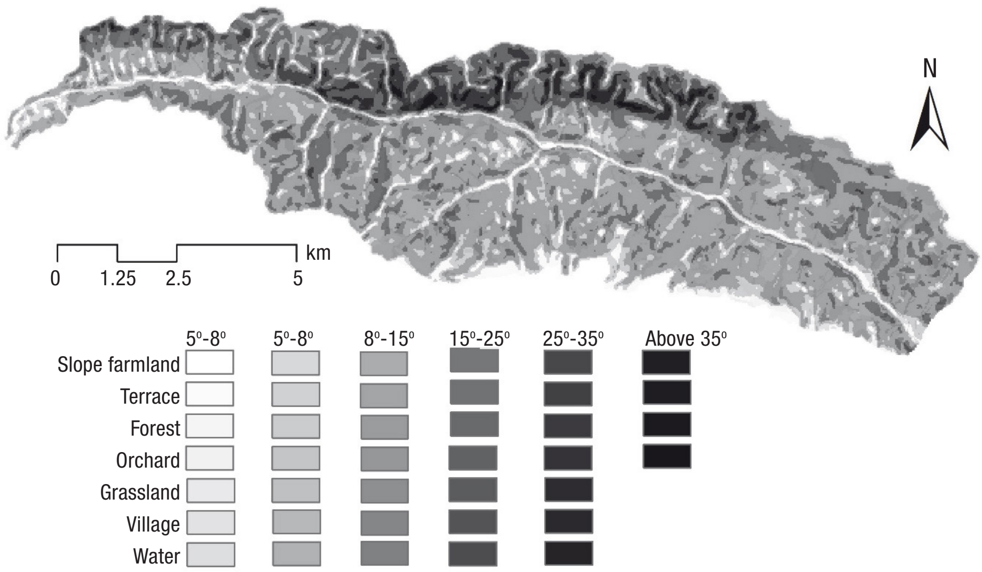

Figure 6. Gradient distribution of optimized land use.

ing t-test technique, and hopped parameter analysis, which had a result of land use/cover changes accounting for 90.11% on sediment (Tang *et al*., 2010). Moreover, expect for vegetation coverage, slope also played an important role in water and soil conservation (Li & Wang, 2007). Terrace had a significant advantage over sloping farmland on water and sediment reduction, which lead to slope-to-terrace taking an important part in land use optimization.

SWAT development in the Luoyugou watershed

First, we developed the SWAT model for the Luoyugou watershed. As previously described, the calibration period was 1986–1994 using the land use in 1986 (Figure 2a), whereas the validation period was 1995–2000, using the land use in 1995 (Figure 8b).

As shown in Figure 8 and Table 2, for surface runoff, the certainty coefficient (*Ens*) was 0.88, the relative error (*Re*) was 5.10%, and the correlation coefficient (R^2) was 0.94 in the calibration period, whereas in the validation period, the *Ens* value was 0.87, the *Re* value was 7.20%, and the R^2 value was 0.98. Similarly, the sediment simulation was also satisfactory, showing decent *Ens*, *Re*, and R^2 values for both the calibration and validation periods. Therefore, we assumed that the SWAT model has captured the underlying hydrological processes in the watershed, which was in agreement with the study on a similar nearby watershed (i.e., the Zhifanggou wa-

