Hindawi Publishing Corporation
Advances in Meteorology
Volume 2015, Article ID 478739, 13 pages
http://dx.doi.org/10.1155/2015/478739

*Research Article*

# An Assessment of Human versus Climatic Impacts on Jing River Basin, Loess Plateau, China

**Yi He,[1] Fei Wang,[2,3] Xingmin Mu,[1,2,3] Huiting Yan,[4,5] and Guangju Zhao[2,3]**

[1] *College of Water Resources and Architectural Engineering, Northwest A&F University, Yangling, Shaanxi 712100, China*
[2] *Institute of Soil and Water Conservation, Northwest A&F University, Yangling, Shaanxi 712100, China*
[3] *Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, Yangling, Shaanxi 712100, China*
[4] *College of Natural Resources and Environment, Northwest A&F University, Yangling, Shaanxi 712100, China*
[5] *Northwest Research Institute of Engineering Investigations and Design, Xi'an, Shaanxi 710003, China*

Correspondence should be addressed to Fei Wang; wafe@ms.iswc.ac.cn

Received 19 January 2015; Revised 30 March 2015; Accepted 1 April 2015

Academic Editor: Gwo-Fong Lin



The impacts of climate change and human activities on runoff and sediment load are too integrated to distinguish their own contributions. We develop a new method to assess the impact of human activities based on paired years with similar precipitation and evapotranspiration ($ET_0$) conditions (SPEC) using a 55-year monthly data of climate, runoff, and sediment load in 1958–2012 at Zhangjiashan Hydrologic Station of Jing River, Loess Plateau, China. The SPEC of paired periods is defined by similar annual amounts (difference less than 2.0%) and similar process (linear correlations of monthly data less than 0.05) which could set a precondition fixing the possible influence of climate factors. The runoff declined in all nine paired years, but the sediment load and concentration decreased in seven (78%) and six (67%) paired years, respectively. The further analysis with available data of land use and land cover (LUC), Normalized Difference Vegetation Index (NDVI), and soil and water measures in this basin and the results could explain impacts of human activities well. The method could be used combining with the traditional methods in hydrological research.

## 1. Introduction

Streamflow and sediment load provide useful information not only on the soil erosion and sediment delivery occurring in a basin [1], but also on the key factors of river health. The main causes of runoff and sediment load change are related to natural climate variability and human activities (e.g., land use change and dam construction), which have caused significant changes to the runoff and sediment load of many rivers, such as the Nile [2], the Colorado River [3], and the Yangtze [4] and Yellow rivers [5]. Land use change is the reflection of the surface microtopography change by human activities. It has significant impacts on regional soil degradation, including soil erosion and soil acidification. In recent years, a number of studies have been carried out to estimate the potential effects of land use change on soil erosion. Trimble [6] found that in Mississippi valley reduced rates of soil erosion coincide with improved practices of soil conservation and management. Some researchers [7, 8] found the effects of land use change and check dams on sediment and channel morphology. Several studies [8–13] showed that an important impact of landscape pattern changes on catchment sediment yield. García-Ruiz and Lana-Renault [14] stated that the effect of land cover changed on soil loss, sediment delivery, and hydrological response in Europe. Costa et al. [15] found that a deforestation of about 30% of the basin induced a 24% increment of the annual mean discharge. Foley et al. [16] stated that land use changes modify interception and infiltration affecting surface runoff and groundwater flows. Rainfall is the main dynamic factor that causes soil loss. Xin et al. [17] investigated the spatiotemporal variations characteristic of rainfall erosivity on the Chinese Loess Plateau. Recent studies [18, 19] found that sediment yield rates may be expected to change in response to changes in rainfall.

Therefore, the runoff and sediment discharge variability that is caused by natural climate change and human activities has become one of the key issues in hydrology research and forms the basis for understanding how these patterns of variability form. Much of the current research on runoff and sediment discharge is based on comparative [20, 21] or modeling analysis [19, 22]. While these two methods have assisted in understanding the runoff and sediment discharge variability, there are large differences in the theory and parameters between the methods. For example, the rainfall-runoff and rainfall-sediment statistical model is still controversial when dividing the distinct transition point of runoff or sediment discharge time series by the impacts of human activities, resulting in different division periods showing differing results [23, 24]. Furthermore, although the mechanisms of runoff and discharge are clear in distributed hydrological models [25–28], there are great spatial differences in the model parameters and their selection is too variable. Current models do not take the variation of precipitation and evaporation into account comprehensively in the divided period. To understand the influence of climate change and human activities on runoff and sediment discharge and to reduce the uncertainty in the selection on model parameters and improve the accuracy for evaluation of the effects, we must select a study time period, where the climatic characteristics are similar. Once this premise is observed, the variability of the characteristics can be studied in a meaningful way. Based on data from the Jing River Basin, China, the objectives of this study were (1) to show how discharge and sediment yield from the Jing River varied over the past 55 years, (2) to quantitatively assess the influences between climate and human factor on runoff and sediment discharge, and (3) to discuss implications for watershed management.

## 2. Data and Methods

*2.1. Study Area.* The Jing River, at 455.1 km long, is the second-longest tributary of the Wei River, and a second-level tributary of the Yellow River. The Jing River Basin (area 45421 km$^2$) is located in the center of the Loess Plateau (34°46′–37°19′N, 106°14′–108°42′E). The basin encompasses parts of 30 counties, across the Ningxia Hui Autonomous Region (Ningxia) and the Gansu and Shaanxi provinces. Up to 4.3% of the area is mountainous, 41.7% comprises loess tableland and broken plateau, and 48.8% are loess hilly and gully loess regions. The basin contains several fracture belts and little vegetation cover. A digital elevation model (DEM) of the region and the rivers located in the basin are shown in Figure 1. The total area of soil erosion has reached nearly 73% of the total land cover, making the basin one of the most soil-eroded areas of the Loess Plateau and an important source of coarse sediment to the Yellow River. The area has deep (50–80 m) loess layers. The particle composition is mainly fine sand, silt (up to 50% of the total), and clay. The loess has high porosity and is prone to landslides. The soil is typical black loam soil with a loose structure that is readily degraded [29].

The climate of the Jing River Basin is continental monsoonal, with the average annual precipitation ranging from 400 to 600 mm and average annual air temperature ranging from 8.0 to 10.0°C [30].

Data for the study was obtained from the Zhangjiashan Hydrological Gauge Station (ZHS, 34°38′N, 108°36′E), which controls a 43216 km$^2$ watershed, accounting for 95.15% of the total watershed area. The average annual runoff and sediment load were 1596.6 million m$^3$ and 214.8 million tons, respectively, from 1958 to 2012. The average sediment concentration was 163 kg m$^{-3}$ (Ministry of Water Resources of China 2013).

*2.2. Data.* We used the sharable daily data of the 23 national climatic stations (apart from the mountain station) within and around (a buffering area outside of the basin 120 km) the research area from the National Meteorological Information Centre (NMIC), but we analyzed the induced monthly data in the paper (Figure 1). The data include monthly precipitation ($P$, mm), maximum temperature (TMX, °C), minimum temperature (TMN, °C), relative humidity (RH, %), wind speed (WS, m s$^{-1}$), and sunshine duration (SD, h) from 1958 to 2012. The dataset has been quality assured by NMIC. We performed further routine quality assessment and error correction procedures on the data following methods described by Peterson et al. [31]. Missing values are infrequent (during certain months in 1968 precipitation data was missing from one station and some months between 1967 and 1970 had wind speed data missing from four stations), which were replaced with estimated values predicted from multiple regression relationships established among up to five nearby and highly correlated stations [32]. The potential evapotranspiration of the Jing River Basin was calculated using the Penman-Monteith Method recommended by the Food and Agriculture Organization (FAO) [33]. The potential evapotranspiration and precipitation were spatially averaged based on the monthly records of stations upstream of the ZHS using the spatial interpolation method. Annual potential evapotranspiration and precipitation (a.pptn) were cumulative by month. Annual streamflow (in Mm$^3$) and sediment load (in Mt) data at ZHS from 1958 to 2012 were obtained from the Chinese River Streamflow and Sediment Communiqués, Ministry of Water Resources, China (MWR).

