Chapter

Soil Erosion Influencing Factors in the Semiarid Area of Northern Shaanxi Province, China

Ning Ai, Qingke Zhu, Guangquan Liu and Tianxing Wei

Abstract

The semiarid loess area in north Shaanxi Province is one of the most serious areas of water erosion of China. Vegetation, rainfall, soil, and topography are the most dominant natural factors affecting soil erosion; and land disturbance/restoration is a significant factor influencing runoff and sediment yield in this area. According to the research, the results showed: (1) 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; (2) during a period of the preliminary stage after land disturbance, topography was the most critical factor for the runoff, while sediment yield was soil. During a period of land restoration after land disturbance, runoff was primarily affected by vegetation, while sediment yield was rainfall; (3) this study showed *Hippophae rhamnoides* + *Pinus tabulaeformis* and *Hippophae rhamnoides* were the best vegetation type for reducing runoff and sediment yield, especially if the slope is less than 20°. Land disturbance is caused by human activities in semiarid regions, and in order to reduce the runoff and sediment yield quickly and effectively, artificial measures should be taken for rehabilitation of the disturbed lands.

Keywords: soil erosion, vegetation, soil and water conservation, gray relational analysis

1. Introduction

Soil erosion is one of the global environmental problems facing human survival and development. At present, the global soil erosion area is about 1.643×10^7 km^2, accounting for 10.95% of the total surface area [1, 2]. China is one of the countries with the most severe soil erosion in the world. Soil erosion has the characteristics of wide distribution area, high intensity, complex and diverse forms of erosion, and serious soil loss [3]. According to second remote sensing soil erosion survey data in China, soil erosion area was 3.56 million km^2, accounting for 37% of total land area in China; the hydraulic erosion area was 1.65 million km^2, and the wind erosion area was 1.91 million km^2; all of the erosion causes 5 billion tons of soil loss in China each year [4]. Shaanxi Province 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. The kinetic impact of rain hitting the soil causes water erosion [5, 6], and water erosion will occur when 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 [7–10]. Vegetation type and coverage can reduce the soil erosion index, the effectiveness of rainfall, and the kinetic energy of raindrops and runoff and lead to different soil bulk densities [11–20]. 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, particle size, bulk density, initial water content, and infiltration properties of soils have important roles in water erosion and soil loss [11, 21–26]. Topography restricts the types and configuration of vegetation and affects soil moisture, runoff production, and runoff pathways, thus affecting water erosion and soil loss [22, 27–31].

Land use/cover and management are considered to be the most important factors influencing soil erosion [32–37], especially in the semiarid loess regions [11, 25, 38–41]. However, land disturbance and restoration are key factors influencing land use/cover and management [42–46]. The vegetation, root system, soil characteristics, and topography are strongly influenced by land disturbance/restoration, such as trampling and digging [46–49]. All these factors are critically important regarding runoff and sediment yield. Other human activities, such as overgrazing and deforestation, also increased the possibility of producing runoff and sediment yield [31, 50–57]. Here, we use trampling as an example to illustrate the importance of land disturbance or land mismanagement. Trampling can decrease the soil macro-porosity and the associated hydraulic conductivity, thus increasing runoff production [47, 58]. Trampling can also damage plant root system, reduce vegetation coverage, and destroy soil structure, thus rendering the soil surface more susceptible to erosion [48, 49].

In recent years, with the implementation of the Grain for Green Program and other forestry ecological engineering, a great deal of scientific attentions has been focused on the land disturbance or/and land mismanagement and their impacts on runoff production and soil erosion. Zhao et al. studied the dynamic effects of pastures and crops on runoff production and sediment yield under simulated rainfall conditions and found that vegetation restoration can reduce sediment yield more effectively at the growing stage and can reduce runoff production more effectively at the mature stage [59]. Pan et al. investigated the influence of grass and moss on runoff production and sediment yield also under simulated rainfall conditions and found that the grass and moss can efficiently reduce sediment yield and runoff production [60]. Wei et al. studied the effects of surface conditions and rainfall intensities on runoff production using micro-runoff plots and rainfall simulation and concluded that the runoff production varies drastically with different surface conditions and also with different rainfall intensities [61]. Li et al. investigated the soil detachment capacity and its relationships with sediment yield and runoff production and found that such factors as soil aggregate median diameter, organic matter, and root density can affect soil detachment capacity and thus runoff production and sediment yield [40].

However, the effects of natural rainfall events on runoff and sediment yield were found strongly different with artificial rainfall simulations [22]. Few scholars have studied the relative weights of the four primary factors that control runoff and sediment yield. Moreover, few works in the literature focused on the weights of various factors on runoff and sediment yield during the process of land disturbance/restoration under the conditions of natural rainfall. Above all, the specific objectives of this research were to: (1) Better understand the effects of the four factors—vegetation, rainfall, soil, and topography—on rainfall-runoff and sediment yield in the semiarid loess area of Shaanxi, China, and (2) examine the characteristics of annual runoff and sediment yield under different vegetation types during a period of the preliminary stage (PPS) after land disturbance and a period of land restoration after land disturbance (PLR).