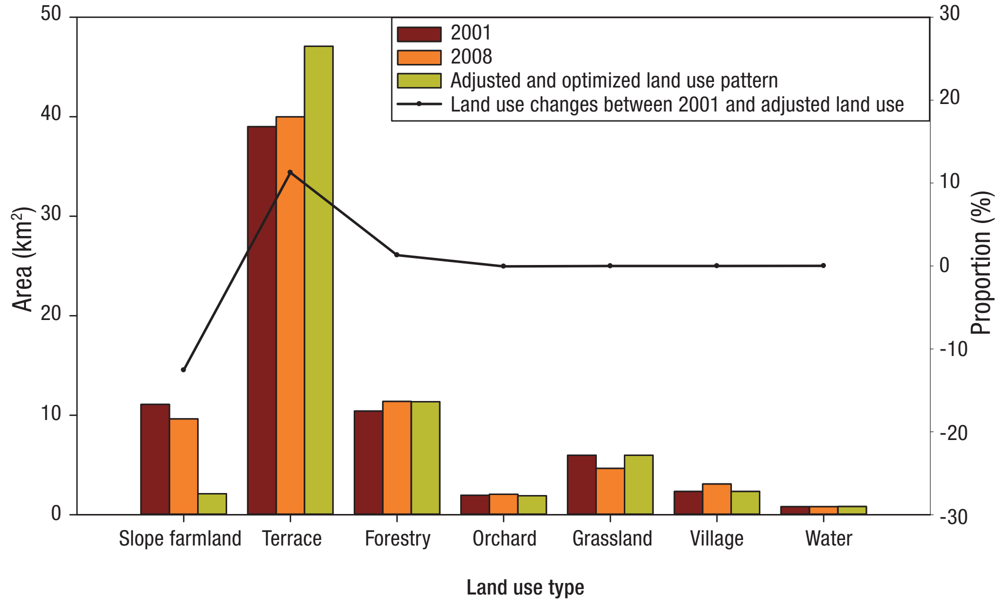

Figure 7. Areas of land use in 2001 and 2008 and of the adjusted optimized land use of the Luoyugou watershed.

tershed) (Qiu *et al*., 2012). Nevertheless, it may possibly misestimate the extreme event. In the study of the application of SWAT in the River Grote Laak in Belgium, the SWAT model underestimated the base flow during an extreme dry period in 2003 (Nossent & Bauwens, 2007); while the research in Zhifanggou gave another result that the model might underestimate runoff in wet season and overestimate it in dry period because it is difficult to determine the soil moisture conditions before and during high-flow events (Qiu *et al*., 2012). Hence, it is necessary to improve the parameters and corresponding performance in extreme event simulation in the future study of SWAT model. And as our calibration and validation were performed on the yearly basis, new calibration and validation will be needed for simulations in daily or monthly time-steps.

Impact of land use optimization on surface runoff and sediment loads

In order to evaluate the impact of land use optimization on surface runoff and sediment loads over a long term, we first performed the simulations for the period of 1986–2000 using the land use in 2001 while keeping other input unchanged for each year. Then, we replaced the 2001

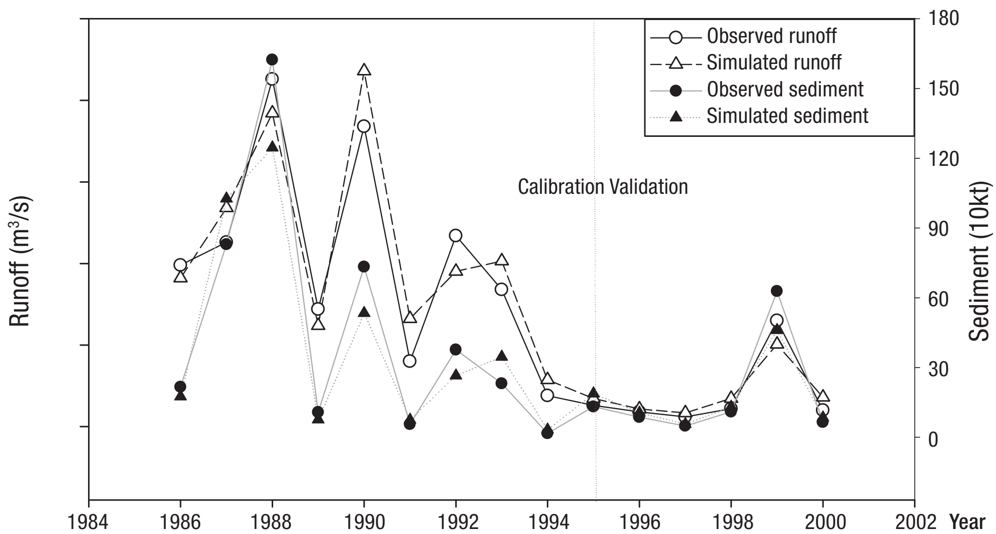

Figure 8. Observed and simulated runoff and sediment.

Tabla 2. Comparison of observed and simulated surface runoff and sediment loads in the Luoyugou watershed [a]

	Stage	Annual values		*Ens*	*Re*	R^2
		Observed value	Simulated value			
Surface runoff (m^3/s)	Calibration period	0.105	0.11	0.88	5.10%	0.94
	Validation period	0.019	0.02	0.87	7.20%	0.98
Sediment load (10kilo-ton)	Calibration period	46.55	41.96	0.88	-9.87%	0.95
	Validation period	17.83	17.1	0.87	-4.09%	0.98

[a] *Ens* is the certainty coefficient, *Re* is the relative error, and R^2 is the coefficient of determination.

land use by the optimized land use and the 2008 land use, respectively, so as to assess the responses of surface runoff and sediment loads to the land use optimization and to no designed land use optimization (i.e., the 2008 land use).

