

Research Article

Coupling Analysis of Hydrometeorology and Erosive Landforms Evolution in Loess Plateau, China

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The purpose of this study is to investigate hydrometeorology changing patterns impacts on erosive landforms evolution in Loess Plateau in the past 60 years (1950–2010). We firstly describe hydrometeorology changing patterns (rainfall-runoff-soil erosion response) at different time scales (daily, monthly, and yearly) in perspective of river basins and then further investigate hydrometeorology impacts on erosive landform through combined analysis of statistical quantification and proposed conceptual model of rainfall-runoff-soil erosion landform. Through the above investigations, the following findings are achieved. Firstly, it shows that annual runoff and sediment discharges decreased obviously although precipitation remained at the same level in the past 50 years (1960–2010). Discharges of annual runoff and sediment decreased by 30%–80% and 60%–90%, respectively. Secondly, contributors of soil erosion are determined by integrated factors such as precipitation, river network, and topography characteristics of river basins. The strong soil erosion area existed in the middle hilly-gully region, while the high precipitation was in southern mountains. Thirdly, erosion landform development was largely shaped by hydrometeorology characteristics in comparison with other contributors. It shows that there is strong positive relationship between precipitation and erosion.

1. Introduction

Soil erosion has been one of the most triggering environmental issues for decades for its destructive effects [1–7]. Soil erosion deteriorates natural environment and socioeconomic properties as well, such as soil quality, agricultural production, ecosystem stability, and Loess of socioeconomic properties [8–10]. Soil erosion, which is classified into different categories (water, wind, glacier, gravity, and human erosions), is caused by contributors such as climate (e.g., rainfall), topography (slope, river network), vegetation and land use cover, and human activities. Soil erosion patterns changed with the changes of these contributors. For example, Mediterranean environments in Spain have become more prone to soil erosion [11], Alpine areas have a high risk for soil erosion associated with the extreme climatic and topographic conditions, and sediments of Mississippi River, Nile River,

and Mekong River also changed significantly during the last several decades [12–16] because of climate change and human activities [17–19]. Sediment yield is primarily controlled by plan curvature and highest-order channel length, followed by hypsometric integral, rainfall, basin relief, and so forth. In Loess Plateau, watershed shape parameters and relief parameters are the major factors that affect sediment yield [20]. With construction of dams and reservoirs, watershed longitudinal linkages are weakened which caused decrease of sediment yield, while natural vegetation clearance and mining activity reduce resistance of land surface and enhance the effectiveness of flow on sediments, thus increasing sediment yield [21, 22]. In Loess Plateau, precipitation decrease is the main reason for reduction of sediment transport, and their spatiotemporal patterns are consistent in the last several decades. Contribution rate of human activities is 61%–93%

to decrease of sediment discharge in 10 tributaries of Yellow River's middle reach [23].

Various approaches were developed to investigate soil erosion and its related issues, including field observation, laboratory test, quantitative analysis, and model simulation [13, 24]. Field observations provide the first hand data for soil erosion investigations [21, 25]. Mathematical statistics mainly focus on the trend analysis, test of observed streamflow, and precipitation, which include parametric and nonparametric tests. Nonparametric tests are generally used to quantify hydrological parameters; for example, Mann-Kendall Test has been widely used for trend analysis [26–30]. Geographic statistics is mainly used for spatial distribution analysis of observed data. However, the statistical methods cannot reveal the physical process and relations of hydrological parameters and explain the reasons of change. As a result, mathematical and hydrological models have been widely used. Hydrological models are commonly applied to effectively and efficiently analyze changes of hydrological parameters and their response to climate change, human activities, and landform evolution. Soil and Water Assessment Tool (SWAT) model, Distributed Biosphere-Hydrological (DBH) model, and Community Land Model (CLM4) version 4 were often used to investigate response of streamflow to LUCC, climate change, and human activities [31]. The Universal Soil Loss Equation [32] and its successors, the Revised Universal Soil Loss Equation (RUSLE), are by far the most often used models for soil erosion predictions. USLE and WEPP were used to study fluctuations of soil erosion on the influence of rainfall, vegetation coverage, conservation measures, and land use [33–36].