The Global Inventory Monitoring and Modeling Studies (GIMMS) Normalized Difference Vegetation Index (NDVI) dataset was derived from the NOAA Advanced Very High Resolution Radiometer (AVHRR) (http://www.noaa.gov, the dataset was downloaded from http://westdc.westgis.ac.cn), which provides information on the monthly changes in terrestrial vegetation from August 1981 to December 2006. Because of incomplete data in 1981, we used data from 1982 to 2006. The GIMMS data are based on a 15-day interval with 8 km spatial resolution [34]. The dataset has been corrected for solar zenith angle change, distortions caused by cloud cover, sensor intercalibration differences, solar zenith angle and viewing angle effects, volcanic aerosols, missing data in the Northern Hemisphere during winter, and low signal to noise ratios. To further eliminate the influence of clouds, atmosphere, and solar altitude angle, we used the international universal Maximum Value Composites (MVCs)

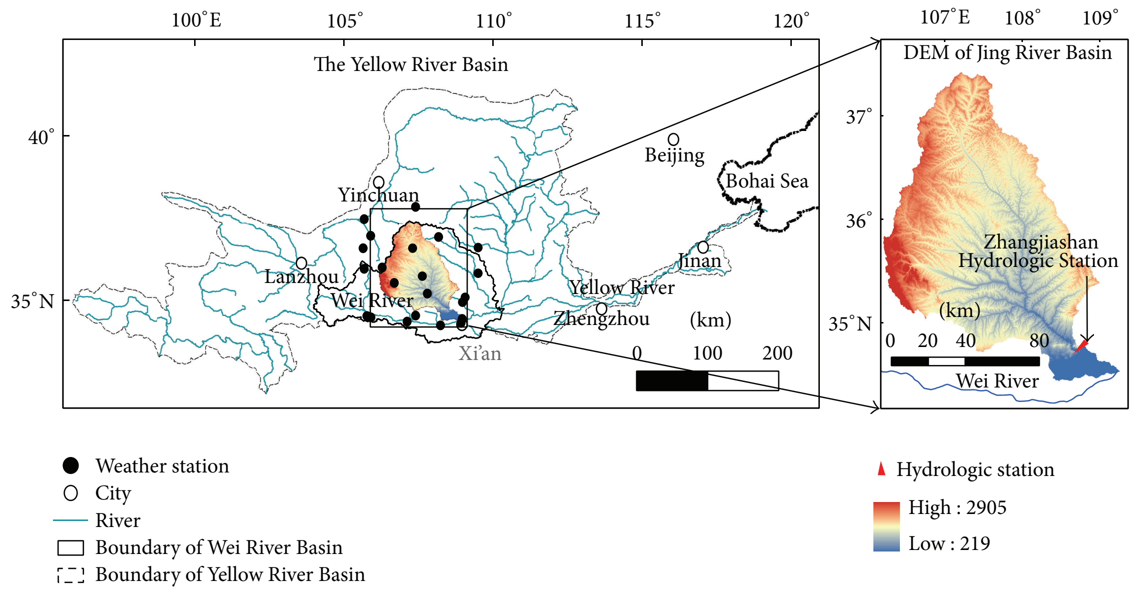



Figure 1: Location of the Jing River Basin study area, China.

technique to calculate monthly maximum NDVI [35], which selects the highest NDVI at each pixel from GIMMS NDVI (15-day interval) [36]. The vegetation in the study area is most developed during the productive months of June to September. The vegetation change is usually small from October to the following May. The NDVI values of the four productive months can best reflect the long-term change of vegetation cover during a year. Therefore, the NDVI from June to September of each year was calculated using the MVCs method and this value was used as an indicator of the annual vegetation growth of the study area.

The land use and land cover (LUC) data was obtained from the Data Sharing Infrastructure of Earth System Science, National Scientific Data Shared Platform (http://www2.geodata.cn/). LUC includes five digital maps from 1980, 1985, 1996, and 2000 to 2005. The map scale for 1985, 1996, and 2000 was 1 : 100000 and 1 : 250000 for 1980 and 2005. This series of maps describes the LUC change. The large scale maps were used to evaluate the total change over time, but they do not show the fine-scale information and detail, in particular, of the built-up area. The classification procedure was based on image interpretation combined with field investigation. The LUC data were classified into the following six categories according to Liu [37].

The categories for the study area include the following: (1) forest, which mainly represents land with a tree or shrub-crown areal density (crown closure percentage) of 10% or more, as well as nurseries and orchards, (2) cropland including dry-farming and irrigated cropland, lower-cover agroforestry land used mainly for food cultivation, and new cultivated river washland in existence for over three years, (3) grassland that is predominantly covered by grass, mixtures of grass, and shrubs or trees, but with tree coverage of less than 10%, (4) built-up land comprising areas of intensive use covered by structures including cities, towns, villages, strip developments along highways, and transportation, power, and communications facilities, (5) wetland/water body areas consisting of natural wetlands, such as swamps, lakes, and rivers and water engineering structures, including reservoirs and newly built check dams, and (6) barren land referring to land with limited ability to support life, such as sand or rocks where vegetation cover is normally less than 5%.

We obtained soil and water conservation data ranging from 1960 to 1999 from the Soil and Water Conservation Data Compilation of the Yellow River, compiled by the Upper and Middle Yellow River Bureau in 2010 based on on-site field surveys and measures. The data covers some general characteristics of the Jing River Basin, as well as biological conservation measurements such as man-made forest, grass-planting, and hillside closures (natural restoration area with little to no disruption from human activity), and structural measures, such as terraces, reservoirs, check dams, and key projects for gully control.

*2.3. Principle and Methods.* In order to assess the human versus climatic impacts on Jing River Basin, the following principle and methods were used.

*2.3.1. Principle.* The water balance of the watershed can be expressed as

$$P + W_i = R + W_g + W_s + \mathrm{ET}_c + \delta W, \quad (1)$$

where $P$ is the areal precipitation, $W_i$ is the water input from other watersheds, $\delta W$ is the change in water storage of engineered structure, such as reservoirs, $R$ is the surface runoff, $W_g$ is the underground runoff, $W_s$ is the soil water storage, and $\mathrm{ET}_c$ is the actual evapotranspiration.

Considering the specific hydrogeological conditions of the study area, (1) there is no water input from other

watersheds in this study area and $W_i$ can be ignored; (2) as there is a thick soil layer, a deep water table [38], and little recharge underground runoff from the limited infiltration [39], $W_g$ is assumed to be approximately 0; (3) there is little vegetation cover in the Jing River Basin, the infiltration capacity of surface soil is weak, and the main surface runoff generated by infiltration-excess rainfall is characterized by heavy rainfall with high intensity and short duration [40] and therefore $W_s$ can be ignored; (4) the water in reservoirs mainly supplies the needs of people's daily lives and $\delta W$ can be considered the human impact. Therefore, from a long process, (1) can be simplified to

$$P = R + \mathrm{ET}_c, \quad (2)$$

where $P$ is the areal precipitation, $R$ is the surface runoff, and $\mathrm{ET}_c$ is the actual evapotranspiration. Consider

$$\mathrm{ET}_c = k \times \mathrm{ET}_0, \quad (3)$$

where $\mathrm{ET}_c$ is the actual evapotranspiration, $k$ is the coefficient, and $\mathrm{ET}_0$ is the potential evapotranspiration. When under adequate water supply, $k = 1$ and $\mathrm{ET}_c = \mathrm{ET}_0$. We assume that $k$ does not change for the same land under the similar weather conditions and the vegetation change induced by human could change $k$. We analyze $\mathrm{ET}_0$ in the study instead of $\mathrm{ET}_c$ that implies the faster change than the natural evolution of $\mathrm{ET}_c$ is also the result of human activities.

*2.3.2. FAO Penman-Monteith Method.* The FAO Penman-Monteith (PM) approach to estimate evapotranspiration ($\mathrm{ET}_0$, mm day$^{-1}$) is regarded as a global standard and is given by FAO-56 report [33]. In this study, monthly potential evapotranspiration was calculated according to Allen et al. [33]. Monthly potential evapotranspiration was calculated by multiplying $\mathrm{ET}_0$ with the number of days in that month.

*2.3.3. Spatial Interpolation Method.* Spatial interpolation methods are developed for specific data types or a specific variable [41, 42]. In this study, we therefore selected the Simple Kriging (SK) spatial interpolation method to calculate the spatially averaged precipitation and the potential evapotranspiration for the Jing River Basin because SK has the lowest root mean squared error (RMSE) among the 12 of the most popular spatial interpolation methods (see Supplementary Material 1 in Supplementary Material available online at http://dx.doi.org/10.1155/2015/478739).

*2.3.4. Trend Detection.* Parametric and nonparametric methods have been developed and applied successfully in hydroclimatic field analysis because of their ability to detect the physical relationships between ecological elements [43–45]. However, they require more detailed data than other methods, which may be difficult to provide, as well as clear descriptions of processes, which might not have been developed yet [20]. In this study, a linear regression method is used to detect the precipitation trends, potential evapotranspiration, runoff, and sediment load.

*2.3.5. Similar Weather Condition Analysis.* Because the LUC data are only available from 1980 onward and do not cover all years, and because precipitation is the main source of runoff and the main driving force of erosion, paired periods with similar precipitation and potential evapotranspiration conditions (SPEC) were selected to facilitate the analysis [46, 47]. To define paired periods with SPEC the following conditions were applied: (1) the two years should have annual precipitation that differs by less than 2%; (2) the potential evapotranspiration should differ by less than 2%; and (3) the two years should be more than five years apart. Because the evolution of natural landforms and vegetation is quite slow, the changes to runoff and sediment load in a SPEC pair are mainly induced by human activities. Applying the conditions stated above, we selected nine pairs of years. It is important to emphasize that this method assumes that the weather conditions were similar based on just the yearly averages and totals. This is a significant assumption for the study area, because it is well known that individual rainfall events can contribute approximately 60% to 90% of the yearly rainfall total [48]. Though the individual rainfall events are more functional to describe the impacts of rainfall on runoff and sediment generation in its influenced area, the rainfall events are very uneven in space that it is difficult to use data of events in the whole basin. The monthly data of precipitation and $\mathrm{ET}_0$ is rational to abstract the similar weather conditions of two years at the regional scale.

*2.3.6. LUC Change Analysis.* The areas of each category of the five maps are calculated by geographic information system to show the land use change process in several sections. A LUC change matrix was used to illustrate the changes of land use and cover for the period from 1980 to 2005 based on the LUC maps.