As shown in Figure 9, the runoff in each year was decreased significantly after the optimization of the land use pattern in the Luoyugou watershed. In the SWAT model development for the Luoyugou watershed, the average simulated annual runoff for the period of 1986–2000 was about 0.074 m^3/s, which serves as the baseline value for comparison. When the 2001 land use data or the 2008 land use data were used for the period of 1986–2000, the simulated average annual runoff was 0.072 m^3/s or 0.070 m^3/s, respectively (Figure 9), suggesting that little reduction in surface runoff would occur without more targeted land use optimization. Conversely, when the optimized land use pattern was used, the simulated average annual runoff was 0.061 m^3/s, i.e., a reduction of 17.6% from the baseline value (i.e., 0.074 m^3/s). Compared with the scenario that the land use optimization was not implemented (i.e., the 2008 land use), the runoff was decreased by 12.9% (i.e., 0.009 m^3/s).

Similarly, the sediment loads were remarkably reduced with the optimization of the land use pattern compared with the simulated results using the 2001 land use (Figure 9). Again the simulated baseline sediment load was 32.01 million ton per year averaged over the period of 1986–2000. If the land use optimization was not implemented, the simulated sediment load was 31.35 million ton per year or 30.42 million ton per year for the 2001 land use or the 2008 land use, respectively. This observation suggests that little reduction in the sediment transport would occur if the current practice remains unchanged. However, if the land use optimization was implemented (i.e., using the optimized land use pattern for the simulation over 1986–2000), the average simulated sediment load was decreased to 26.33 million ton per year, i.e., a reduction of 17.74% from the baseline value. Our optimization scheme of land use pattern mainly focuses on converting the sloping farmland to the terraces, while other researchers proposed more aggressive strategies by converting the farmland to the forests. Expectedly, the reduction in surface runoff and sediment loads in this study were lower than the results of Wang *et al.* (2006). Another assumption in the Luoyugou watershed gave a result that when forest coverage greater than 80% of the total area, the sediment would be similar with our reduction (Xie, 2009). Nonetheless, given that farming is the livelihood of many rural communities and food security is of paramount importance, our approach balances the need of conserving water and soil resources while maintain the food production area.

Further validate of land use optimization

Given the significant driving forces of rainfall, and possibly other meteorological and climatic factors in impacting surface runoff and sediment transport, we further performed the scenario analysis using the invariant meteorological-climatic input. Because the annual rainfall was 378.6 mm in 1997 and 380.1 mm in 2008, the similarity of rainfall between the ends of this decadal period provides a unique opportunity to pinpoint the dominating role of land use change by excluding the climatic variations. Subsequently we used the rainfall and other climatic input from 1997 to simulate surface runoff and sediment loads using our developed SWAT model for the watershed with the optimized land use. According to the 2008 communique data, the observed runoff and sediment load was 681700 m^3 per year and 73090 t, respectively (Table 3). When using the optimized land use, the runoff and sediment loads were decreased by 68.59% and 31.13% compared with the observed values. The results suggest that: first, the land use optimization was responsible for the reduction in surface runoff and sediment loads despite the potential role of climate forcing; second, the runoff decreased by a large proportion makes water conservation easier inside the watershed.

Conclusions and suggestions

According to the principle of returning farmland to forest, and ensuring grain yield preferentially, the study