2. Materials and methods

2.1 Study area

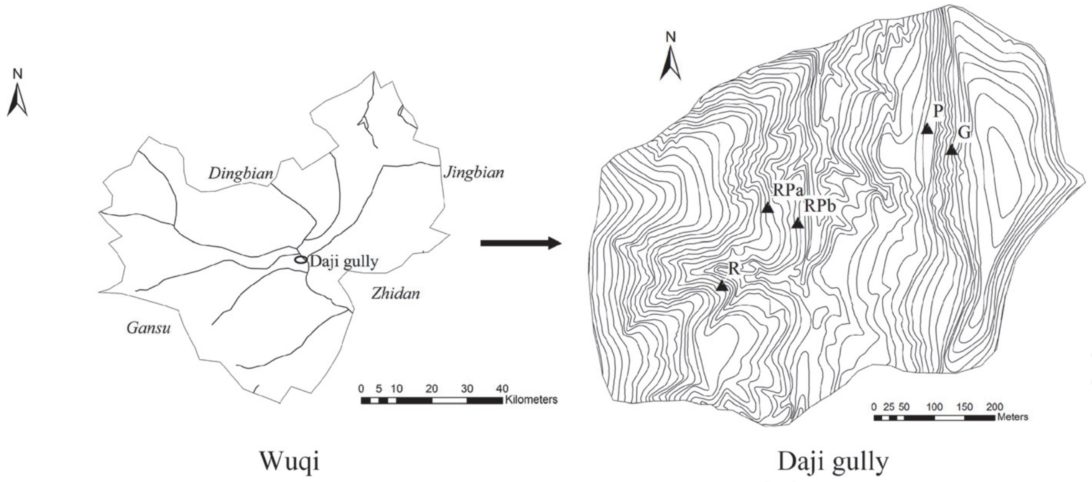
The study area is located at the field station (**Table 1** and **Figure 1**) in Dajigou catchment, a typical loess hilly area, at northwestern Loess Plateau, Shaanxi Province, China (36°33′33″–37°24′27″N, 107°38′37″–108°32′49″E; 1233–1809 MASL). The area belongs to the semiarid temperate climate zone. The mean annual precipitation is approximately 464.5 mm (1957–2013), of which approximately 61% falls in the summer from July to September. The monthly temperature ranges from −28.5°C (December 1967) to 38.3°C (July 2001), with an annual mean temperature of 7.9°C (1957–2013). The typical soils in Wuqi County are loess soils with relatively coarse particles [62]. The original vegetation almost disappeared. In recent years, to protect the environment in this region, the Chinese government implemented the Grain for Green Program to restore the ecological environment, namely, by restoring forest and grass vegetation. 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*).

2.2 Experimental design

After a complete catchment survey, together with an evaluation of topography and vegetation types, five plots (20 m × 5 m) were constructed at the study areas in July 2009. The vegetation types in the five plots are *Hippophae rhamnoides* + *Pinus tabuliformis* (I) (PRa), *Hippophae rhamnoides* + *Pinus tabuliformis* (II) (PRb), *Pinus tabuliformis* (P), *Hippophae rhamnoides* (R), and *Lespedeza davurica* + *Leymus*

Plot code	**Vegetation type**	**Density**		**High**	**Slope gradient**	**Slope aspect**	**Elevation**	**Canopy density (%)**	
		Pinus tabuliformis	***Hippophae rhamnoides***					**PPS**	**PLR**
RPa	*Hippophae rhamnoides* + *Pinus tabuliformis* (I)	800/hm^2	1500/hm^2	1.88 m	12°	ES37°	1396 m	48	63
RPb	*Hippophae rhamnoides* + *Pinus tabuliformis* (II)	700/hm^2	1400/hm^2	1.98 m	29°	ES35°	1380 m	32	50
P	*Pinus tabuliformis*	1200/hm^2	3000/hm^2	3.33 m	17°	WS12°	1386 m	40	53
R	*Hippophae rhamnoides*	2300/hm^2	2300/hm^2	2.62 m	17°	NE34°	1406 m	35	55
G	*Lespedeza davurica* + *Leymus secalinus*				28°	WS3°	1398 m	55	81

Table 1.
The specific conditions of five runoff plots.



Wuqi

Daji gully

Figure 1.
The location of the study area and distribution of the five runoff plots.

secalinus (G) (**Table 1**). During the preliminary stage of establishing the plots, the vegetation, soil, and earth surface were severely degraded by the constructors through trampling and digging. With time, the vegetation and soil conditions in the plots obviously improved. The runoff and sediment yield during PPS and PLR were extremely different. This study uses the data measured in 2009 as of PPS and in 2010–2012 as of PLR for analysis. We ultimately drew conclusions regarding the order of weight for factors affecting runoff and sediment yield during the two different stages. **Figures 2** and **3** show part of the runoff plots during these two stages.