Loess Plateau has been experiencing severe soil erosion for decades influenced by climatic change, hydrology change, and human activities [37–40]. Previous investigations show that rainfall density played an important role in soil erosion process compared to other features in Loess Plateau [41, 42]. Land use is critical in controlling soil erosion in this area [43, 44], and it was reported that soil erosion decreased dramatically with the increase of vegetation cover during the past decades in Loess Plateau. Soil erosion intensity, process, and mechanism are influenced by topographic factors such as slope, water velocity, amount of penetration, and runoff amount in Loess Plateau [20, 45–49]. Soil erosion closely related to the sediment transportation in the middle Yellow River. Changes of sediment in the mainstreams of the middle Yellow River reflected the changes of soil erosion in Loess Plateau [50]. These investigations provide abundant background knowledge in soil erosion in Loess Plateau. However, these studies mainly focus on spatiotemporal characteristics of soil erosion and climate change at large scales and rainfall and erosion process at watershed scale. Interaction between hydrometeorology and erosive landform evolution in Loess Plateau remains unclear. Coupling response of soil erosion and landform evolution has not been quantitatively analyzed in detail, especially in Loess Plateau. Therefore, it is necessary to carry out coupling analysis and quantitative investigation of hydrometeorology and erosive landform evolution in Loess Plateau. The purpose of this study is to investigate hydrometeorology changing patterns impacts on erosive landforms

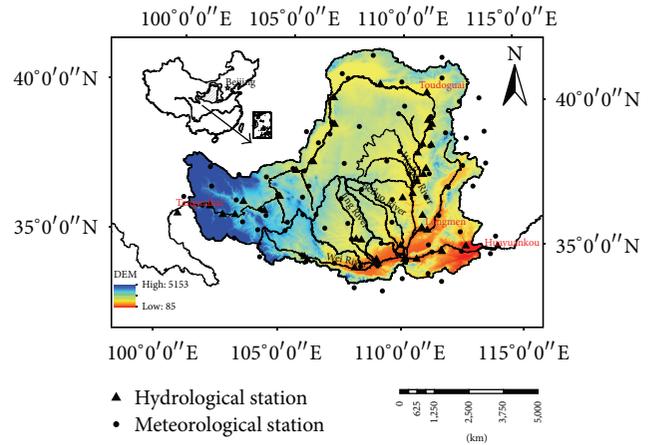


FIGURE 1: Sketch map and DEM of the study area (Loess Plateau) (triangle, hydrological gauged stations; rectangle, meteorological station).

evolution in Loess Plateau in the past 60 years (1950–2010) through combined analysis of statistical quantification and proposed conceptual model of rainfall-runoff-soil erosion landform. We firstly describe hydrometeorology changing patterns (rainfall-runoff-soil erosion response) at different time scales (hourly, daily, monthly, and yearly) from the perspective of river basins and then analyze hydrometeorology and erosive landforms evolution.

2. Study Area

The Loess Plateau (100°54' to 114°33'E and 33°43' to 41°16'N) which covers 624,000 km² with over 60% subjected to soil and water losses is mainly located in the middle reaches of the Yellow River (3943 km) (Figure 1). The average annual precipitation on the Loess Plateau ranges from 250 mm to 600 mm, which gradually increases from northwest to southeast. Precipitation of rainy season (from June to September) accounts for 60–70% of the total of the year. Heavy rain in form of rainstorms occurs frequently in rainy season which causes flood and severe soil erosion. Strong erosion forms specific geomorphologic features with many gullies and fragmented landforms in Loess Plateau. Tableland (Yuan), ridges (Liang), and hills (Mao) are typical erosion landforms of Loess Plateau. Gully erosion accounts for more than 80% of the soil erosion in this area. Gully density and segmentation of the ground are as high as 8 km/km², and segmentation of the ground is about 43.7% in some area. The average erosion modulus reaches 5000–10000 t·km⁻²·a⁻¹, sometimes even reaching to 20000–30000 t·km⁻²·a⁻¹, and it decreased to 2205.4 t·km⁻²·a⁻¹ in He-Long region in 2011 [51]. The sediment discharge of He-Long section of Yellow River was about 3.1×10^8 t during 1980–2010 and 1.6×10^8 t during 2000–2010 [51]. Vegetation destruction was one of the key contributors to soil erosion in Loess Plateau for decades because of improper human activities (such as cultivation, deforestation, and development of economy). However, it improved a lot after implementation of Grain-for-Green