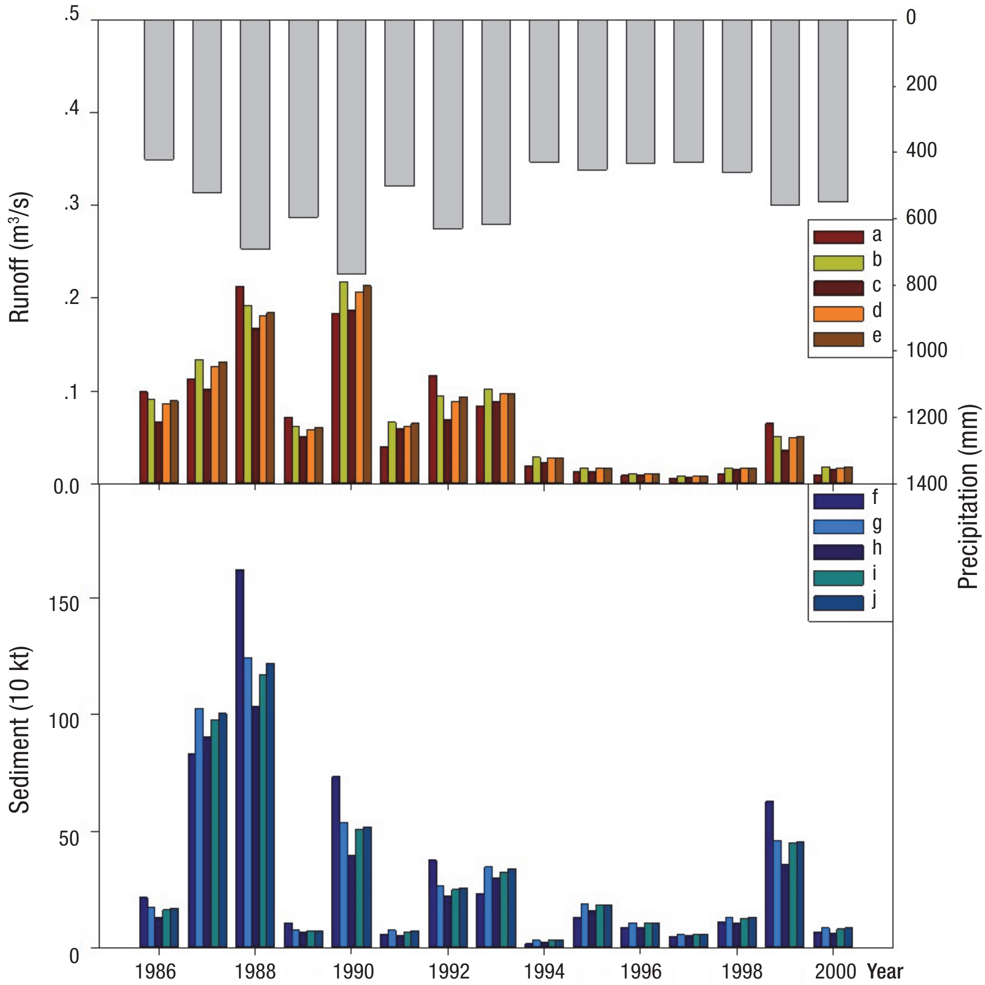

Figure 9. Simulated annual surface runoff and sediment loads after land use optimization in the Luoyugou watershed (a. Observed runoff; b. Simulated runoff under the optimized land use pattern; c. Simulated runoff under the land use pattern of 2008;d. Simulated runoff under the land use pattern of 2001; e. Observed rainfall; f. Observed sediment loads; i. Simulated sediment loads under the optimized land use pattern; j. Simulated sediment loads under the land use pattern of 2008; k. Simulated sediment loads under the land use pattern of 2001).

adjusted mismanaged land use patterns in 2001 in the Luoyugou watershed, developed an adjusted and optimized land use pattern, and used the adjusted and optimized land use pattern as input data for the SWAT model. The outcomes were then compared between the adjusted and actual land use patterns. The results indicated that the optimized land use pattern can reduce soil erosion effectively. The average simulated runoff would decrease by 0.013m^3/s (about 17.6%). The average simulated value of sediment production would decrease by 5.68 million tons (17.7%). At the same time, when the land use in 2008 was used as input data, the average simulation value of runoff reduced by 0.004m^3/s (5.41%), and the average simulation value of sediment production reduced by 1.59 million ton (4.97%).

The adjusted and optimized structure was developed based on the policy of converting farmland into forest and the method of landscape pattern optimization. Scenario simulation was used to distinguish the effects of the adjusted and optimized land use structure with the original land use in terms of runoff and sediment reduction. However, there is a strong artificial guiding role in this study, and research in the next step should be based on land use structure and function of water transport, according to actual situations in the Loess plateau Hilly-Gully region, to deduce a possible optimized structure on the basis of minimum allowed erosion. The results will have important effects for regional construction and policy formulation.

The effect of land use changes based on an optimized vegetation structure on water and sediment transport were analyzed systematically. The problem of water shortage in the Loess plateau Hilly-Gully region is still serious, however, and vegetation itself

Tabla 3. Comparison of the simulation data for the adjusted and optimized land use with the observed data from 2008

Project	Runoff (m³)	Sediment (t)
Observed data in 2008	681700	73090
Simulation data for the adjusted land use	214075	50336
Variation between the observed data and simulation data for the adjusted land use	-467625	-22754

consumes water. Hence, a promising research field will be to investigate how to obtain optimized vegetation structure, so as to maintain a balance between water consumption in promoting vegetation growth and water and soil conservation.

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