*2.3.7. Landscape Metrics Analysis.* In this study, twelve common landscape indicators were presented [8, 9, 49]. Three types of landscape metrics (fragmentation, shape, and diversity) were calculated with Fragstats model [50]. Five metrics (number 1–number 5) were analyzed to describe landscape feature at the patch level (Table 1). Besides these indicators, eight more metrics (number 5–number 12) were added at landscape level [49, 51, 52].

## 3. Results

*3.1. Statistics of Runoff and Sediment Load.* The statistics for runoff, sediment load, sediment concentration, precipitation, and potential evapotranspiration are shown in Table 2. The mean annual runoff, sediment concentration, and sediment load were 1596.6 Mm$^3$, 163.3 kg m$^{-3}$, and 214.8 Mt, respectively. The difference between the maximum and minimum values for each variable was large. The runoff in 1964 was 5.96 times that in 2009; the sediment concentration in 1977 was 15.49 times that in 2011 and the sediment load in 1964 was 25.29 times that in 2011. The coefficients of variation (CVs) of runoff, sediment concentration, and sediment load were 0.421, 0.478, and 0.708, respectively, showing that the runoff and sediment changes are highly unstable.

Table 1: Regional landscape characteristics in this study.

| Category | Number | Code | Code description |
|---|---|---|---|
| Fragmentation metric | 1 | PD | Patch density |
| | 2 | ED | Edge density |
| | 3 | LSI | Landscape shape index |
| Shape metric | 4 | PARA | Perimeter to area ratio |
| | 5 | FI | Fragmentation index |
| | 6 | FRAC | Fractal distribution index |
| | 7 | PAFRAC | Perimeter-area fractal dimension |
| | 8 | CONTAG | Contagion index |
| Diversity metric | 9 | SHDI | Shannon's diversity index |
| | 10 | MSIDI | Modified Simpson's Diversity index |
| | 11 | SHEI | Shannon's evenness index |
| | 12 | MSIEI | Modified Simpson's Evenness index |

*3.2. Variation of Precipitation and Potential Evapotranspiration.* Potential evapotranspiration and precipitation are the main weather variables that influence runoff and sediment. Precipitation is the driving force for soil erosion and sediment delivery, as well as the water source for runoff and soil moisture in this region. In the Jing River Basin, the mean annual precipitation and potential evapotranspiration were 503.7 mm and 943.4 mm, respectively (Table 2). The maximum a.pptn (781.3 mm) in 1964 was 2.21 times the minimum a.pptn (353.4 mm) in 1997, and the CV for a.pptn was 0.194. The maximum recorded mean potential evapotranspiration in 1997 (1046.7 mm) was 1.32 times the minimum recorded value in 1964 (792.1 mm), with a low CV of 0.060. The precipitation and potential evapotranspiration were more stable than runoff, sediment concentration, and sediment load.

*3.3. Trends of Runoff and Sediment Load.* The annual sediment concentration had no significant trend during the study period ($P = 0.1066$). Both the annual runoff and the sediment load had significant trends with a linear decline over the past 55 years (Figure 2). The average rate of decline of annual runoff and sediment load was 23.07 $\mathrm{Mm^3\,yr^{-1}}$ and 4.23 $\mathrm{Mt\,yr^{-1}}$, respectively. There was significant ($P < 0.001$) synchronized variation between the annual runoff and sediment load.

*3.4. Trends of Precipitation and Potential Evapotranspiration.* The annual precipitation declined ($P = 0.043$) during the study period, while the annual potential evapotranspiration had no significant trend (Figure 3).

*3.5. Precipitation and $ET_0$ between Paired Years with SPEC.* The nine pairs of years based on similar weather conditions (Table 3) range from the 1960s to the 2000s, and the number of years of difference between each pair varies from 8 to 40. The difference in a.pptn and $ET_0$ ranged between 2.0–7.6 mm and −16.0–16.8 mm, respectively, from the absolute value of the paired years (Table 3), and the difference in a.pptn and $ET_0$ from the relative value of the paired years ranged between 0.37–1.38% and −1.71–1.84%, respectively.

*3.6. Runoff and Sediment Load between the Pairs of Years with SPEC.* The SPEC analysis of the changes in runoff ($R$), sediment load ($S$), and sediment concentration (SC) is shown in Table 4. In SPEC, $R$ of the later year is less than that of the earlier year of the pair. There is a general decreasing trend in $R$, which is in agreement with the statistics results (Figure 2). Seven (1, 2, 3, 4, 5, 8, and 9) of the nine pairs showed a reduced $S$, and six (1, 3, 4, 5, 8, and 9) of the nine pairs had a reduced SC. When comparing the later year with the earlier year in each pair, six (1, 3, 4, 5, 8, and 9) of the nine showed a reduced $R$, SC, and $S$; two (6 and 7) had a decreasing $R$ and an increasing SC and $S$; and one (2) had a negative SC, but positive $R$ and $S$. The amplitudes of $R$, $S$, and SC between the paired years ranged within −42.06–54.72%, −806.47–83.90%, and −827.27–77.52%, respectively. The $R$, $S$, and SC for Pair 3 showed the most dramatic change among the nine pairs, with amplitudes of $R$, $S$, and SC of −31.17%, −806.47%, and −827.27%, respectively.

*3.7. An Example of LUC and NDVI Change in Pair 5.* Because precipitation and potential evapotranspiration are similar for the paired years, the effects on $R$, $S$, and SC can be attributed primarily to human activity. We selected pair 5 with runoff, sediment load, and sediment concentration amplitudes of 54.72%, 83.90%, and 74.17%, respectively, as an example and applied the LUC data digital maps from 1980 and 2005 to further confirm the applicability of the SPEC method to analyzing the influence of human activity on the runoff and sediment load of a river. LUC is not only an important component of global environmental change and one of the most direct forms of human activities, but also a major cause of global environmental change. Land use change can directly affect the surface runoff, watershed runoff yield [15, 53]. Figure 4 provides a visual representation of the LUC for upstream of ZHS in 1980 and 2005. The proportion of unchanged LUC area during this time period was 97.48%, while 2.52% had changed. The variability of different LUC types from 1980 to 2005 is shown in Figure 5, with forest, arable land, and grassland accounting for over 98.10% of the entire area. Over the study period, the area covered by forest increased sporadically from 358.4 thousand ha in 1980 to 383.0 thousand ha in 2005, a conversion of 6.84% of the entire region to forest over 25 years. The grassland area first decreased from 2030.1 thousand ha in 1980 to 1958.0 thousand ha in 1985 and then increased from 1965.2 thousand ha in 1996 to 2035.7 thousand ha in 2005. The area used as arable land declined intermittently from 1891.1 thousand ha in 1980 to 1851.5 thousand ha in 2005 and then increased by 9.3 thousand ha from 1985 to 1996. The built-up land area increased to 1.5 times its original size because of intensive housing and infrastructure development; however, it was still less than 40 thousand ha by 2005. Approximately 92% of

Table 2: Statistics for runoff ($R$), sediment concentration (SC), sediment load ($S$), precipitation (pptn), and potential evapotranspiration ($ET_0$) for the Jing River for 1958–2012.

| Statistic | $R$ $Mm^3$ | $S$ Mt | SC $kg\,m^{-3}$ | a.pptn mm | a.$ET_0$ mm |
|---|---|---|---|---|---|
| Mean | 1596.6 | 214.8 | 163.3 | 503.7 | 943.4 |
| Minimum | 701.8 | 27.8 | 21.5 | 353.4 | 792.1 |
| (Year) | (2009) | (2011) | (2011) | (1997) | (1964) |
| Maximum | 4184.0 | 703.0 | 333.0 | 781.3 | 1046.7 |
| (Year) | (1964) | (1964) | (1977) | (1964) | (1997) |
| Median | 1410.0 | 160.0 | 141.0 | 488.6 | 949.6 |
| Standard deviation | 6.7 | 1.5 | 78.1 | 97.6 | 57.0 |
| Confidence levels (95.0%) | 1.82 | 0.41 | 21.12 | 26.38 | 15.41 |
| Coefficients of variation | 0.421 | 0.708 | 0.478 | 0.194 | 0.060 |

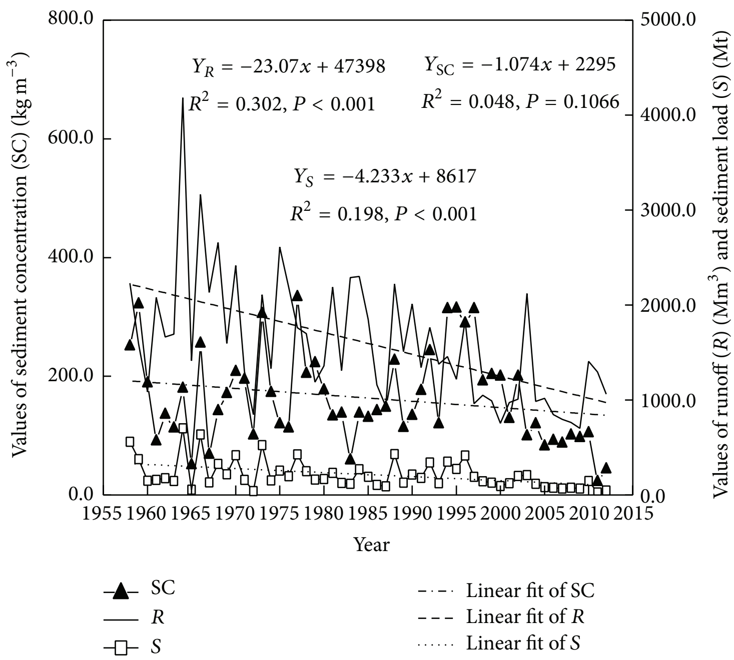



Figure 2: Annual runoff, sediment concentration, and sediment load change in 1958–2012.

