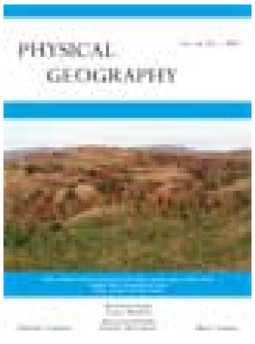

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Factors affecting runoff and sediment yield on the semiarid loess area in Northern Shaanxi Province, China

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The semiarid loess area in north Shaanxi Province is one of the most serious areas of water erosion in China. The Chinese government initiated the project "Grain-for-Green" for soil erosion control in 1999, with significant effect. Vegetation, rainfall, soil, and topography are the most dominant natural factors affecting soil erosion; therefore, the aim of this research was to investigate the effects of these four factors on runoff and soil loss at the runoff-plot scale over five years and use the Gray relational analysis methods to compare the impacts of these factors. Five runoff-measuring sites were established in five different vegetation types. The results show that the relative impacts of the four factors on runoff were: rainfall > soil > topography > vegetation, and the relative impacts of the factors on sediment yield were soil > runoff > rainfall > topography > vegetation. We also analyzed the weights of these four factors on runoff and sediment yield during the wettest year alone. For that year, the relative weights of the factors on runoff were topography > rainfall > soil > vegetation, and the relative weights of the factors on sediment yield were runoff > soil > rainfall > topography > vegetation.

Keywords: Gray relational analysis; runoff; sediment yield; semiarid loess area, Shaanxi Province

Introduction

Water erosion affects the semiarid loess area in north Shaanxi Province, China, which is one of the most serious areas of soil erosion in the world. Vegetation, rainfall, soil, and topography are the primary factors influencing soil erosion, although other factors may be involved (Smith & Wischmeier, 1962). The kinetic impact of rain hitting the soil causes water erosion (Smith & Wischmeier, 1962; Wang, 2000; Zhang, Xie, & Liu, 2002). However, water erosion will not occur unless rainfall exceeds a certain value in a single rainfall event. Many scholars have calculated a rainfall erosion standard based on research in the loess area (Wang, 1983; Wang, Jiao, & Hao, 1998; Xie, Liu, & Zhang, 2000; Zhang & Zhu, 2006; Zhou & Wang, 1992). Vegetation type and coverage can minimize the soil erosion index, the effectiveness of rainfall, and the kinetic energy of raindrops and runoff, and lead to different soil bulk densities (Chen,

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Huang, Gong, Fu, & Huang, 2007; Elwell & Stocking, 1976; Huang et al., 2006; Martinez-Mena, Rogel, Albaladejo, & Castillo, 2000; Sasal, Castiglioni, & Wilson, 2010; Wang, Zhao, Xu, Wang, & Peng, 2013; Xiao, Yao, & Römkens, 2011; Zhang, Liu, & Wang, 2010; Zokaib & Naser, 2011). Splash from raindrops falling on the soil surface may destroy the structure of soil by causing the displacement of soil particles (splash erosion), allowing soil movement and transportation with runoff. Therefore, soil particle size, bulk density, initial water content, and infiltration properties of soils have important roles in water erosion and soil loss (Chen et al., 2007; Defersha & Melesse, 2012; Ekwue & Harrilal, 2010; Fernández, Vega, Fonturbel, Jiménez, & Pérez, 2008; Foltz, Rhee, & Yanosek, 2007; Lentz & Sojka, 1994; Martinez-Mena et al., 2000; Mathys, Klotz, Esteves, Descroix, & Lapetite, 2005; Mohammad & Adam, 2010). Topography, including slope gradient, slope length, and slope aspect, restricts the types and configuration of vegetation and affects soil moisture, runoff production, and runoff pathways, thereby affecting water erosion and soil loss (Chaplot & Le Bissonnais, 2003; DiBiase & Whipple, 2011; Fujimoto, Ohte, & Tani, 2011; Jiang, Liu, & Jia, 1990; Kinnell, 2000; Mathys et al., 2005; Nadal-Romero, Lasanta, & García-Ruiz, 2013; Taye et al., 2013; Wang, 2000).

In this study, high rates of rainfall runoff occurred during special meteorological events, such as rainfall extremes. Some scholars have found that rainfall extremes have become more variable, stochastic, and unpredictable in the context of climate change in the past several decades and will induce more frequent and severe water erosion (Apaydin, Erpul, Bayramin, & Gabriels, 2006; Wei, Chen, Fu, Lü, & Gong, 2009; Wei et al., 2007; Weltzin et al., 2003). At same time, extreme precipitation has increased globally and is predicted to increase further (Easterling et al., 2000). This will probably induce serious soil erosion, especially in fragile ecosystems and under harsh natural conditions, like those on the semiarid loess area of China. In contrast to rainfall in average years of the past, higher rates of rainfall runoff are expected to result in more serious disasters and cause greater losses. Therefore, research on the main factors that affect rainfall runoff is particularly important and has important scientific significance.