Project in 1990s with increase of grassland cover (30.5% of the total) and forest (12.0% of the total) in Loess Plateau. What is more, the vegetation improved after a large number of ecological engineering projects such as check dams, terraces, and reforestation were implemented.

3. Materials and Methodology

3.1. Data Sources and Materials. In this study, precipitation and hydrology datasets were obtained from the hydrological and meteorological stations of Loess Plateau (Figure 1), and topographic datasets were extracted from digital elevation model (DEM). All these datasets are used to investigate hydrometeorology changing patterns impact on erosive landforms evolution in Loess Plateau in the past 60 years. The meteorological datasets of 76 observation stations, which include daily, monthly, and annual precipitation during 1960–2011, were used to illustrate situations of climate change and human activities in Loess Plateau. Precipitation datasets are further trimmed and classified as erosive precipitation and rainstorms in terms of rainfall intensity. For example, an erosive precipitation is defined when daily precipitation is equal or larger than 12 mm/d [52], while it is defined as rainstorm if daily precipitation is equal or larger than 50 mm/d. These datasets were provided by National Meteorological Information Center (NMIC), China Meteorological Administration (CMA). The hydrological datasets of 41 gauge stations were used to carry out hydrometeorological analysis and soil erosion as well. These datasets include daily streamflow and sediment discharge from 1960 to 2011. Among these 41 gauges stations, 5 stations are located in the mainstream of the middle Yellow River, including Tangnaihui, Toudaoguai, Longmen, Tongguan, and Huayuankou, which will be emphasized in this study. These datasets were provided by Ecological Environment Database of Loess Plateau, Chinese Academy of Sciences and Ministry of Water Resources (CAS&MWR). Topographic parameters, such as gully density, slope, relief amplitude (RDLS), and river network, were extracted from 30-meter resolution DEM which was downloaded from International Scientific and Technical Data Mirror Site, Computer Network Information Center of Chinese Academy of Sciences.

3.2. Analysis of Hydrometeorological Spatiotemporal Distribution. Hydrometeorological spatiotemporal distribution patterns were analyzed by using Mann-Kendall Test (Mann, 1945; Kendall, 1975), Geographic Information System approaches, for example, Inverse Distance Weighted (IDW) [53]. Mann-Kendall Test is applied for detecting changing points in hydroclimatic time series. Meanwhile, temporal characteristics and relationships of precipitation, runoff and sediment in Loess Plateau, and the middle Yellow River basin were also described by Mann-Kendall Test. Changing patterns of climatic and hydrologic spatial distributions were illustrated by spatial interpolation technique, the Inverse Distanced Weighted (IDW). Topographic parameters were further analyzed after extraction from DEM, such as gully density, slope, aspect, relief, and river network, which were

extracted from 30-meter resolution DEM. In comparison, soil erosion landforms in different river basins were characterized through these topographic parameters.