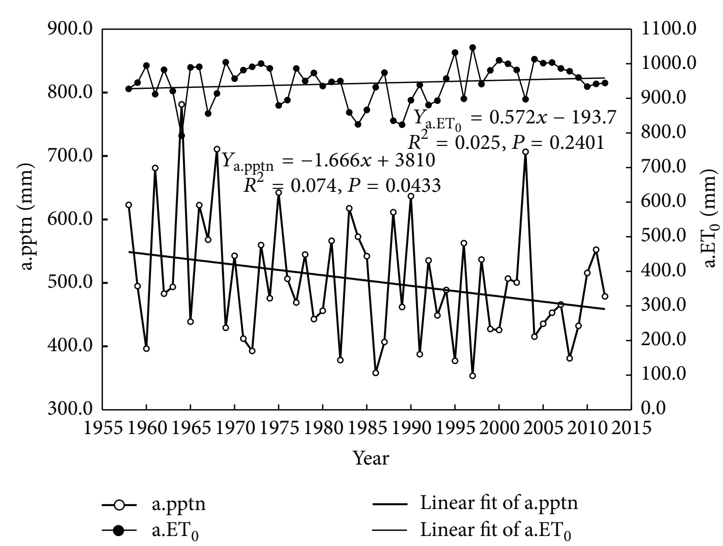



Figure 3: Annual precipitation and $ET_0$ change in 1958–2012.

Table 3: Precipitation and $ET_0$ of the paired years.

| Number | Paired years with SPEC | | | a.pptn/mm | | | | a.$ET_0$/mm | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Year 1 | Year 2 | D-year | Year 1 | Year 2 | D-a.pptn | *a* (%) | Year 1 | Year 2 | D-a.$ET_0$ | *a* (%) |
| 1 | 1968 | 2003 | −35 | 710.7 | 706.7 | 4.0 | 0.56 | 913.9 | 897.1 | 16.8 | 1.84 |
| 2 | 1975 | 1990 | −15 | 642.2 | 636.7 | 5.5 | 0.86 | 879.4 | 894.4 | −15.0 | −1.71 |
| 3 | 1978 | 2011 | −33 | 544.6 | 552.2 | −7.6 | −1.38 | 950.1 | 941.7 | 8.4 | 0.89 |
| 4 | 1970 | 1978 | −8 | 542.6 | 544.6 | −2.0 | −0.37 | 956.7 | 950.1 | 6.6 | 0.69 |
| 5 | 1977 | 2007 | −30 | 469.0 | 465.9 | 3.1 | 0.66 | 986.1 | 986.2 | −0.1 | −0.01 |
| 6 | 1965 | 1979 | −14 | 438.8 | 442.9 | −4.1 | −0.93 | 989.1 | 973.1 | 16.0 | 1.64 |
| 7 | 1965 | 2005 | −40 | 438.8 | 435.5 | 3.3 | 0.75 | 989.1 | 1001.6 | −12.5 | −1.26 |
| 8 | 1971 | 1987 | −16 | 411.9 | 406.7 | 5.2 | 1.26 | 981.2 | 973.9 | 7.3 | 0.74 |
| 9 | 1960 | 1972 | −12 | 396.3 | 392.7 | 3.6 | 0.91 | 994.6 | 990.8 | 3.8 | 0.38 |

Note: D-year is the year in Year 1 minus that of Year 2; D-a.pptn is the precipitation in Year 1 minus that of Year 2; D-a.$ET_0$ is the $ET_0$ in Year 1 minus that of Year 2; and *a* is the amplitude (%).

Table 4: Changes to runoff and sediment load within the nine pairs of years with SPEC.

| Character | Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Pairs of years with SPEC | Year 1 | 1968 | 1975 | 1978 | 1970 | 1977 | 1965 | 1965 | 1971 | 1960 |
| | Year 2 | 2003 | 1990 | 2011 | 1978 | 2007 | 1979 | 2005 | 1987 | 1972 |
| Runoff ($Mm^3$) | Year 1 | 2658 | 2610 | 1700 | 2415 | 1760 | 1412 | 1412 | 1300 | 1086 |
| | Year 2 | 2120 | 2011 | 1296 | 1700 | 797 | 1190 | 1019 | 932 | 847 |
| | Difference | 538 | 599 | 404 | 715 | 963 | 222 | 393 | 368 | 239 |
| | *a* (%) | 20.24 | 22.95 | 31.17 | 42.06 | 54.72 | 18.66 | 27.83 | 28.31 | 22.01 |
| Sediment load (Mt) | Year 1 | 328 | 256 | 252 | 419 | 428 | 56 | 56 | 159 | 149 |
| | Year 2 | 209 | 215 | 27.8 | 252 | 68.9 | 162 | 83 | 92 | 42 |
| | Difference | 119 | 41 | 224.2 | 167 | 359.1 | −106 | −27 | 67 | 107 |
| | *a* (%) | 36.28 | 16.02 | 806.47 | 66.27 | 83.9 | −65.43 | −48.21 | 42.14 | 71.81 |
| Sediment concentration (kg $m^{-3}$) | Year 1 | 141 | 119 | 204 | 207 | 333 | 49.9 | 49.9 | 194 | 188 |
| | Year 2 | 99 | 133 | 22 | 204 | 86 | 222 | 82 | 147 | 100 |
| | Difference | 42 | −14 | 182 | 3 | 247 | −172.1 | −32.1 | 47 | 88 |
| | *a* (%) | 29.79 | −11.76 | 827.27 | 1.47 | 74.17 | −77.52 | −64.33 | 24.23 | 46.81 |

Note: *a* is amplitude (%).

the built-up area was converted from arable land. The actual areal change of wetland and water bodies (Figure 5) was less than 2.3 thousand ha during the study period. The area classified as barren land changed by less than 0.25 thousand ha during the study period, apart from reaching a peak of up to 7.8 thousand ha in 1996.

A matrix based on the LUC changes in the ZHS upstream area was developed to show the change between different types of land use categories in 1980 and 2005 (Table 5). We found that 18.18 thousand ha, 1.35 thousand ha, 0.03 thousand ha, and 0.03 thousand ha of forest changed into grassland, arable land, built-up land, and water bodies, respectively, and 32.99 thousand ha of grassland and 11.16 thousand ha of arable land changed into forest. During the same period, 6.50 thousand ha, 0.70 thousand ha, and 0.08 thousand ha of grassland changed into arable land, built-up land and wetland, and water bodies, respectively.

Spatial configuration of land covers also influences connectivity between sediment source and sink, as sediment transport capacity is different for different land cover types [10, 11, 13]. Most of the spatial pattern of land use experienced little changes during the whole study period, apart from LSI of both arable land and barren land, and PARA of wetland and water body increased (Supplementary Material 2). A high LSI and PARA indicate a more fragmented land use pattern with more small isolated patches of different land use. Therefore, although the net amount of change between the major land use systems (i.e., forest, grassland, and arable land) was relatively small, the spatial distribution and fragmentation of the LUC systems changed significantly.

NDVI is a sensitive indicator of green plant material and an index of the vegetation cover of a region [54], which directly affects the water yield and sediment load. Considering availability of data on NDVI, we analyzed NDVI data in 1982 and 2005 for pair 5. The mean annual NDVI for 1982 and 2005 were 0.398 and 0.431, respectively. The NDVI decreased in 27.56% and increased in 72.44% of the area. The vegetation cover increased mainly in the upper and