However, few scholars have studied the relative weights of the four primary factors that control runoff and sediment yield. The overall objective of this study was to better understand the effects of the four factors – vegetation, rainfall, soil, and topography – on rainfall runoff and sediment yield in the semi-arid loess area of Shaanxi, China. The specific objectives were to (1) analyze the relationship between rainfall amount and runoff as well as that between rainfall and sediment yield; (2) understand the relative weights of vegetation, rainfall, soil, and topography on runoff and sediment over a 5-year period (2009–2013) and in the wettest of those years (2013); and (3) quantify the effects of specific factors on runoff and sediment yield, with factors including vegetation type, vegetation coverage, rainfall amount, rainfall duration, average rainfall intensity, maximum rainfall intensities over different time periods, soil bulk density, soil steady infiltration rate, slope aspect, and slope gradient. The results will be useful in vegetation restoration, water and soil conservation, and flood control in the semi-arid loess area of Shaanxi, China.

Materials and methods

Study area

The study site is located in Wuqi County, which lies northwest of Yan'an City, Shaanxi Province in China (36°33′33″–37°24′27″N 107°38′37″–108°32′49″E). The typical arid and semi-arid area features a warm temperate continental climate that experiences a monsoon season. This area of ecotone between agricultural and pastoral lands has an elevation of 1233–1809 m. The average annual precipitation is approximately 464.5 mm (1957–2013), of which approximately 61% falls during the three summer months (July to September). Monthly temperature ranges from −28.5 °C (December, 1967) to 38.3 °C (July, 2001), with an average annual temperature of 7.9 °C (1957–2013). The typical loess and aeolian sandy soils of Wuqi County have relatively coarse particles (0.05–2 mm) (Compiling Committee of Wuqi Chronicle, 1991). The poor water-retention capacity and low soil fertility of the county's soils make restoration of degraded vegetation quite difficult. The original vegetation has almost disappeared as a result of excessive herding. However, in recent years, the Chinese government has implemented the Green for Grain and the Three North Shelterbelt projects to restore the environment. The Grain for Green Program, launched in 1999, is the largest ecological restoration and rural development program in the world, involving 124 million people, 32 million households in a total of 1897 counties and 25 provinces, and the Xinjiang Production and Construction Corps (Mao et al., 2013). In the first stage, from 1999 to 2013, China reforested a total of 28.20 million ha through the Grain for Green Program. In 2014, the Chinese government started a new round of the Grain for Green Program, with the plan to reforest 42.40 million ha by 2020 (Xie et al., 2015). The Chinese government made a direct investment of 191.8 billion RMB (approximately 28.8 billion US dollars) in the implementation of the Grain for Green Program during the period of 1999–2008, and plans for further investments of Yuan 240 billion, bringing the total investment to no less than Yuan 431.8 billion by 2016 (National Development & Reform Commission, 2008). The Grain for Green Program is the reforestation and ecological restoration program with the largest investment, greatest involvement, and broadest degree of public participation in history (Delang & Yuan, 2015).

The Three North Shelterbelt is the largest and most distinctive artificial ecological engineering project in China (Li et al., 2012). It has been conducted since 25 November 1978 in the "Three-North" (i.e. Northeast China, North China, and Northwest China) regions (Li et al., 2012). The range of this program is 4480 km from east to west and 560–1460 km from south to north (Li et al., 2012). The region involves 13 provinces (autonomous regions or municipalities): Heilongjiang, Jilin, Liaoning, Hebei, Shanxi, Shaanxi, Gansu, Qinghai, Tianjin City, Beijing City, the Inner Mongolia, Ningxia, and Xinjiang autonomous regions. The area encompasses about 4069,000 km^2 and occupies 42.39% of the total territory of the country (Li et al., 2012). The objectives of the Three North Shelterbelt program are to control sand and wind erosion, harness soil and water losses, improve ecological environments, and produce multiple forest products (Li et al., 2012). The major vegetation types are grasses, *Hippophae rhamnoides* (a spiny deciduous shrub) *Pinus tabulaeformis*, *Robinia pseudoacacia* (black locust) and other shrub and tree species. The shrub vegetation contains mixed deciduous broad-leaved species (i.e. *Robinia pseudoacacia* + *Hippophae rhamnoides*) and evergreen coniferous species (i.e. *Hippophae rhamnoides* + *Pinus tabulaeformis*).

Research methods

Runoff plot data collected from 2009 to 2013 were used to analyze the influence various factors on runoff and sediment yield. Between July and August 2013, the Yan'an region experienced the longest, strongest, and most intense, continuous heavy rainfall occurring within the shortest time interval since meteorological records were first kept in 1945 (http://sn.chinadaily.com.cn/news/2013/1010/2686.html). Data from this greater than once-in-a-century rain event were used in the analysis to represent the wettest year.