Figure 2.
The plots and meteorological station conditions during a period of the preliminary stage (PPS) after land disturbance.

Figure 3.
Contrast in plot regions and conditions during PPS and a period of land restoration (PLR) after land disturbance.

2.3 Measurement

We monitored the daily runoff and sediment yield during the main rainy season (July–September) from 2009 to 2013. **Table 1** shows the detailed parameters of these runoff plots. 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 composed of concrete with a dimension of $1 \times 1 \times 1$ m^3. The data were measured from July to September of each year. Following each rainfall event, three samples of approximately 1.65 L were removed from each sump to estimate the sediment yield.

2.4 Meteorological data

A simple meteorological field station (HOBO Weather Station, Onset Computer Co., Bourne, MA, USA), including a tilting rain gauge, was installed in the study area to record year-round meteorological data (**Figure 2**). The weather station recorded once 5 min passed. So, we calculated the I_5, I_{10}, I_{15}, and I_{30} values from the weather station record (I_5 = 5-min maximum rainfall intensity; I_{10} = 10-min maximum rainfall intensity; I_{15} = 15-min maximum rainfall intensity; I_{30} = 30-min maximum rainfall intensity).

2.5 Soil bulk density

Three soil profiles were excavated at the uphill, middle, and downhill areas which are near the runoff plots. Soil samples were collected from each profile at the depths of 0–20, 20–40, 0–60, 60–80, and 80–100 cm. Soil bulk density was tested using a ring knife (diameter, 5 cm; height, 5 cm).

2.6 Soil steady infiltration rate

An instrument for recording the process of water infiltration into the soil was employed, and the depth of infiltration was calculated by the empirical equation:

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

where H is the depth of infiltration, h is the change in the standing water level, and a is the slope gradient. At the beginning of the experiment, data were recorded every 10 s for 90 s; then, data were recorded every 30 s for 5 min; at the end, data were recorded once every minute. The experiment was not completed until similar measurements were observed 5–6 times [63].

2.7 Data processing

We used the Principal Coordinates Analysis (PCoA) method to convert the qualitative variables, such as vegetation and slope aspect, into quantitative variables [64]. To reduce the error of the evaluation, we used PCoA for numerical transformation and calculate the characteristic value of each item, and then we used characteristic value for analysis.

The Chinese scholar Deng Julong first proposed the gray correlation method. This method is based on developmental trends of the degree of similarity or dissimilarity between factors. By comparing a sequence of an established family of curves and a reference sequence curve, using geometric similarity, one can determine the degree of connection between the reference sequence and a comparison sequence set of data. If the shapes are similar, then a greater degree of similarity is identified. The comparison sequence and the reference sequence include both temporal series and nontemporal series. Therefore, the gray correlation method provides a quantitative measurement for the development of a system. This method is highly suitable for the analysis of a dynamic process. The specific method is shown as below [65]:

1. The parameters are standardized using:

$$x'_i(\mathrm{k}) = \frac{x_i(\mathrm{k}) - \mathit{min}\, x_i(\mathrm{k})}{\mathit{max}\, x_i(\mathrm{k}) - \mathit{min}\, x_i(\mathrm{k})} \tag{2}$$

where $x'_i(\mathrm{k})$ are the new values obtained when the parameters are standardized by Eq. (2) and $x'_i(\mathrm{k})$ are the original parameters.

2. Then, the correlation coefficient is calculated using:

$$\gamma\left(x'_0(\mathrm{k})\mathrm{k}, x'_i(\mathrm{k})\right) = \frac{\Delta x_{min} + \varepsilon \Delta x_{max}}{\Delta x_{0i}(k) + \varepsilon \Delta x_{max}} \tag{3}$$

$$\Delta x_{min} = \min_{\forall j \epsilon i} \min_{\forall k} \left| x'_0(\mathrm{k}) - x'_j(\mathrm{k}) \right| \tag{4}$$

$$\Delta x_{max} = \max_{\forall j \epsilon i} \max_{\forall k} \left| x'_0(\mathrm{k}) - x'_j(\mathrm{k}) \right| \tag{5}$$

$$\Delta x_{0i}(\mathrm{k}) = \left| x'_0(\mathrm{k}) - x'_i(\mathrm{k}) \right| \tag{6}$$

where $\Delta x_{0i}(\mathrm{k})$ is the absolute value of the difference between the comparison sequence and the reference sequence and ξ is the distinguishing coefficient. The