3.3. Erosive Landform Evolution Index for Soil Erosion and Landform Evolution. To quantify soil erosion contributors to landform evolution, we proposed an Erosive Landform Evolution Index (ELEI) for description of soil erosion and landform evolution in Loess Plateau. Considering the complexity of landforms and contributors to soil erosion, those parameters of gully density, relief amplitude (RDLS), and hilly slope are chosen to quantify landform changes, and precipitation, runoff, and sediment are defined as primary parameters of soil erosion. Landform evolution change (Ev_{landform}) is function of gully length (L_g), relief amplitude (A_r), and hilly slope (S_h). Soil erosion intensity (Er_{landform}) is function of precipitation (P), runoff (R), and sediment transportation (S). Erosive Landform Evolution Index (ELEI) is function of landform evolution change (Ev_{landform}) and soil erosion intensity (Er_{landform}). By using the principal components analysis (PCA), we can select comprehensive factors for landform evolution change (Ev_{landform}) and soil erosion intensity (Er_{landform}) from parameters of Erosive Landform Evolution Index (ELEI) and climate factors and establish functions for landform evolution change (Ev_{landform}) and soil erosion intensity (Er_{landform}). Meanwhile, we can also build the function between Ev_{landform} and Er_{landform} by using linear regression analysis:

$$\begin{aligned} Ev_{\text{landform}} &= F(L_{\text{gully}}, A_{\text{relief}}, S_{\text{hilly}}), \\ Er_{\text{landform}} &= G(P, R, S), \\ ELEI &= H(F, G). \end{aligned} \quad (1)$$

According to referenced geomorphological mapping taxonomy, it defines RDLS as flat (0–20 m), small (20–75 m), middle (75–300 m), mountain (300–600 m), and high mountain (>600 m). On the basis of characteristics of DEM in Loess Plateau, the slope can be defined as 5 grades (<3°, 3~7°, 7~15°, 15~25°, and >25°). In this study, we calculated percentages of different RDLS and slope.

4. Results

4.1. Changing Patterns of Rainfall-Runoff-Soil Erosion Process in the Loess Plateau (1950–2010). Changes of precipitation, runoff, and sediment displayed different patterns during the past 60 years (1950–2010). Although annual precipitation had no obvious change, average annual runoff has decreased by 30%–80%, and sediment discharge has decreased by 60%–90% in 2000s in comparison with those in 1960s. Figure 2 displays distribution of annual rainfall, rainfall erosivity (rainfall erosivity is the kinetic energy of raindrop's impact and the rate of associated runoff, $\text{MJ}\cdot\text{mm}\cdot\text{ha}^{-1}\cdot\text{h}^{-1}\cdot\text{yr}^{-1}$), and specific soil yield (SSY refers to sediment export per unit area, $\text{Mg}\cdot\text{km}^{-2}\cdot\text{y}^{-1}$) from 1960 to 2010. It shows that only four stations in the west and north part indicate increasing trend (0–1.7 $\text{mm}\cdot\text{y}^{-1}$), and all the other stations present downward