This research used data from 16 rainfall events (events 1–4 in 2009; 5–6 in 2010; 7–8 in 2011; 9–11 in 2012; and 12–16 in 2013) with rainfall-runoff data from five different vegetation types. The four natural factors having important impacts on runoff and sediment yield – vegetation, rainfall, soil, and topography – were selected for analysis. Vegetation data included vegetation type and coverage. Rainfall data included rainfall amount, rainfall duration, average rainfall intensity, and four levels of rainfall intensity, named I_5, I_{10}, I_{15}, and I_{30} (I_5: 5-min maximum rainfall intensity, I_{10}: 10-min maximum rainfall intensity, I_{15}: 15-min maximum rainfall intensity, and I_{30}: 30-min maximum rainfall intensity). Soil data included soil bulk density and soil steady infiltration rate. Topographic data included slope aspect and slope gradient.

The setting of the runoff plots at the study site

Five 100-m^2 runoff plots (20 m long and 5 m wide) were established in Daji Gully Forest Park; topographic conditions and the type of vegetation in the research area were considered during the process of site selection. The vegetation types of the five runoff plots were: (1) *Hippophae rhamnoides* + *Pinus tabulaeformis* (I), (2) *Hippophae rhamnoides* + *Pinus tabulaeformis* (II), (3) *Pinus tabulaeformis*, (4) *Lespedeza davurica* + *Leymus secalinus*, and (5) *Hippophae rhamnoides*. Table 1 and Figures 1 and 2 show details of the runoff plots.

Meteorological data acquisition in the runoff plots

A simple field meteorological station (HOBO Weather Station, Onset Computer Co., Boerne, MA, USA), including a tilting rain gage, was installed in the study area to record year-round meteorological data.

Runoff and sediment yield measurement

At the lower end of each plot, a sump was used to collect runoff and sediment yield during each rainfall-runoff event. The sump was made of concrete with dimensions of

Table 1. Slope gradient, aspect, elevation, and canopy density of the runoff plots in Wuqi County, Shaanxi Province, China.

Plot code	Vegetation types	Slope gradient (°)	Slope aspect (°)	Elevation (m)	Canopy density (cover degree) 2009 Year	Canopy density (cover degree) 2013 Year
RPa	*Hippophae rhamnoides* + *Pinus tabulaeformis* (I)	12	127	1396	0.48	0.68
RPb	*Hippophae rhamnoides* + *Pinus tabulaeformis* (II)	29	125	1380	0.32	0.57
P	*Pinus tabulaeformis*	17	258	1386	0.40	0.62
G	*Lespedeza davurica* + *Leymus secalinus*	28	267	1398	0.55	0.89
R	*Hippophae rhamnoides*	17	34	1406	0.35	0.65

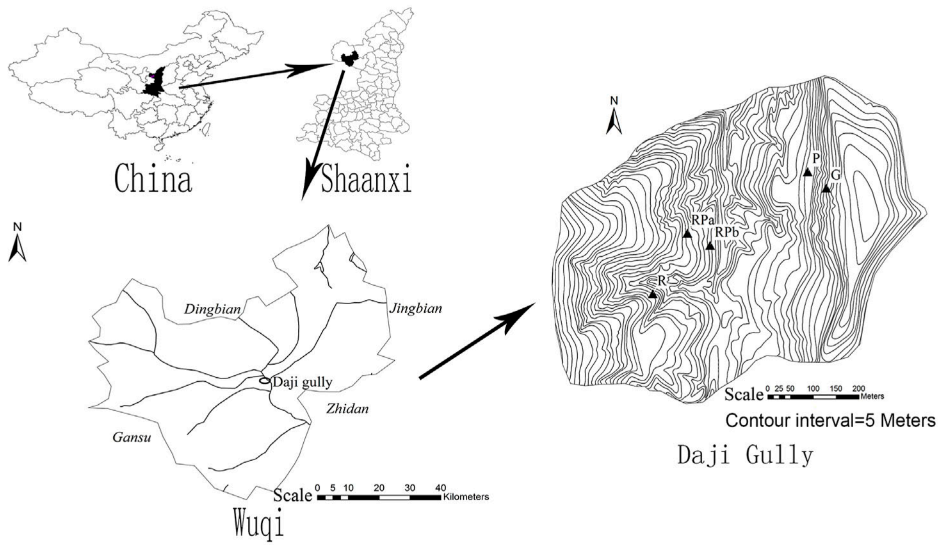


Figure 1. Vicinity maps and a terrain map of the runoff plots in Wuqi County, Shaanxi Province, China.

Figure 2. The condition of the runoff plots at different periods.