		Runoff			**Sediment yield**		
		Correlation	**Rank**	**Proportion**	**Correlation**	**Rank**	**Proportion**
Vegetation	Vegetation types	0.5791	13	22.28%	0.5851	13	16.85%
	Vegetation coverage	0.5908	12		0.5393	14	
Rainfall	Rainfall amount	0.7685	1	27.85%	0.6922	4	20.74%
	Rainfall duration	0.704	6		0.6474	8	
	Average rainfall intensity	0.7526	2		0.8285	2	
	I_5	0.6994	7		0.643	9	
	I_{10}	0.7112	5		0.6666	7	
	I_{15}	0.7358	4		0.687	5	
	I_{30}	0.7482	3		0.6797	6	
Soil	Soil bulk density	0.6948	8	25.53%	0.8657	1	22.57%
	Soil steady infiltration rate	0.6455	10		0.6411	10	
Topography	Slope aspect	0.6655	9	24.34%	0.6315	11	18.46%
	Slope gradient	0.6124	11		0.6009	12	
Runoff					0.7134	3	21.38%

Note: I_5, 5-min maximum rainfall intensity; I_{10}, 10-min maximum rainfall intensity; I_{15}, 15-min maximum rainfall intensity; I_{30}, 30-min maximum rainfall intensity; GRG, gray relational grade

Table 2.
Gray relational grade between runoff and sediment yield and the factors influencing runoff and sediment yield.

		PPS			**PLR**		
		GRG	**Rank**	**Proportion**	**GRG**	**Rank**	**Proportion**
Vegetation	Vegetation type	0.6133	6	0.2476	0.6757	2	0.2594
	Vegetation cover	0.6023	7		0.6061	8	
Rainfall	Rainfall amount	0.6417	3	0.2411	0.6415	3	0.2539
	Rainfall duration	0.6303	4		0.7443	1	
	Average rainfall intensity	0.5835	10		0.5675	12	
	I_5	0.5584	12		0.6146	7	
	I_{10}	0.5662	11		0.6186	5	
	I_{15}	0.6209	5		0.6032	9	
	I_{30}	0.5406	13		0.6012	10	
Soil	Soil bulk density	0.5936	9	0.2539	0.5665	13	0.2408
	Soil steady infiltration	0.6524	2		0.6231	4	
Topography	Slope aspect	0.6681	1	0.2574	0.5995	11	0.2459
	Slope gradient	0.5955	8		0.6156	6	

Note: I_5, 5-min maximum rainfall intensity; I_{10}, 10-min maximum rainfall intensity; I_{15}, 15-min maximum rainfall intensity; I_{30}, 30-min maximum rainfall intensity; GRG, gray relational grade

Table 3.
Gray relational grade between runoff and its influential factors.

value of ξ ranges from 0 to 1, but generally $\xi = 0.5$. $\gamma\left(x'_0(\mathrm{k})\mathrm{k}, x'_i(\mathrm{k})\right)$ is the correlation coefficient.

3. Lastly, the gray relational grade (GRG, Γ) is calculated using:

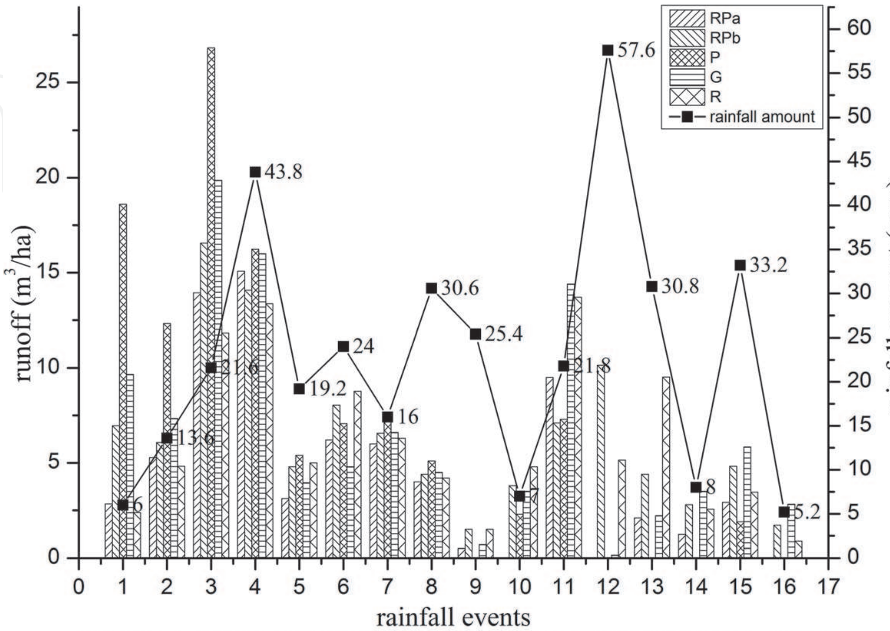
$$\Gamma = \frac{1}{n}\sum_{k=1}^{n}\gamma\left(x'_0(\mathrm{k}), x'_i(\mathrm{k})\right) \tag{7}$$

We selected runoff and sediment yield as the reference sequences; several indicators were used as comparative sequences, including vegetation type, vegetation coverage, rainfall amount, rainfall duration, average rainfall intensity (I_5, I_{10}, I_{15}, I_{30}), soil bulk density, soil steady infiltration rate, and slope aspect and gradient. Then, the gray relational grade was calculated for the reference and comparison sequences (**Tables 2** and **3**). Deng pointed out in his book that if the gray relational grade is large, then a close relationship exists between the sequence and reference parameters [65].