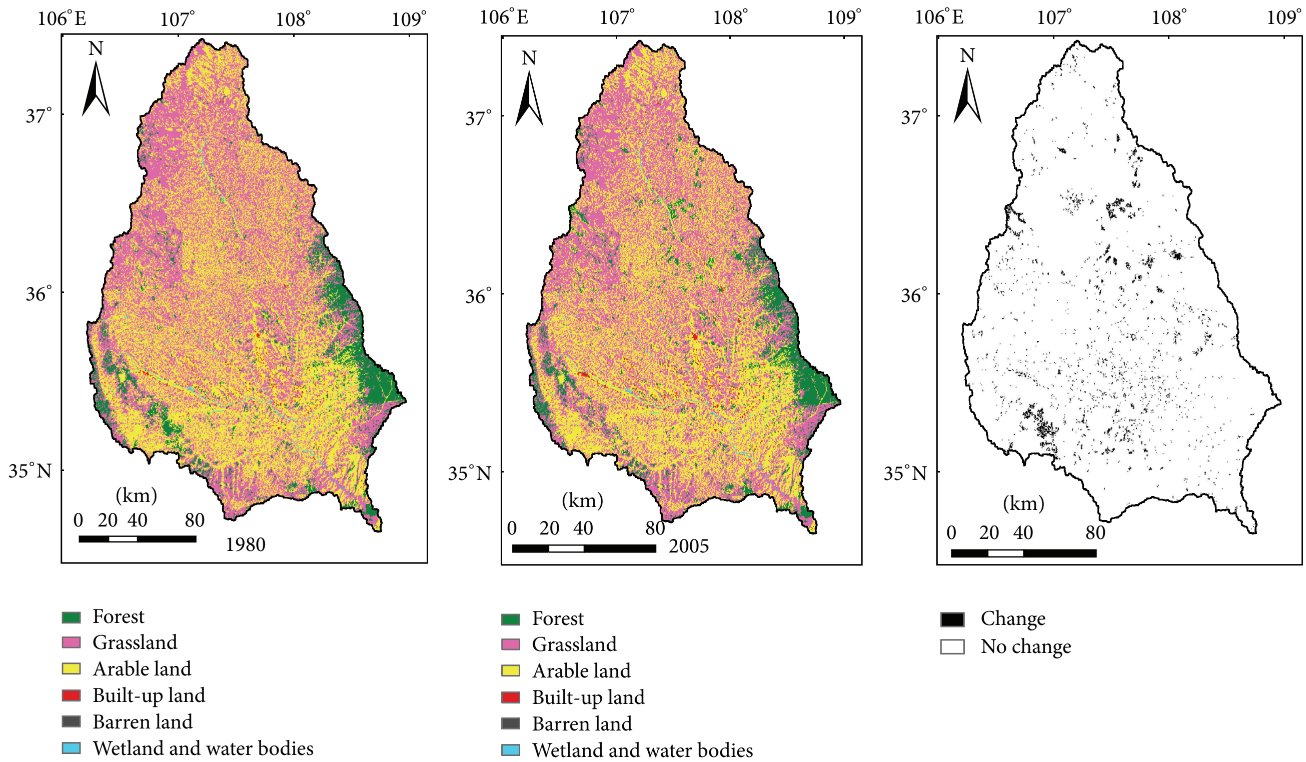



Figure 4: LUC of the ZHS upstream area from 1980 and 2005.

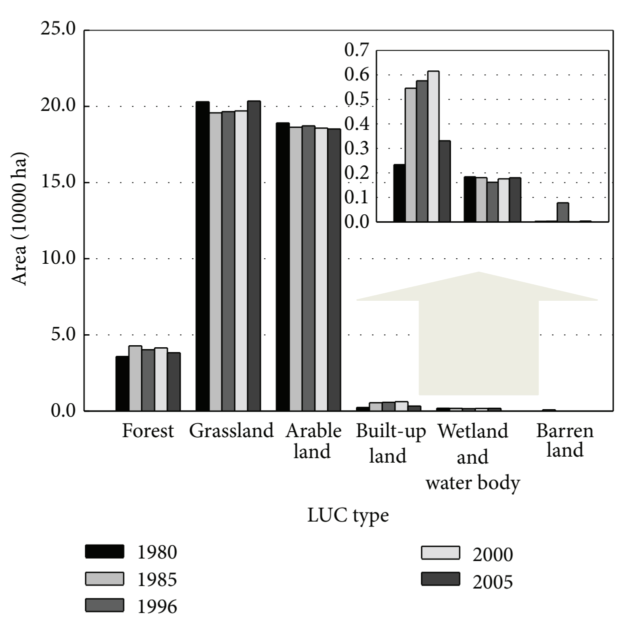



Figure 5: LUC change in the Jing River Basin from 1980 to 2005.

the middle reaches of the Jing River (Figure 6), which may be the main reason for the runoff reduction in the Jing River Basin [55].

*3.8. Soil and Water Conservation Engineering.* In addition to land use and NDVI changes, engineering is also likely to have influenced the runoff, sediment load, and sediment concentration of the Jing River. Based on the Soil and Water Conservation Data Compilation of the Yellow River Basin (Table 6), there are 94 reservoirs in the upstream area of ZHS, with 36, 20, and 38 reservoirs in Ningxia, Gansu, and Shaanxi, respectively. The total area controlled by reservoirs is 8870.4 $km^2$. The amount of siltation measured was 572.4 $Mm^3$, 20.4 $Mm^3$, and 17.1 $Mm^3$ in the reservoirs, the key projects for gully control, and check dam, respectively. Using the dry bulk density of sediment of 1.35 $t\,m^{-3}$ [56], an estimated 823.3 Mt of sediment, or 20.58 Mt per year when considering the 40-year period between the start of the implementation and 1999, silted up this region and therefore did not enter the Jing River. This is a much lower value than the mean of 214.8 Mt per year that is transported from the Jing River Basin as sediment load (Table 2). The total amount of siltation (823.3 Mt), or the annual average (20.58 Mt/yr), may explain the decreased trend of sediment load in Figure 2. In addition, areas covered by planted forest and grassland were quite large by 1999, with 362.45, 89.64, 82.78, and 285.23 thousand ha of arbor, shrub, economic trees, and grass, respectively (Soil and Water Conservation Data Compilation of the Yellow River Basin). The soil and water control functions of these areas are therefore closely related to the vegetation coverage, and the soil erosion of land with coverage of more than 70% would be well controlled [57].

*3.9. Causes for Decreased Runoff and Sediment Load.* The variability of runoff and sediment in the Jing River Basin has been shown above. A relatively small decrease in rainfall

Table 5: LUC change matrix of the ZHS upstream area from 1980 to 2005 (in 1000 ha).

| Year | LUC | 2005 ($j$) 1 (forest) | 2 (grassland) | 3 (arable land) | 4 (built-up land) | 5 (wetland and water bodies) | 6 (barren land) | 1980 Total |
|---|---|---|---|---|---|---|---|---|
| 1980 ($i$) | 1 (forest) | 338.80 | 18.18 | 1.35 | 0.03 | 0.03 | — | 358.38 |
| | 2 (grassland) | 32.99 | 1989.81 | 6.50 | 0.70 | 0.08 | — | 2030.08 |
| | 3 (arable land) | 11.16 | 27.49 | 1843.06 | 9.06 | 0.10 | 0.28 | 1891.14 |
| | 4 (built-up land) | — | 0.08 | 0.03 | 23.26 | — | — | 23.36 |
| | 5 (wetland and water bodies) | — | 0.13 | 0.43 | 0.05 | 17.81 | — | 18.41 |
| | 6 (barren land) | — | — | 0.18 | — | — | 0.05 | 0.23 |
| 2005 | Total | 382.95 | 2035.69 | 1851.54 | 33.09 | 18.01 | 0.33 | 4321.60 |

Note: $V_{i,j}$ is the value at the cross of row $i$ in 1980 and column $j$ in 2005. The symbols $i$ and $j$ denote the following: 1 = forest; 2 = grassland; 3 = arable land; 4 = built-up land; 5 = wetland and water bodies; 6 = barren land. $V_{i,j}$ represents the area within a category with no change if $i = j$. The area of category $i$ in 1980 changed into category $j$ in 2005 if $i \neq j$; for example, there were approximately 18.9 thousand ha and 18.5 thousand ha arable land in 1980 and 2005, respectively, and approximately 18.4 thousand ha of land was always arable land without any change ($V_{3,3}$). However, there were approximately 0.11, 0.27, 0.09 thousand ha of arable land in 1980 converted into forest, grassland, and built-up land ($V_{3,1}$, $V_{3,2}$, and $V_{3,4}$), respectively, and approximately 0.013, 0.065, 0.00025, 0.004, and 0.002 ha of forest, grassland, built-up land, wetland and water bodies, and barren land changed into arable land ($V_{1,3}$, $V_{2,3}$, $V_{4,3}$, $V_{5,3}$, and $V_{6,3}$), respectively.

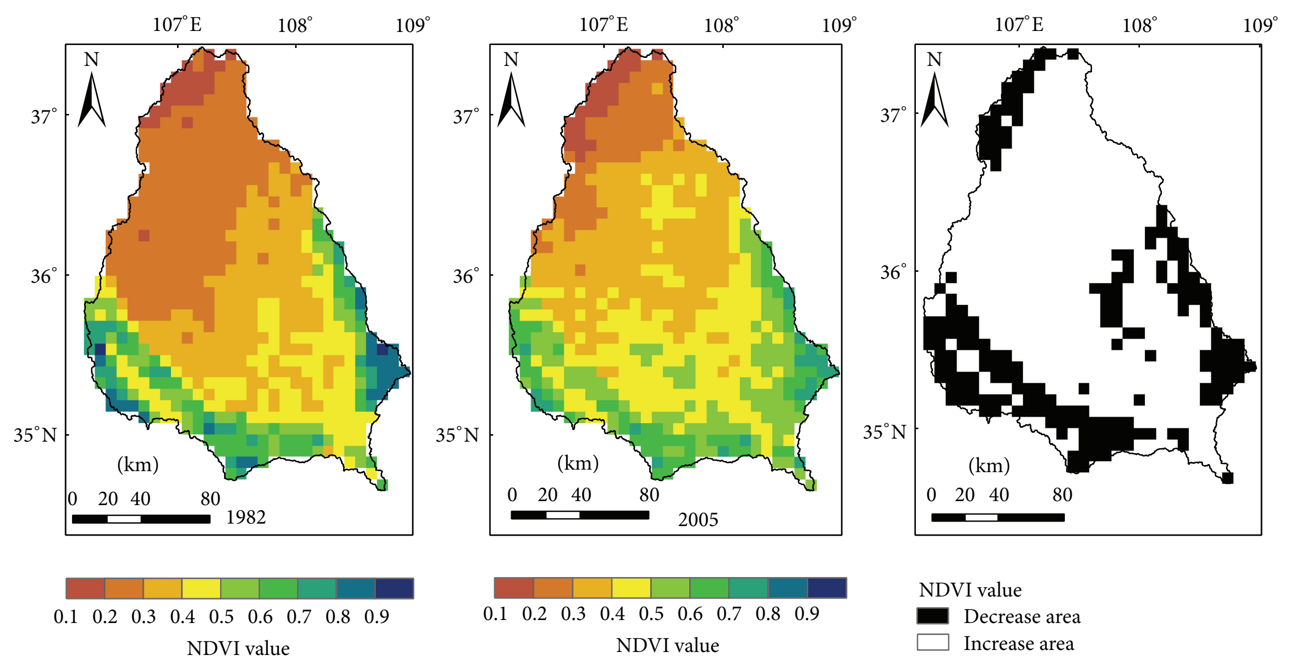



Figure 6: NDVI change in 1982 and 2005 of the area upstream of ZHS.