1 m (length) × 1 m (width) × 1 m (height). Data were measured from July to September of each year. Following each rainfall event, three samples of nearly 1.65 L of water were removed from the sump for estimating the sediment yield.

Soil bulk density measurement

To measure bulk density, three soil profiles were excavated 1 m deep near the runoff plots at the upper, middle and bottom areas of the plots. Samples were collected from every soil profile at five depths (0–20, 20–40, 0–60, 60–80, and 80–100 cm). Metal rings were used to collect the samples.

Soil stability and infiltration rate measurement

An instrument for measuring the process of the infiltration of water into the soil was used, and the depth of infiltration was calculated by an empirical equation:

$$H = 0.19635 \times h \times \cos a \tag{1}$$

where H is depth of infiltration, h is the change in standing water level, and a is the slope gradient. At the beginning of the experiment, data were recorded once every 10 s for 90 s; then, data were recorded once every 30 s for 5 min; then, data were recorded once every 1 min; the experiment did not stop until the same or almost the same infiltration rate appeared 5–6 times (Zhao, Wei, Chen, Zhu, & Zhou, 2010).

Data processing

In this study, we used the Principal Coordinates Analysis method to convert the qualitative variables, such as vegetation and slope aspect, into quantitative variables (Zhang, 2004).

A Chinese scholar Deng (1982a) first put forward the Gray correlation method. This method is based on the development trends of the degree of similarity or dissimilarity between factors, namely "Gray correlation," as a way to measure the degree of correlation between factors. By comparing a sequence of an established family of curves and a reference sequence curve, using the geometric similarity, one can determine the degree of connection between the reference sequence and comparison sequence set of data. If the shape is similar, then a greater degree of similarity is identified. The comparison sequence and the reference sequence can be for temporal series, or for non-temporal series. Therefore, the Gray correlation method provides a quantitative measurement for the development of a system. This method is suitable for the analysis of a dynamic process (Deng, 1982a, 1982b, 1989, 1990; Liu, Singh, & Xiang, 2005). The specific method is shown below:

Because the units of parameters were always different, parameters usually need to be standardized.

(1) Parameters were standardized using Equation (2):

$$x_i'(k) = \frac{x_i(k) - \min x_i(k)}{\max x_i(k) - \min x_i(k)} \tag{2}$$

where $x_i'(k)$ are new value when the parameters were standardized by Equation (2) and $x_i(k)$ are the original parameters.

(2) Then the correlation coefficient is calculated using Equations (3–6):

$$\Delta x_{0i}(k) = \left|x_0'(k) - x_i'(k)\right| \tag{3}$$

$$\Delta x_{\min} = \min_{\forall j \in i} \min_{\forall k} \left|x_0'(k) - x_j'(k)\right| \tag{4}$$

$$\Delta x_{\max} = \max_{\forall j \in i} \max_{\forall k} \left|x_0'(k) - x_j'(k)\right| \tag{5}$$

$$\gamma\left(x_0'(k), x_i'(k)\right) = \frac{\Delta x_{\min} + \varepsilon \Delta x_{\max}}{\Delta x_{0i}(k) + \varepsilon \Delta x_{\max}} \tag{6}$$

where $\Delta x_{0i}(k)$ is the absolute value of the difference between the comparison sequence and the reference sequence; ξ is distinguishing coefficient; the value of ξ ranges from 0 to 1, but generally $\xi = 0.5$; $\gamma\left(x_0'(k), x_i'(k)\right)$ is the correlation coefficient.

(3) Lastly, the Gray relational grade (Γ) is calculated using Equation (7):

$$\Gamma = \frac{1}{n} \sum_{k=1}^{n} \gamma\left(x_0'(k), x_i'(k)\right) \tag{7}$$