3. Results

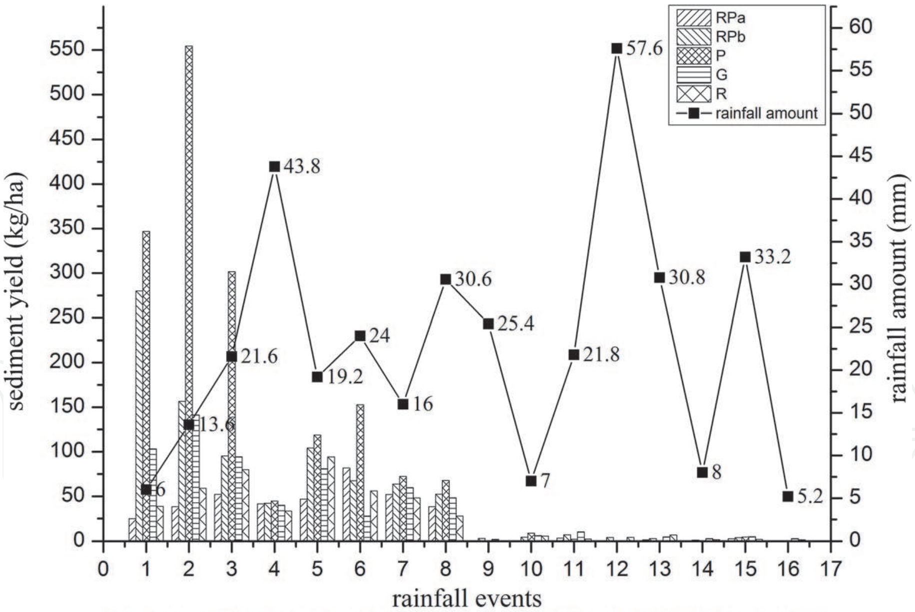
3.1 The relationship between rainfall amount, rainfall-runoff, and sediment yield

Figures 4 and **5** 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%. Also, at the preliminary stage after runoff plots had been constructed, vegetation destroyed, and vegetation canopy lowered, the benefits of soil and water conservation were better in *Hippophae rhamnoides* + *Pinus tabuliformis* and *Hippophae rhamnoides* vegetation types. With the recovery of vegetation, the benefits of soil and water conservation increased in all of the vegetation



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.
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 5.
Sediment yield trend with rainfall amounts in the study area of Wuqi County, Shaanxi Province, China.

types at rainfall event. However, the *Pinus tabuliformis* was more obvious, especially in low rainfall intensity and long-duration rainfall events; *Hippophae rhamnoides* + *Pinus tabuliformis* was still low at low slope gradient when contrasted with other vegetation types in runoff plots; *Hippophae rhamnoides* decreased. Comparing grassland and *Hippophae rhamnoides* + *Pinus tabuliformis* in the same slope gradient, we conclude that grass on a slope with a gradient >25° cannot take the initiative to configure arbors or shrubs and make it natural succession to grow. At same time, we suggest that some shrubs and arbors should be active configuration to enhance the effect of soil and water conservation at low slope gradient less than 25 degrees; and 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 4 and **5** show that vegetation types and rainfall amount had large effects on runoff and sediment yield; however, the change rule 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.

3.2 The factors affecting runoff and sediment yield based on gray relational analysis

While selecting runoff and sediment yield 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 5 years of data with the gray correlation method that analyzes 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. Average 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, and 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**).

Several conclusions can be drawn using the gray correlation method to analyze the factors affecting sediment yield at the loess region study plots during 2009–2013. First, soil and runoff are 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 here. 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 small relative to 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.

3.3 Factors affecting runoff

As shown in **Table 3**, during PPS, it is clear that the slope aspect had the strongest impact on the runoff, with a GRG of 0.6681. The GRG for the soil steady infiltration rate was 0.6524, below only the slope aspect. The third factor was the rainfall amount, with a GRG of 0.6417, followed by rainfall duration, with a GRG of 0.6303. For the rainfall intensity, the GRG for I_{15} was the largest, and the relationship with runoff was similar. The influences of vegetation type and cover on the runoff were intermediate among the 13 factors and both with GRG values higher than 0.6. The smallest GRG value was I_{30} and the value was 0.5406 for the 13 factors, which is higher than 0.5. Therefore, all the 13 factors were closely related to runoff.

During PLR (**Table 3**), the rainfall duration replaced the slope aspect as the most critical factor affecting the runoff with a GRG of 0.7443. The GRG for vegetation type was 0.6757 and ranked second among the 13 factors. The rainfall amount ranked third with a GRG of 0.6415, and its influence on runoff showed no change in comparison with PLR. The GRG of the soil steady infiltration rate was ranked fourth (GRG, 0.6231), indicating a strong effect on runoff. I_{10} was the most critical factor among the rainfall intensity parameters. The influences of slope gradient and vegetation cover on runoff showed little changes. The influence of slope aspect on runoff showed a particularly notable decrease, ranking only at the 11th.