and sediment concentration, and a relatively small increase in $ET_0$, causes a significant decrease in the runoff and sediment load. Data on land use change indicates that the main changes that have occurred in the watershed consist of an increase in forested area and a decrease in arable land, both of which would influence runoff and erosion. Furthermore, the increase of vegetation cover will also have an effect on runoff and erosion. Finally, as shown in Section 3.8, soil and water conservation engineering measures also trapped large amounts of sediment much of which would have otherwise reached the outlet of the Jing River Basin.

## 4. Discussions

In this paper, we selected discrete time periods based on the similar weather conditions to analyze the effect of human activities on runoff and erosion. In this way, we ensured a relative uniformity for precipitation, which generates runoff

Table 6: Engineering measures of area upstream of ZHS before 1999 (in ha).

| Type | Character | Unit | Ningxia | Gansu | Shaanxi | Amount |
|---|---|---|---|---|---|---|
| Reservoir | Number | Set | 36 | 20 | 38 | 94 |
| | Control area | $km^2$ | 1354.9 | 3969.5 | 3546.0 | 8870.4 |
| | Capacity | $Mm^3$ | 93.3 | 566.3 | 365.8 | 1025.4 |
| | Siltation | $Mm^3$ | 39.1 | 316.2 | 217.1 | 572.4 |
| | | Mt | 52.8 | 426.9 | 293.1 | 772.7 |
| Key projects for gully control | Number | Set | 21 | 69 | 5 | 95 |
| | Control area | $km^2$ | 376.1 | 362.7 | 57.4 | 796.2 |
| | Capacity | $Mm^3$ | 57.5 | 49.7 | 3.8 | 111.0 |
| | Siltation | $Mm^3$ | 0 | 18.6 | 1.8 | 20.4 |
| | | Mt | 0 | 25.1 | 2.4 | 27.5 |
| Check dam | Number | Set | 1291 | 143 | 72 | 1506 |
| | Siltation | $Mm^3$ | 0.4 | 7.7 | 9.0 | 17.1 |
| | | Mt | 0.5 | 10.4 | 12.2 | 23.1 |
| Total amount of siltation | | $Mm^3$ | 39.5 | 342.5 | 227.9 | 609.9 |
| | | Mt | 53.3 | 462.4 | 307.7 | 823.3 |

and erosion, but also improved the objectivity and accuracy of the data analysis and therefore the results. Compared with the traditional Hydrologic Method, our method does not use distinct transition points for hydrological series to divide the study period, which avoids divergence resulting from the different dividing of "unaffected" hydrological series period [23, 24]. Under SPEC, the change of runoff and sediment load at the watershed hydrological control station can be treated as human impact directly, and it can be used to explain the results from traditional statistics analysis, and avoiding the influence of the calibration of key parameters in a distributed hydrological model [25–28]. In addition, the results from our method (SPEC method) can be compared to and verify the results from a distributed hydrological model, and they can improve our understanding of the anthropogenic influence on runoff and erosion.

The result of annual runoff in Jing River had significant decline trends during the study period consistent with former studies [23, 55, 58, 59]. Another reason for this is the regulating of 94 reservoirs [23, 59]. In addition, the "rainwater collection project" implemented in the Wei River Basin has also contributed to runoff reduction since 1996; two million small cisterns were built to collect storm water to provide drinking water and irrigation; nearly $6 \times 10^6$ $m^3$ of precipitation water has been collected each year, including the rainfall of precipitation events that did not produce runoff [60]. The sediment concentration had a relatively small decrease during the study period. The reason for this may be explained by the basin landscape pattern change [61]. Although the net amount of change between the major land use systems was relatively small, the spatial distribution and fragmentation of the LUC systems changed significantly. These results were comparable with former studies [8, 9] which also may explain why the runoff and sediment decrease. These findings have important consequences for integrated basin management.

There are two alternatives for the analysis of the influence of human activities using the similar weather condition analysis method. The first is considering the effect of human activities effect on runoff and erosion as a whole, and not distinguishing between different human activities. If more data is available, the effect of the different types of activity, such as irrigation, industrial water consumption could be distinguished in the runoff and sediment load. The second option is to consider the same human activities occurring in the paired years as a net change instead of a new effect on runoff and erosion, which makes it easier to describe the influence of human activities between the paired years.

On the Loess Plateau, the main surface runoff and erosion are generated by rainstorms characterized by high intensity and short duration. When the scale of the data and time was the same, the similar weather condition analysis method could also be applied to daily analysis. Furthermore, the selection of thresholds was flexible. The smaller the threshold and the fewer paired years, the better the accuracy of the results. Finally, if more hydrological data, such as soil water storage and underground runoff, are available, the accuracy of the results from this similar weather condition analysis method will improve. Because of the complexity of geological processes, there are obvious disadvantages, such as lack of mechanism in this method when describing changes to geography. If more methods, such as model simulation, were combined with the similar weather condition analysis, this would help clarify the variability in the characteristics and influencing factors of the hydrologic and sedimentary elements.

## 5. Conclusions

The river runoff and sediment load have decreased substantially over the past 55 years. There are a significant decline in the precipitation and a small, statistically not significant,

increase in potential evapotranspiration. There is a significant ($P < 0.001$) synchronized variation between annual runoff and annual sediment load.

Nine pairs of years were selected ranging from the 1960s to the 2000s using SPEC method. All paired years showed the runoff reduced and sediment load reduced in seven of the nine pairs. These results were consistent with the trend detected by regression analysis. This means that the reduction in the sediment load of the Jing River Basin caused by human activities occurs in most of the time period studied. The extent of the decrease in runoff and sediment load caused by human activities was related to the compared time period. That is, the variability of runoff and sediment load caused by human activities is different in different pair year.

The human impacts relating to LUC change and soil and water measures in the basin were important. Not only was there a change of sloping cropland into nonfood crop vegetation or cultivable terraces, but 823.3 Mt of silt was collected in reservoirs and behind check dams during 1960–1999. Land use change analysis indicates that overall changes in the surface area of the major land use systems were relatively small. However, the spatial distribution and fragmentation of the various land use classes changed significantly during the past decades.

## Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

## Acknowledgments

This research was supported by the National Natural Science Foundation of China (41171420), the Key Research Program of the Chinese Academy of Sciences (KZZD-EW-04), the West Light Foundation of The Chinese Academy of Sciences (2013-165-04), and National Key Basic Research Special Foundation of China (2014FY210100).

## References

[1] J. Siakeu, T. Oguchi, T. Aoki, Y. Esaki, and H. P. Jarvie, "Change in riverine suspended sediment concentration in central Japan in response to late 20th century human activities," *Catena*, vol. 55, no. 2, pp. 231–254, 2004.

[2] A. M. Fanos, "The impact of human activities on the erosion and accretion of the Nile Delta coast," *Journal of Coastal Research*, vol. 11, no. 3, pp. 821–833, 1995.

[3] J. D. Carriquiry and A. Sánchez, "Sedimentation in the Colorado River delta and upper gulf of California after nearly a century of discharge loss," *Marine Geology*, vol. 158, no. 1–4, pp. 125–145, 1999.

[4] J. X. Xu, "Plausible causes of temporal variation in suspended sediment concentration in the upper Changjiang River and major tributaries during the second half of the 20th century," *Quaternary International*, vol. 208, no. 1-2, pp. 85–92, 2009.

[5] C. Miao, J. Ni, A. G. L. Borthwick, and L. Yang, "A preliminary estimate of human and natural contributions to the changes in water discharge and sediment load in the Yellow River," *Global and Planetary Change*, vol. 76, no. 3-4, pp. 196–205, 2011.

[6] S. W. Trimble, "Changes in sediment storage in the Coon Creek basin, driftless area, Wisconsin, 1853 to 1975," *Science*, vol. 214, no. 4517, pp. 181–183, 1981.

[7] C. Boix-Fayos, G. G. Barberá, F. López-Bermúdez, and V. M. Castillo, "Effects of check dams, reforestation and land-use changes on river channel morphology: case study of the Rogativa catchment (Murcia, Spain)," *Geomorphology*, vol. 91, no. 1-2, pp. 103–123, 2007.