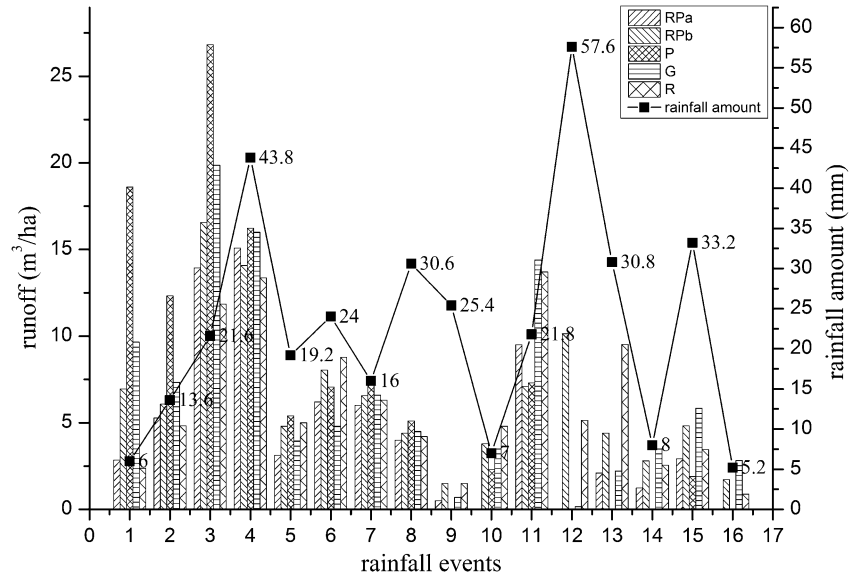
Results and analysis

The relationship between rainfall amount, rainfall runoff, and sediment yield

Figures 3 and 4 show that if rainfall conditions are held constant, the runoff and sediment yield vary among the five runoff plots with different vegetation types. In the 16 rainfall events, relative to variations in sediment yield, variations in runoff were smaller, and the coefficient of variation was 88.26%. The coefficient of variation for sediment yield was 172.70%.

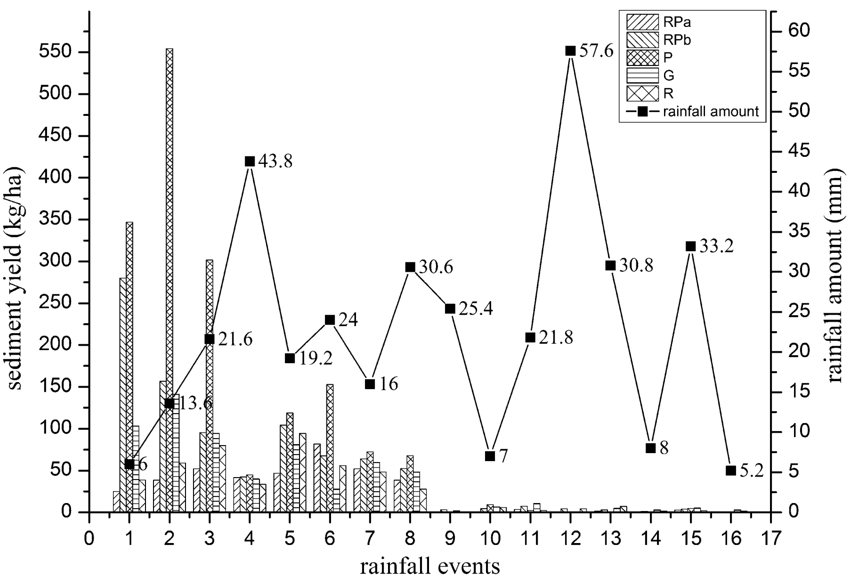
At the preliminary stage, after runoff plots had been constructed, vegetation destroyed, and vegetation canopy lowered, the benefits of soil and water conservation were greater in plots with *Hippophae rhamnoides* + *Pinus tabuliformis* and *Hippophae rhamnoides* vegetation types (Figures 3 and 4). With the recovery of vegetation, less sediment was moved per rainfall event in plots of all of the vegetation types. However, the decrease in rainfall runoff and sediment yield in the *Pinus tabuliformis* plot was more obvious, especially under low rainfall intensity and long duration rainfall events.

Runoff and sediment yield were low on low-gradient slopes with *Hippophae rhamnoides* + *Pinus tabuliformis* when contrasted with runoff plots with other types of vegetation; plots with *Hippophae rhamnoides* had less runoff and sediment yield. Comparing grassland and *Hippophae rhamnoides* + *Pinus tabuliformis* in the same slope gradient, we conclude that trees and shrubs should not be artificially planted to expedite natural succession on slopes with gradients >25°. At same time, we suggest



Note:1-4 test at 2009; 5-6 test at 2010; 7-8 test at 2011; 9-11 test at 2012; 12-16 test at 2013.

Figure 3. Runoff trend with rainfall amounts in the study area of Wuqi County, Shaanxi Province, China.



Note:1-4 test at 2009; 5-6 test at 2010; 7-8 test at 2011; 9-11 test at 2012; 12-16 test at 2013.

Figure 4. Sediment yield trend with rainfall amounts in the study area of Wuqi County, Shaanxi Province, China.

that some shrubs and trees should be present to enhance the effect of soil and water conservation at low slope gradients of <25°. Considering that soil and water losses in pure *Pinus tabuliformis* forest were greater in the early stage of afforestation, we especially recommend *Hippophae rhamnoides* + *Pinus tabuliformis* mixed forests.

Figures 3 and 4 show that vegetation types and rainfall amount had large effects on runoff and sediment yield; however, the tendency for variation of runoff and sediment yield with vegetation types and rainfall amounts was not obvious. This study demonstrated that runoff and sediment yield are not solely determined by rainfall amount or by any single factor, but more likely by a combination of vegetation type, vegetation coverage, rainfall amount, rainfall duration, rainfall intensity (average and for specified time periods), soil bulk density, soil steady infiltration rate, slope aspect, and slope gradient. Therefore, this research used the Gray correlation method to comprehensively analyze the factors that influence runoff and sediment yield from multiple angles.