3.4 Factors affecting sediment yield

Table 4 shows that during PPS, the influence of soil bulk density was significantly higher than that of the other factors, with a GRG of 0.8113. The average rainfall intensity ranked second, with a GRG of 0.7444, followed by the soil steady infiltration rate. Among the rainfall intensity factors, I_{30} had the closest relationship with sediment yield. The GRG for vegetation type was 0.6487, indicating that this factor is more closely related to sediment yield than vegetation cover. The smallest GRG value was 0.5945, indicating that all the factors had close relationships with sediment yield.

During PLR, I_{10} replaced the soil bulk density as the most significant factor affecting the runoff, with a GRG of 0.8012. The GRG values of I_5, I_{15}, I_{30}, and average rainfall density were high among the 14 factors, indicating that rainfall intensity had the most important relationship with sediment yield during PLR. The rainfall duration ranked from the 10th to the 5th. In contrast, the soil bulk density ranked the 10th from the 1st during PPS, illustrating that the influence of the soil bulk density changed substantially during PLR. At the same time, the rank of soil steady infiltration rate was down to the eighth from the third. The rank of runoff moved up in comparison with PPS. The effects of vegetation type and vegetation cover on sediment yield were reduced according to the GRG analysis. The rank of slope aspect added, while the rank of slope gradient was down.

3.5 Runoff and sediment yield under different vegetation types

Significant differences were observed among the treatments in terms of runoff and sediment yield during PPS and PLR (**Figure 6**). The runoff and sediment yield during PPS were remarkably larger than during PLR, especially for P. During PPS, the runoff was 13.55-fold higher than that during PLR, and the sediment yield was 3.13-fold higher than that during PLR. In the analysis of grassland during PPS, the

		PPS			PLR		
		GRG	**Rank**	**Proportion**	**GRG**	**Rank**	**Proportion**
Runoff	Runoff	0.6129	13	18.62%	0.6323	11	19.32%
Vegetation	Vegetation type	0.6487	7	19.31%	0.6119	13	18.73%
	Vegetation coverage	0.6229	11		0.6141	12	
Rainfall	Rainfall amount	0.6198	12	20.22%	0.6627	9	22.54%
	Rainfall duration	0.6316	10		0.6926	5	
	Average rainfall intensity	0.7444	2		0.6758	6	
	I_5	0.6668	5		0.7953	2	
	I_{10}	0.6595	6		0.8012	1	
	I_{15}	0.6482	8		0.7779	3	
	I_{30}	0.689	4		0.7593	4	
Soil	Soil bulk density	0.8113	1	23.15%	0.6532	10	20.14%
	Soil steady infiltration rate	0.7128	3		0.6652	8	
Topography	Slope aspect	0.6362	9	18.69%	0.6658	7	19.26%
	Slope gradient	0.5945	14		0.5949	14	

Table 4.
Gray relational grade between sediment yield and its influential factors.

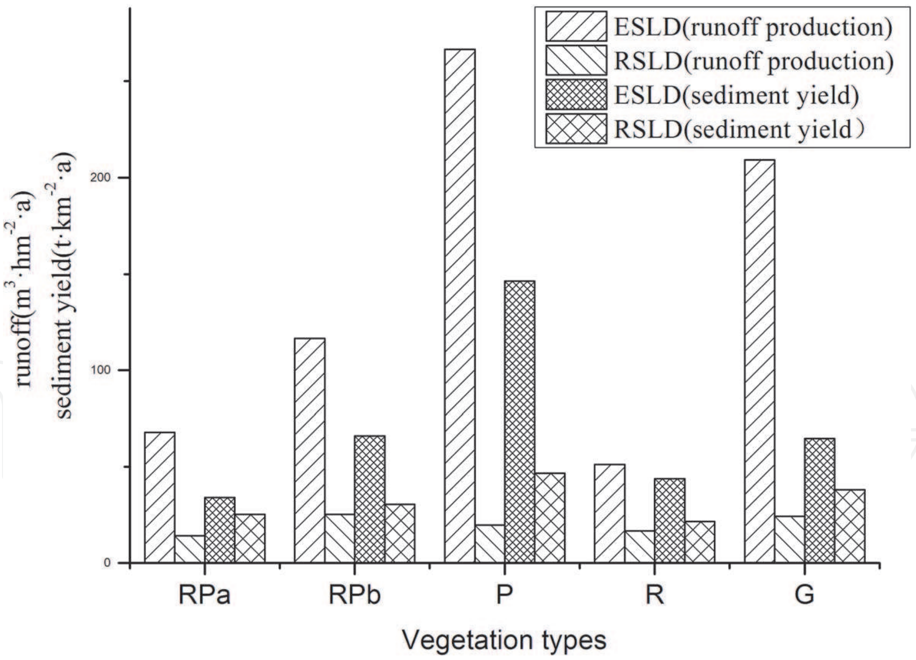


Figure 6.
Annual runoff and sediment yield during PPS and PLR for five different vegetation types.

runoff and sediment yield were 8.59-fold and 1.70-fold than those for PLR. In addition, the fold differences between PPS and PLR for the RPa, RPb, and R vegetation types in terms of runoff were 4.81, 4.60, and 3.07; the fold differences in sediment yield were 1.35, 2.17, and 2.03. This result demonstrates that vegetation recovery can effectively reduce the runoff and sediment yield.