[8] C. Boix-Fayos, J. de Vente, M. Martínez-Mena, G. G. Barberá, and V. Castillo, "The impact of land use change and check-dams on catchment sediment yield," *Hydrological Processes*, vol. 22, no. 25, pp. 4922–4935, 2008.

[9] V. Vanacker, G. Govers, S. Barros, J. Poesen, and J. Deckers, "The effect of short-term socio-economic and demographic change on landuse dynamics and its corresponding geomorphic response with relation to water erosion in a tropical mountainous catchment, Ecuador," *Landscape Ecology*, vol. 18, no. 1, pp. 1–15, 2003.

[10] A. Van Rompaey, J. Krasa, and T. Dostal, "Modelling the impact of land cover changes in the Czech Republic on sediment delivery," *Land Use Policy*, vol. 24, no. 3, pp. 576–583, 2007.

[11] J. de Vente, J. Poesen, M. Arabkhedri, and G. Verstraeten, "The sediment delivery problem revisited," *Progress in Physical Geography*, vol. 31, no. 2, pp. 155–178, 2007.

[12] M. M. Bakker, G. Govers, A. van Doorn, F. Quetier, D. Chouvardas, and M. Rounsevell, "The response of soil erosion and sediment export to land-use change in four areas of Europe: the importance of landscape pattern," *Geomorphology*, vol. 98, no. 3-4, pp. 213–226, 2008.

[13] M. Yang, X. Li, Y. Hu, and X. He, "Assessing effects of landscape pattern on sediment yield using sediment delivery distributed model and a landscape indicator," *Ecological Indicators*, vol. 22, pp. 38–52, 2012.

[14] J. M. García-Ruiz and N. Lana-Renault, "Hydrological and erosive consequences of farmland abandonment in Europe, with special reference to the Mediterranean region—a review," *Agriculture, Ecosystems and Environment*, vol. 140, no. 3-4, pp. 317–338, 2011.

[15] M. H. Costa, A. Botta, and J. A. Cardille, "Effects of large-scale changes in land cover on the discharge of the Tocantins River, Southeastern Amazonia," *Journal of Hydrology*, vol. 283, no. 1–4, pp. 206–217, 2003.

[16] J. A. Foley, R. DeFries, G. P. Asner et al., "Global consequences of land use," *Science*, vol. 309, no. 5734, pp. 570–574, 2005.

[17] Z. B. Xin, X. X. Yu, Q. Y. Li, and X. X. Lu, "Spatiotemporal variation in rainfall erosivity on the Chinese Loess Plateau during the period 1956–2008," *Regional Environmental Change*, vol. 11, no. 1, pp. 149–159, 2011.

[18] G. H. Old, G. J. L. Leeks, J. C. Packman et al., "The impact of a convectional summer rainfall event on river flow and fine sediment transport in a highly urbanised catchment: Bradford, West Yorkshire," *Science of the Total Environment*, vol. 314–316, pp. 495–512, 2003.

[19] M. A. Nearing, V. Jetten, C. Baffaut et al., "Modeling response of soil erosion and runoff to changes in precipitation and cover," *Catena*, vol. 61, no. 2-3, pp. 131–154, 2005.

[20] D. E. Walling and D. Fang, "Recent trends in the suspended sediment loads of the world's rivers," *Global and Planetary Change*, vol. 39, no. 1-2, pp. 111–126, 2003.

[21] J. D. Restrepo and J. P. M. Syvitski, "Assessing the effect of natural controls and land use change on sediment yield in a major Andean River: the Magdalena Drainage Basin, Colombia," *AMBIO*, vol. 35, no. 2, pp. 65–74, 2006.

[22] J. K. Lørup, J. C. Refsgaard, and D. Mazvimavi, "Assessing the effect of land use change on catchment runoff by combined use of statistical tests and hydrological modelling: case studies from Zimbabwe," *Journal of Hydrology*, vol. 205, no. 3-4, pp. 147–163, 1998.

[23] D. C. Ran, B. Liu, Q. H. Luo, Z. P. Zhang, and C. R. Wang, "Hydrological analysis on the variability of runoff and sediment in Jinghe watershed," *Yellow River*, vol. 23, no. 2, pp. 9–11, 2001 (Chinese).

[24] S. L. Zhang, Y. H. Wang, P. T. Yu, H. J. Zhang, and X. W. Tu, "Study for separating the impact of precipitation variation and human activities on runoff change of the upper reaches of Jing River," *Journal of Soil and Water Conservation*, vol. 24, no. 4, pp. 53–59, 2010 (Chinese).

[25] Z. G. Wang, H. X. Zheng, C. M. Liu, X. F. Wu, and W. M. Zhao, "A distributed hydrological model with its application to the Jinghe watershed in the Yellow River Basin," *Science in China, Series E: Engineering & Materials Science*, vol. 47, supplement 1, pp. 60–71, 2004.

[26] H. X. Zheng, Z. G. Wang, C. M. Liu, and W. M. Zhao, "GIS/RS based distributed hydrological modeling, 2, model test and application," *Advanced in Water Science*, vol. 15, no. 4, pp. 506–510, 2004 (Chinese).

[27] G. Y. Qiu, J. Yin, Y. J. Xiong et al., "Studies on the effects of climatic warming-drying trend and land use change on the runoff in the Jinghe River Basin," *Journal of Natural Resources*, vol. 23, no. 2, pp. 211–218, 2008 (Chinese).

[28] C. M. Liu, H. X. Zheng, Z. G. Wang, and S. T. Yang, "Multi-scale integrated simulation of hydrological processes using HIMS with verified case studies," *Journal of Beijing Normal University (Natural Science)*, vol. 46, no. 3, pp. 268–272, 2010 (Chinese).

[29] B. Fu and H. Gulinck, "Land evaluation in an area of severe erosion: the loess plateau of China," *Land Degradation & Development*, vol. 5, no. 1, pp. 33–40, 1994.

[30] D. C. Ran, B. Liu, H. Wang, Q. H. Luo, and Y. Ma, *Soil and Water Conservation Measures and their Benefits in Runoff and Sediment Reductions of Typical Tributary in the Middle of Yellow River*, The Yellow River Water Conservancy Press, Zhengzhou, China, 2006.

[31] T. C. Peterson, D. R. Easterling, T. R. Karl et al., "Homogeneity adjustments of in situ atmospheric climate data: a review," *International Journal of Climatology*, vol. 18, no. 13, pp. 1493–1517, 1998.

[32] Z.-X. Fan, A. Bräuning, A. Thomas, J.-B. Li, and K.-F. Cao, "Spatial and temporal temperature trends on the Yunnan Plateau (Southwest China) during 1961–2004," *International Journal of Climatology*, vol. 31, no. 14, pp. 2078–2090, 2011.

[33] R. G. Allen, L. S. Pereira, D. Raes, and M. Smith, "Crop evapotranspiration guidelines for computing crop water requirements," FAO Irrigation and Drainage Paper no. 56, FAO, Rome, Italy, 1998.

[34] C. J. Tucker, J. E. Pinzon, M. E. Brown et al., "An extended AVHRR 8-km NDVI dataset compatible with MODIS and SPOT vegetation NDVI data," *International Journal of Remote Sensing*, vol. 26, no. 20, pp. 4485–4498, 2005.

[35] D. Stow, A. Petersen, A. Hope, R. Engstrom, and L. Coulter, "Greenness trends of Arctic tundra vegetation in the 1990s: comparison of two NDVI data sets from NOAA AVHRR systems," *International Journal of Remote Sensing*, vol. 28, no. 21, pp. 4807–4822, 2007.

[36] L. Zhou, R. K. Kaufmann, Y. Tian, R. B. Myneni, and C. J. Tucker, "Relation between interannual variations in satellite measures of northern forest greenness and climate between 1982 and 1999," *Journal of Geophysical Research*, vol. 108, no. D1, pp. ACL3.1–ACL3.16, 2003.

[37] J. Y. Liu, *Macro Scale Survey and Dynamic Study of Natural Resources and Environment of China by Remote Sensing*, Chinese Scientific Technological Press, Beijing, China, 1996 (Chinese).

[38] Z. P. Shangguan and S. X. Zhen, "Ecological properties of soil water and effects on forest vegetation in the Loess Plateau," *International Journal of Sustainable Development and World Ecology*, vol. 13, no. 4, pp. 307–314, 2006.

[39] J. B. Gates, B. R. Scanlon, X. Mu, and L. Zhang, "Impacts of soil conservation on groundwater recharge in the semi-arid Loess Plateau, China," *Hydrogeology Journal*, vol. 19, no. 4, pp. 865–875, 2011.

[40] T. X. Zhu, Q. G. Cai, and B. Q. Zeng, "Runoff generation on a semi-arid agricultural catchment: field and experimental studies," *Journal of Hydrology*, vol. 196, no. 1–4, pp. 99–118, 1997.

[41] A. G. Journel and C. J. Huijbregts, *Mining Geostatistics*, Academic Press, London, UK, 1978.

[42] P. A. Burrough and R. A. McDonnell, *Principles of Geographical Information Systems*, Oxford University Press, Oxford, UK, 1998.