The factors affecting runoff based on Gray relational analysis

While selecting runoff as a reference sequence, multiple indicators were used as comparative sequences, including vegetation type, vegetation coverage, rainfall amount, rainfall duration, average rainfall intensity, rainfall intensity for specified times (I_5, I_{10}, I_{15}, I_{30}), soil bulk density, soil steady infiltration rate, slope aspect, and slope gradient. Then the Gray relational grade was calculated for the reference and comparison sequences (Table 2). Scientists generally agree that if the Gray relational grade is large, then a close relationship exists between the sequence and reference parameters.

Several conclusions can be drawn using five years of data with the Gray correlation method to analyze the factors that affect runoff. First, rainfall is the most critical factor affecting runoff; it accounted for 27.86% of the total factor weight. This was followed by soil (25.53%), topography (24.34%), and vegetation (22.28%). Second, analysis of the specific factors related to rainfall found that the Gray relational grade is 0.7685 for rainfall amount and that rainfall amount has the strongest influence on runoff of the top seven of 13 indicators analyzed here. Averaged rainfall intensity and I_{30} ranked second and third, respectively. Soil bulk density, another important factor affecting runoff, had a Gray relational grade of 0.6948, which was greater than that of the soil steady infiltration rate. Slope aspect is the most important of the topographic factors affecting runoff; its Gray relational grade was 0.6655, larger than that of slope gradient. Of the vegetation factors, vegetation coverage had the largest effect on runoff and its Gray relational grade, 0.5908, was larger than that of vegetation type (Table 2).

Based on the analysis of factors affecting runoff in the year 2013, which represents years with a maximum number and intensity of rainstorms, one can draw several conclusions. First, topography, rainfall, soil, and vegetation were the four most important factors affecting runoff, accounting for 25.80, 25.55, 25.15, and 23.50% of the variation in runoff, respectively. Second, when topographic factors were analyzed, slope aspect had the greatest effect on runoff; its Gray relational grade was 0.6831, and it ranked second among the 13 specific indicators. Of the rainfall factors, rainfall amount had the greatest effect on rainfall runoff, and it ranked first among the 13 indicators. Other indicators related to rainfall also dominated the Gray correlation; therefore, rainfall factors had the strongest effect on runoff in the wettest year. Among the soil indicators, soil bulk density had a strong effect on runoff. The Gray relational grade for vegetation type and vegetation coverage was more than 0.59, and the two measures had nearly the same value (Table 2).

Table 2. Gray relational grade between runoff and the factors influencing runoff for all five years (2009–2013).

Years		Vegetation					Rainfall				Soil		Topography	
		Vegetation types	Vegetation coverage	Rainfall amount	Rainfall duration	Average rainfall intensity	I_5[a]	I_{10}[b]	I_{15}[c]	I_{30}[d]	Soil bulk density	Soil steady infiltration rate	Slope aspect	Slope gradient
2009–2013 years	Correlation	0.5791	0.5908	0.7685	0.704	0.7526	0.6994	0.7112	0.7358	0.7482	0.6948	0.6455	0.6655	0.6124
	Rank	13	12	1	6	2	7	5	4	3	8	10	9	11
	Proportion (%)	22.28					27.85				25.53		24.34	
2013	wettest year 0.6214	Correlation	0.5966	0.5914	0.6841	0.6801	0.6378	0.6751	0.6195	0.6152	0.6103	0.6399	0.6318	0.6831
	Rank	12	13	1	3	6	4	9	10	11	5	7	2	8
	Proportion (%)	23.50					25.55				25.15		25.80	

[a]I_5 = 5 min maximum rainfall intensity,
[b]I_{10} = 10 min maximum rainfall intensity,
[c]I_{15} = 15 min maximum rainfall intensity,
[d]I_{30} = 30 min maximum rainfall intensity.

Influence of sediment yield based on the Gray relational analysis

Sediment yield was selected as the reference sequence. Comparison sequences were runoff, vegetation type, vegetation coverage, rainfall amount, rainfall duration, average rainfall intensity, rainfall intensities for specific time intervals (I_5, I_{10}, I_{15}, I_{30}), soil bulk density, soil steady infiltration rate, slope aspect, and slope gradient. Then, the Gray relational grade was calculated for the reference and comparison sequences (Table 3). A larger Gray relational grade indicates a closer relationship between sequence and reference parameters.