4. Discussion

4.1 Relationship between rainfall amount, rainfall-runoff, and sediment yield

Rainfall, vegetation, soil, and topography are the main factors involved in soil erosion [66, 67]. Based on the analysis presented here (**Table 2**), 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 of erosion. If the force of rainfall increases, this can potentially have a significant effect on soil loss and runoff (**Figures 4** and **5**). This conclusion, based on the data in this study, is consistent with the findings of other scholars [9, 26, 28, 68].

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 (**Tables 2** and **3**). 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 (**Table 1**). 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 [69–74].

In the high runoff year, after rainfall amount and intensity, topography also had a dominating influence on runoff and sediment yield (**Figures 4** and **5** and **Table 2**). 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 (**Figure 1** and **Table 1**). 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 [25, 26, 75–79]. 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 are related to the soil water content during the early stage of rainfall.

4.2 Effects of land disturbance and restoration on runoff

The weights of different factors on runoff differed significantly during PPS and PLR (**Figures 2** and **3**). **Table 3** shows that the weight significance order of the factors was topography>soil>vegetation>rainfall during PPS and the order was vegetation>rainfall>topography>soil in PLR. During PPS, the plot environments were severely degraded by trampling and digging (**Figure 2**). Slight soil disturbances do not produce serious runoff or soil erosion problems [80, 81]. In the study areas, the surface soil was destroyed, and the vegetation was heavily reduced with low vegetation coverage and canopy. The vegetation growth conditions became poor and were fragile at this time; however, stable and suitable vegetation was an effective method for reducing runoff and sediment yield [25, 82, 83].

In this study, we found that trampling and digging quantitatively decreased plant cover and vegetation, reduced soil aggregate stability, reduced soil fertility, and therefore lead to increased runoff. When the land was disturbed and the plant cover decreased, canopy interception of raindrops was low (**Figure 2** and **Table 1**). All these changes resulted in decreased mulches in the runoff plots, and thus the soil surface could not be effectively protected. This situation led to decreased rainwater infiltration and soil moisture content, and the threshold of runoff generation correspondingly decreased [39, 61, 84]. At the same time, vegetation roots were destroyed; vegetation roots can modify the structure of soil pores and can improve the soil infiltration capacity, thus reducing runoff [16, 85–88]. It has been noted that the decrease in water erosion rates with increasing root mass is exponential.

During PPS, the influence of vegetation on runoff is relatively weak, ranking the third (**Table 3**). We speculated that the protective function of vegetation on runoff was small, because during this period, all the runoff plots collected large amounts of runoff after rainfall events (**Figure 6**). Rainfall ranked fourth, for the same reason as vegetation: as long as there are rainfall-runoff events, large amounts of runoff can be produced at each runoff plot [89].

The soil surface was degraded in an irregular manner by the construction of runoff plots; therefore, the disturbances in each plot were quite different. Thus, the soil characteristics were significantly changed, especially the soil bulk density and soil steady infiltration rate. At the same time, the topography of each plot was also affected, especially the microtopography. Wilcox et al. noted that disturbances can modify surface topographical features and change the vegetation patch structure, eventually decreasing water storage within the hillslope [39]. Mohr et al. found that the impact of microtopography on surface runoff connectivity and water-repellent properties is the first-order control for hydrological and erosion processes. Therefore, during PPS, the weights of soil and topography were greater than those of vegetation and rainfall. Thus, topography and soil were major influential factors on runoff [43].

However, due to the different vegetation succession stages, the processes of runoff and soil loss are complicated and uncertain in terms of the interaction of rainfall and land use [90]. Plant growth can reduce raindrop energy and total runoff depth through canopy interception and stemflow [91, 92]. Vanacker et al. also indicated that the disturbance of vegetation cover by human activities can significantly influence erosion [46]. During PLR, the vegetation recovered, and the vegetation coverage (canopy) improved remarkably (**Table 1**). The effects of vegetation, such as the canopy interception of raindrops, the decreased velocity of raindrops, and overland flow, prevented the rainfall from directly impacting the soil surface. These effects were stronger during PLR than in PPS.

As sufficient time elapsed after the disturbance, the soil and topography became basically stable (**Figure 3**). The soils of the runoff plots consolidated and became difficult to detach by runoff. Improvements in soil characteristics such as soil porosity and organic matter increased the infiltration rate and decreased the runoff. Vegetation recovery can improve soil conditions, such as soil permeability and soil water storage after rainfall, and can control runoff loss through root-network development and litter accumulation [79, 85, 93].