[43] G. Galeati, "A comparison of parametric and non-parametric methods for runoff forecasting," *Hydrological Sciences Journal*, vol. 35, no. 1, pp. 79–94, 1990.

[44] I. Iorgulescu and K. J. Beven, "Nonparametric direct mapping of rainfall-runoff relationships: an alternative approach to data analysis and modeling?" *Water Resources Research*, vol. 40, no. 8, pp. W084031–W0840311, 2004.

[45] H. Xu, B. Zhou, and Y. Song, "Impacts of climate change on headstream runoff in the Tarim River Basin," *Hydrology Research*, vol. 42, no. 1, pp. 20–29, 2011.

[46] F. Wang, X. M. Mu, R. Li, and J. Y. Jiao, "Change characteristic of the runoff and sediment under the similar precipitation condition in the Beiluohe River," *Journal of Water Resources and Water Engineering*, vol. 19, no. 6, pp. 36–40, 2008 (Chinese).

[47] F. Wang, X. Mu, R. Hessel, W. Zhang, C. J. Ritsema, and R. Li, "Runoff and Sediment load of the Yan River, China: changes over the last 60 yr," *Hydrology and Earth System Sciences*, vol. 17, no. 7, pp. 2515–2527, 2013.

[48] Z. Li, F. L. Zheng, and W. Z. Liu, "Analyzing the spatial temporal changes of extreme precipitation events in the Loess Plateau from 1961 to 2007," *Journal of Natural Resources*, vol. 25, no. 2, pp. 291–299, 2010 (Chinese).

[49] W. Ouyang, A. K. Skidmore, F. H. Hao, and T. J. Wang, "Soil erosion dynamics response to landscape pattern," *Science of the Total Environment*, vol. 408, no. 6, pp. 1358–1366, 2010.

[50] M. C. Neel, K. McGarigal, and S. A. Cushman, "Behavior of class-level landscape metrics across gradients of class aggregation and area," *Landscape Ecology*, vol. 19, no. 4, pp. 435–455, 2004.

[51] J. F. Palmer, "Using spatial metrics to predict scenic perception in a changing landscape: Dennis, Massachusetts," *Landscape and Urban Planning*, vol. 69, no. 2-3, pp. 201–218, 2004.

[52] Y. Liu, Y. H. Lü, and B. J. Fu, "Implication and limitation of landscape metrics in delineating relationship between landscape

pattern and soil erosion," *Acta Ecologica Sinica*, vol. 31, no. 1, pp. 267–275, 2011 (Chinese).

[53] X. M. Zhang, W. H. Cao, Q. C. Guo, and S. H. Wu, "Effects of landuse change on surface runoff and sediment yield at different watershed scales on the Loess Plateau," *International Journal of Sediment Research*, vol. 25, no. 3, pp. 283–293, 2010.

[54] T. N. Carlson, R. R. Gillies, and E. M. Perry, "A method to make use of thermal infrared temperature and NDVI measurements to infer surface soil water content and fractional vegetation cover," *Remote Sensing Reviews*, vol. 9, no. 1-2, pp. 161–173, 1994.

[55] S. L. Zhang, Y. H. Wang, P. T. Yu, H. J. Zhang, G. F. Liu, and X. W. Tu, "Spatio-temporal variance of annual runoff in Jinghe River Basin of northwest China in past 50 years and its main causes," *Scientia Geographica Sinica*, vol. 31, no. 6, pp. 721–727, 2011 (Chinese).

[56] D.-C. Ran, Q.-H. Luo, B. Liu, and H. Wang, "Effect of soil-retaining dams on flood and sediment reduction in middle reaches of Yellow River," *Journal of Hydraulic Engineering*, no. 5, pp. 7–13, 2004 (Chinese).

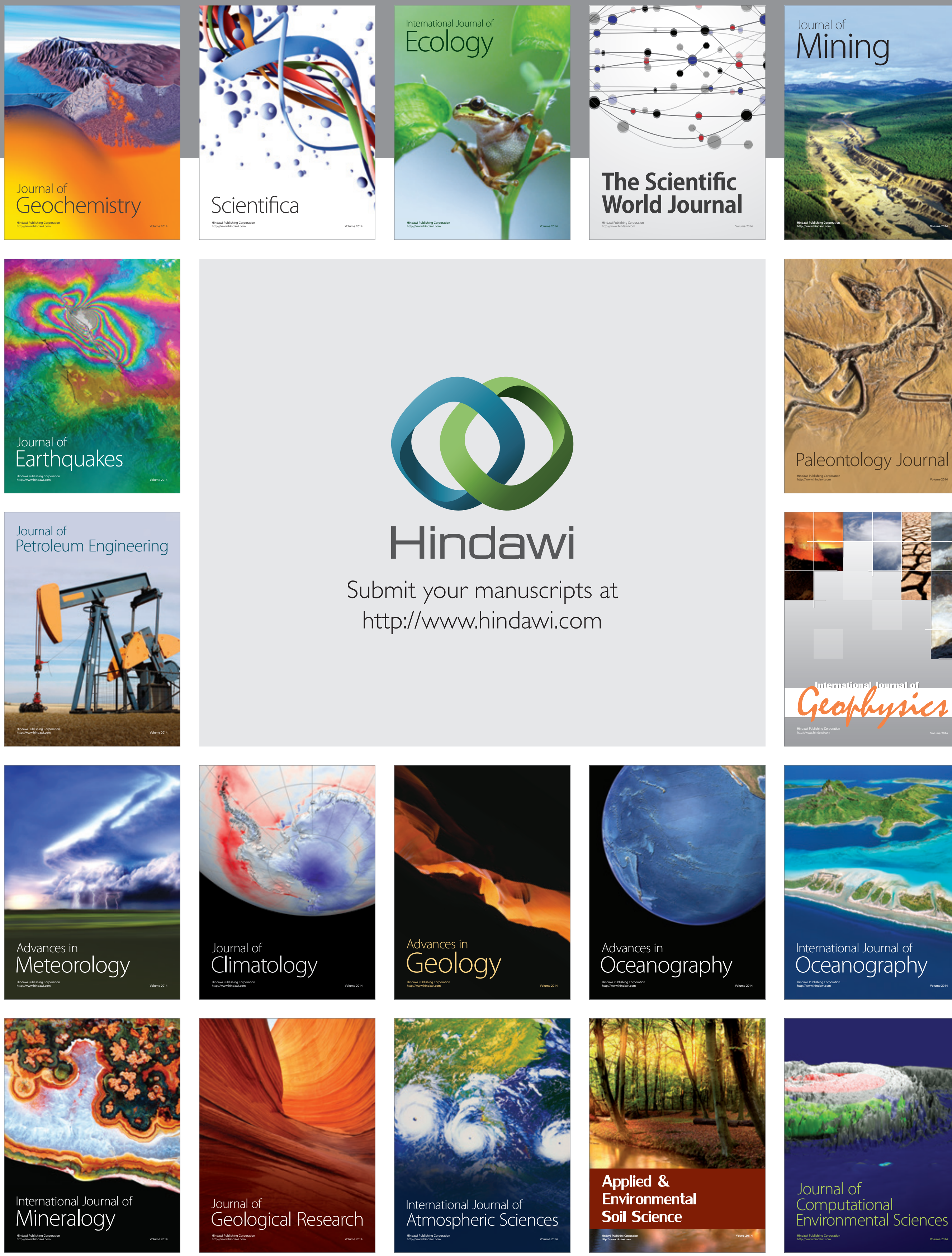
[57] J. Y. Jiao, W. Z. Wang, and J. Li, "Effective cover rate of woodland and grassland for soil and water conservation," *Acta Phytoecologica Sinica*, vol. 24, no. 5, pp. 608–612, 2000 (Chinese).

[58] J. Du and C.-X. Shi, "Effects of climatic factors and human activities on runoff of the Weihe River in recent decades," *Quaternary International*, vol. 282, pp. 58–65, 2012.

[59] P. Gao, V. Geissen, C. J. Ritsema, X. M. Mu, and F. Wang, "Impact of climate change and anthropogenic activities on stream flow and sediment discharge in the Wei River basin, China," *Hydrology and Earth System Sciences*, vol. 17, no. 3, pp. 961–972, 2013.

[60] X. L. Su, S. Z. Kang, X. M. Wei, D. W. Xing, and D. W. Cao, "Impact of climate change and human activity on the runoff of Wei River basin to the Yellow River," *Journal of Northwest A & F University (Natural Science Edition)*, vol. 35, pp. 153–159, 2007 (Chinese).

[61] A. N. Suo, J. Hong, Y. Lin, and J. P. Ge, "Relationships between soil and water loss and landscape pattern on Loess Plateau," *Chinese Journal of Applied Ecology*, vol. 16, no. 9, pp. 1719–1723, 2005 (Chinese).


Journal of Geochemistry
Scientifica
International Journal of Ecology
The Scientific World Journal
Journal of Mining
Journal of Earthquakes
Hindawi
Submit your manuscripts at
http://www.hindawi.com
Paleontology Journal
Journal of Petroleum Engineering
International Journal of Geophysics
Advances in Meteorology
Journal of Climatology
Advances in Geology
Advances in Oceanography
International Journal of Oceanography
International Journal of Mineralogy
Journal of Geological Research
International Journal of Atmospheric Sciences
Applied & Environmental Soil Science
Journal of Computational Environmental Sciences