Several conclusions can be drawn using the Gray correlation method to analyze the factors affecting sediment yield at these loess region study plots during 2009–2013. First, soil and runoff were the two most critical factors affecting sediment yield, accounting for 22.57 and 21.38% of the total proportion, while rainfall and topography accounted for 20.74 and 18.46%, respectively. Second, for the soil factors, soil bulk density had the largest effect on sediment yield and was the main factor among the 14 indicators measured. Runoff ranked third in affecting sediment yield among the 14 indicators. Average rainfall intensity had the largest effect on sediment yield among measures of rainfall and ranked second among the 14 specific indicators. Rainfall amount also had a large effect on sediment yield, ranking fourth among the 14 indicators. The Gray relational grades of other specific factors related to rainfall were also large and had dominant effects on sediment yield. The effects of vegetation type and vegetation coverage on sediment yield were less than those of other indicators; however, the Gray relational grades for vegetation type and vegetation coverage were large (0.5851 and 0.5393, respectively); therefore, sediment yield and vegetation are very closely related.

The year 2013, with extremely heavy rain, represents a wettest year in this region. The analysis of the effects of various factors on sediment yield in 2013 yielded several conclusions. Runoff had the greatest effect on sediment yield, accounting for 24.27% of the total. Soil, rainfall, and topography ranked second, third, and fourth, respectively, in relation to their effect on sediment yield, and their proportions were almost the same. Vegetation had a minimal impact on sediment yield in this unusually wet year, accounting only for 17.64% of the total. The Gray relational grade for runoff was 0.7968, the strongest effect of all 14 factors for sediment yield. Average rainfall intensity and rainfall amount, which ranked second and third among the 14 indicators, had major effects on sediment yield. The soil steady infiltration, the main soil factor that affected sediment yield, ranked fifth among the 14 indicators. Slope aspect, the main topographic factor that affected sediment yield, ranked sixth among the 14 indicators. Vegetation coverage had the greatest effect on runoff among vegetation factors, with a Gray relational grade of 0.6102. Vegetation type had the smallest effect on sediment yield among vegetation factors, with a Gray Relational Grade of 0.5497.

Discussion

Figures 3 and 4 show that, if rainfall conditions are held constant, runoff and sediment yield vary in the five runoff plots with different vegetation types. Peugeot, Esteves, Galle, Rajot, and Vandervaere (1997) and Puigdefabregas, del Barrio, Boer, Gutiérrez, and Solé (1998) found similar results. During different rainfall events in our study, runoff and sediment yield first increased and then decreased with increasing rainfall in the same runoff plot, but the differences were not significant. Zokaib and Naser (2012) came to the same conclusion using similar methods in their study of the Hilkot watershed in Pakistan.

Table 3. Gray relational grade between sediment yield and the factors influencing sediment yield for all five years (2009–2013) and for the wettest year only (2013).

		Runoff	Vegetation					Rainfall				Soil		Topography	
Years		Runoff	Vegetation types	Vegetation coverage	Rainfall amount	Rainfall duration	Average rainfall intensity	I_5[a]	I_{10}[b]	I_{15}[c]	I_{30}[d]	Soil bulk density	Soil steady infiltration rate	Slope aspect	Slope gradient
2009–2013 years	Correlation	0.7134	0.5851	0.5393	0.6922	0.6474	0.8285	0.643	0.6666	0.687	0.6797	0.8657	0.6411	0.6315	0.6009
	Rank	3	13	14	4	8	2	9	7	5	6	1	10	11	12
	Proportion (%)	21.38			16.85				20.74				22.57		18.46
2013	wettest year 0.6061	0.649	Correlation	0.7968	0.5497	0.6102	0.6652	0.6478	0.6699	0.6581	0.5993	0.5806	0.5797	0.6442	0.6549
	Rank	1	14	9	3	7	2	4	11	12	13	8	5	10	6
	Proportion (%)	24.27			17.67				19.15				19.79		19.12

[a] I_5 = 5 min maximum rainfall intensity,
[b] I_{10} = 10 min maximum rainfall intensity,
[c] I_{15} = 15 min maximum rainfall intensity,
[d] I_{30} = 30 min maximum rainfall intensity.

Rainfall, vegetation, soil, and topography are the main factors involved in soil erosion (Smith & Wischmeier, 1962). Based on the analysis presented here, rainfall amount and rainfall intensity have the greatest effect on runoff in the semiarid loess area of Shaanxi, China. This occurs because rainfall amount and intensity are closely related to the force producing erosion. If the force of rainfall increases, this can potentially have a significant effect on soil loss and runoff. This conclusion, based on the data in this study, is consistent with findings of other scholars (e.g. Chaplot & Le Bissonnais, 2003; Defersha & Melesse, 2012; Jia, Jiang, & Liu, 1990; Liu & Jiang, 1994; Tang, Jiang, & Shi, 1984; Wang, Shao, & Chang, 1998; Wischmeier & Smith, 1958; Zhang et al., 2002).