Once the soil and topography were stable, the vegetation restoration and rainfall features became increasingly important for runoff. Rainfall features such as rainfall duration and rainfall intensity exhibited a strong influence on runoff generation [61, 90]. Therefore, when the soil and topography were stable and the weights of these factors on runoff were low, the weights of vegetation and rainfall on runoff increased. Vegetation was a key factor in runoff, and rainfall was the second most important factor during PLR (**Table 3**).

4.3 Effects of land disturbance and restoration on sediment yield

The weights of the studied factors on sediment yield differed significantly between PPS and PLR. The weight significance order of the factors was soil > rainfall > vegetation>topography>runoff during PPS, and the order was rainfall>-soil>runoff>topography>vegetation in PLR (**Table 4**). The sediment yield was different between PPS and PLR. During PPS, as a result of land disturbance, the sediment yield was greater than the land restoration. Through the observation on human activities, the removal of vegetation and disturbance of the soil surface result in the potential for soil structure degradation and sediment movement [94]. The sediment yield increases significantly for a short time after forest harvesting by clearcutting, and compared with good forest, the sediment yield is higher in sparse grass and bare areas which were without good cover [33]. As shown in **Table 4**, the effect of soil and rainfall on sediment yield ranked top two at both PPS and PLR. **Table 4** also shows that the weight of vegetation effect on sediment yield was the lowest at PLR, because during PLR, the vegetation cover in each plot was large (**Table 1**). Some scholars have found that a vegetation cover greater than 60% will significantly stabilize the soil surface and reduce soil erosion [49, 95]. During PPS, sediment transport capacity of the runoff was high; during PLR, sediment transport capacity of the runoff was low (**Figure 6**). Thus, the influence of runoff on sediment yield during PLR was greater than during PPS.

4.4 Influence of vegetation type on runoff and sediment yield

By estimating the annual runoff and sediment yield data for the five different vegetation types in each plot, we found that the runoff and sediment yield differed with respect to the different vegetation types. Similar results have also been observed by other scholars [25, 38, 61, 96–100].

During PPS, the order of vegetation types for producing runoff was P > G > RPb > RPa > R; the order of vegetation types for producing sediment yield was P > RPb > G > R > RPa. During PLR, the order of vegetation types for producing runoff was RPb > G > P > R > RPa; the order of vegetation types for producing sediment yield was P > G > RPb > RPa > R. Ai et al. found similar results in their investigation of nine natural rainfall events [89].

Although the runoff and sediment yield differed for the different vegetation types, the variable coefficient for PLR was lower than that for PPS (**Figure 6**). In other words, the effect of vegetation type on soil erosion is more important during land disturbance than during land restoration or a stable vegetation period. In this study, we concluded that RPa and R were better choices for land restoration or reforestation in this area, especially for slope gradients of less than 20 degrees. A study by Chen et al. indicated that pine woodland induced the largest water loss, followed by sloping cropland, alfalfa, semi-natural grassland, and shrub land, in the Loess Plateau in China [11]. Wei et al. found that shrub species were better than grass species for retaining runoff and reducing surface water loss through overland flow in a loess hilly area in China [61].

5. Conclusion

There are many factors that cause soil erosion; the runoff and sediment yield process is complicated. According to the research of soil erosion influencing factors in the semiarid area in Northern Shaanxi Province in China, the results showed:

1. The order of factors affecting runoff was rainfall > soil > topography > vegetation. Rainfall amount, average rainfall intensity, and I_{30} had the greatest effects on runoff, based on the analysis of specific indices. Rainfall indices ranked high among the 13 specific indicators. The gray relational grade values of vegetation type, which had the smallest impact on runoff among the 13 specific indicators, was 0.5791; this large value indicates a very close relationship between vegetation and runoff in the wettest year.

2. The order of factors affecting sediment yield was soil > runoff > rainfall > topography > vegetation. Soil bulk density, average rainfall intensity, and runoff had the greatest effects on sediment yield of 14 specific indicators.

3. Land disturbance and restoration significantly influence the runoff and sediment yield. The weights of influential factors (vegetation, rainfall, soil, topography) for runoff and sediment yield were also different during PPS and PLR. In this work, we determined the order of influential factor weights during PPS and PLR. This paper identified effective vegetation types for controlling runoff and reducing sediment yield. Our findings revealed that the PR and R vegetation types are better plant selections for reforestation, especially when the slope gradient is less than 20 degrees. Our research suggests that in cases of land disturbance caused by humans in semiarid regions, to quickly and effectively reduce the runoff and sediment yield, artificial measures should be taken for rehabilitation of the disturbed lands.

The results of this study will provide an important theoretical basis for the effective reduction of soil erosion during PPS and PLR, the reconstruction of low-efficiency forests, the management of spatial vegetation, and replanting of vegetation in abandoned farmlands in the semiarid loess region.

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Conflict of interest

The authors declare no conflict of interest.

Notes

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