While the Gray relational grade values of vegetation factors were large and the relationship between runoff and sediment yield was close, vegetation had the smallest influence of all the specific indicators. This may be because vegetation coverage was high during this experiment. Vegetation coverage of runoff plots was at least 32% in 2009 (Table 1). After 5 years of growth, the area with the least coverage had 57% vegetation cover. Therefore, the effect of vegetation on runoff may be relatively low in this study area. Others have drawn the same conclusion; that is, an increase in vegetation coverage will result in a reduction in runoff so that vegetation plays a smaller role in further reducing runoff as vegetation cover increases (Chen et al., 2011; Foltz, Copeland, & Elliot, 2009; Fu, 2011; Yu, Zhang, Wu, Wei, & Zhang, 2006; Zhang, Yu, Wu, Wei, & Zhang, 2005; Zhu, Li, Li, & You, 2010).

In the high runoff year, after rainfall amount and intensity, topography also had a dominating influence on runoff and sediment yield. This mainly occurred because different topographic conditions led to variations in soil water content in the early stage of vegetation recovery and because surface runoff differed as topography varied. Low soil water content affects the infiltration capacity of soil water. If soil water content is high, soil infiltration is slow; therefore, runoff generation from excess rain leads to soil erosion (Defersha & Melesse, 2012; Huang, Zhao, & Wu, 2012; Léonard, Ancelin, Ludwig, & Richard, 2006; Liu, Feng, Chen, Wu, & Gu, 2011; Mohammad & Adam, 2010; Yao, Fu, & Lv, 2012; Zhang et al., 2012). The effect of rainfall intensity on runoff and sediment yield in a high runoff year was ranked from high to low, from I_5, I_{10}, I_{15}, to I_{30}. However, the ranking of the effect of rainfall intensity on runoff and sediment yield in most years was I_{30}, I_{15}, I_{10}, and I_5. Both rankings appear related to the soil water content during the early stage of rainfall.

In this study, the relative influence of different factors during the 5-year period of analysis differed from that of the wettest year mainly because the conditions of rainfall, soil, vegetation, and topography were different. During 2009–2013, the average annual rainfall was 440.53 mm, while it was 713.20 mm in 2013. Rainfall amount was the most critical factor influencing runoff for both the 5-year study and the wettest year (Table 2). During the wettest year, because of the duration of rainfall and the short intervals between rainfall events, antecedent soil moisture was higher than that measured over five years. Slope aspect was the most important factor affecting antecedent soil moisture at 0–30 cm (Li, Bi, Zhang, Liu, & Na, 2006). Thus, in the wettest year, slope aspect replaced average rainfall intensity as the most important factor for runoff, showing topography to have more influence on runoff than in the 5-year study.

In sum, during the 5-year study, rainfall intensity had a greater effect than other factors on runoff; however, the Gray relational grades of rainfall, vegetation, soil and topography were not much different, indicating that the importance of these four factors was almost same. Sediment yield differed significantly with runoff (Table 3). Runoff, along with soil and rainfall factors, strongly influenced sediment yield in the 5-year study. In the wettest year, runoff dominated the effects of other factors on sediment yield.

Conclusions

(1) In this study, we suggest that a mixture of shrubs and trees should be planted to enhance the effect of soil and water conservation at low slope gradients (<25°); we especially recommend *Hippophae rhamnoides* + *Pinus tabuliformis* mixed forests.
(2) Based on the analysis of data for the full 5-year study, the order of factors affecting runoff was rainfall > soil > topography > vegetation. Rainfall amount, average rainfall intensity, and I_{30} (maximum 30-min rainfall intensity) had the greatest effects on runoff, based on our analysis of specific indices. Rainfall indices ranked high among the 13 specific indicators. The Gray Relational Grade value of vegetation type, which had the smallest impact on runoff among the 13 specific indicators, was 0.5791; this relatively large value indicates a close relationship between vegetation and runoff.
(3) In the wettest year, rainfall and topography had the most important effects on runoff; at the same time, the influence of soil on runoff was also important. Rainfall amount, slope aspect, and rainfall duration had the largest effects on runoff. Relatively speaking, the effect of vegetation on runoff was less important. The Gray relational grade values of vegetation coverage and vegetation type were smallest among the 13 specific indicators, so vegetation had less effect on runoff when compared with other factors.
(4) Based on the analysis of five years of data, soil conditions had the greatest effect on sediment yield. The order of factors affecting sediment yield was soil > runoff > rainfall > topography > vegetation. Soil bulk density, averaged rainfall intensity, and runoff had the greatest effects on sediment yield of the 14 specific indicators.
(5) In the wettest year, runoff had more effect on sediment yield than other factors did. Based on the analysis of the wettest year, the factors affecting sediment yield were divided almost evenly among rainfall amount, topography, soil, and vegetation. Examining the rankings of all 14 specific indicators leads us to conclude that the combination of the factors, representing rainfall, topography, soil, and vegetation, have the strongest effect on sediment yield.

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