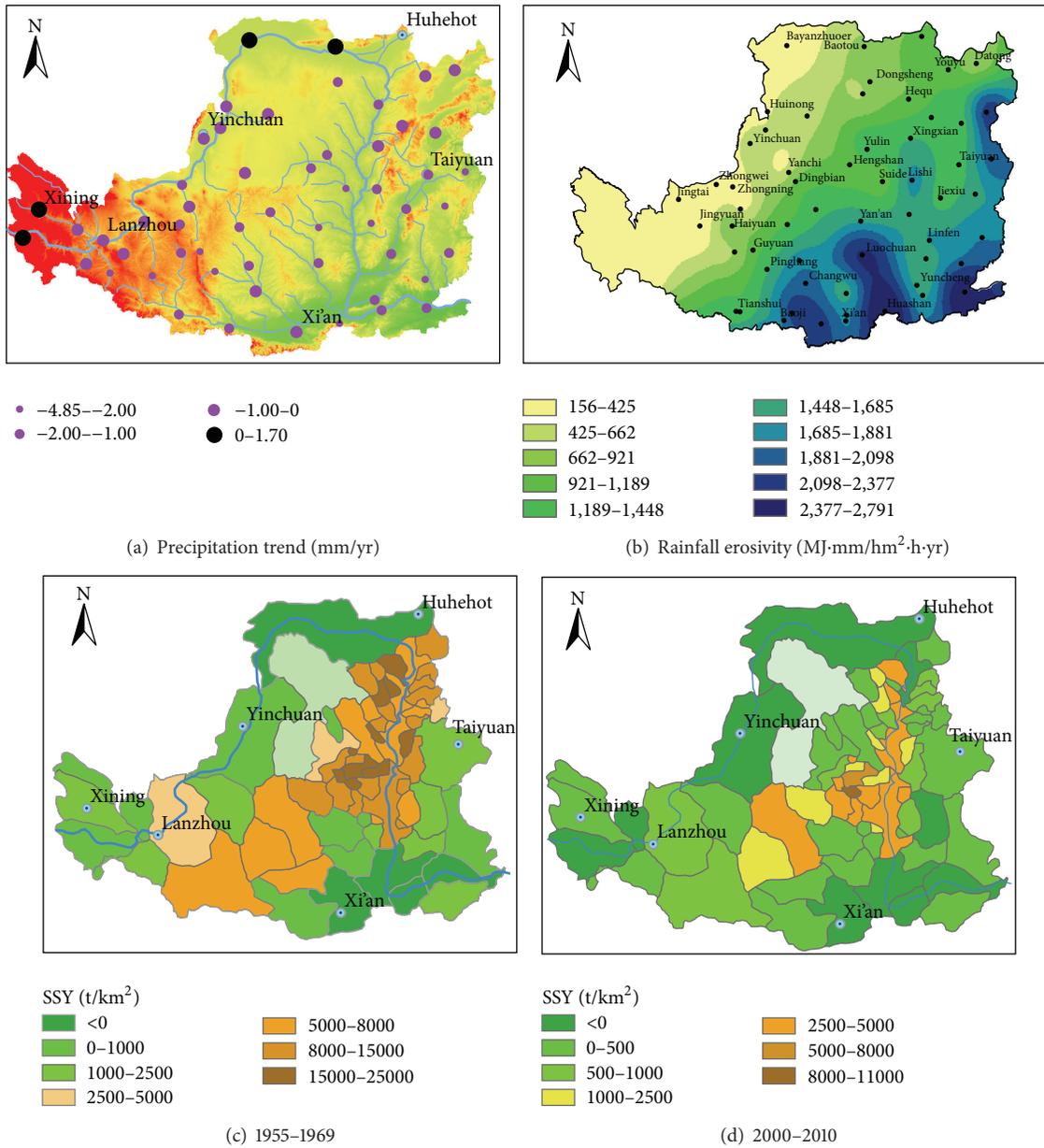


FIGURE 2: Distribution of precipitation, rainfall erosivity, and specific soil yield (SSY) in Loess Plateau (modified after [37]). ((a) Precipitation trend distribution map, (b) rainfall erosivity distribution map, (c) specific soil yield distribution map (1955–1969), and (d) specific soil yield distribution map (2000–2009)).

trend ranging from -4.85 mm to -0.02 mm, particularly near Lanzhou and Yinchuan cities as well as the northeast of Loess plateau [37]. Further, through the Mann-Kendall Test, the change points of annual precipitation usually occur in late 1980s, and annual precipitation increased slightly after change points (Figure 3). Annual runoff of all hydrological stations decreased at 99% confidence interval during the past 50 years, and the significant change often began after 1980s ($p = 0.01$) through the Man-Kendall Test. Spatial distribution of average annual Specific Sediment Yield on Loess Plateau within the two periods. During the period from 1955 to 1969, the most severe soil erosion regions with SSY higher than

$8,000 \text{ Mg}\cdot\text{km}^{-2}\cdot\text{y}^{-1}$ lie in the section between Toudaoguai and Longmen stations (Figure 1), which is also called “the Coarse Sandy Hilly Catchments” [19]. This region covers an area of $7.86 \times 10^4 \text{ km}^2$, accounting for only 14.8% of the whole Yellow River basin but producing nearly 80% of the coarse sediment to the Yellow River [37]. Obviously, heavy rain causes increase in runoff and the tendencies of them are consistent, but the impact of precipitation is postponed because of runoff and flood process. In Loess Plateau, more than 50% of annual precipitation and runoff concentrate during the rainy season (June, July, August, and September), and soil erosion is mainly caused by heavy rainfall (Figure 4).

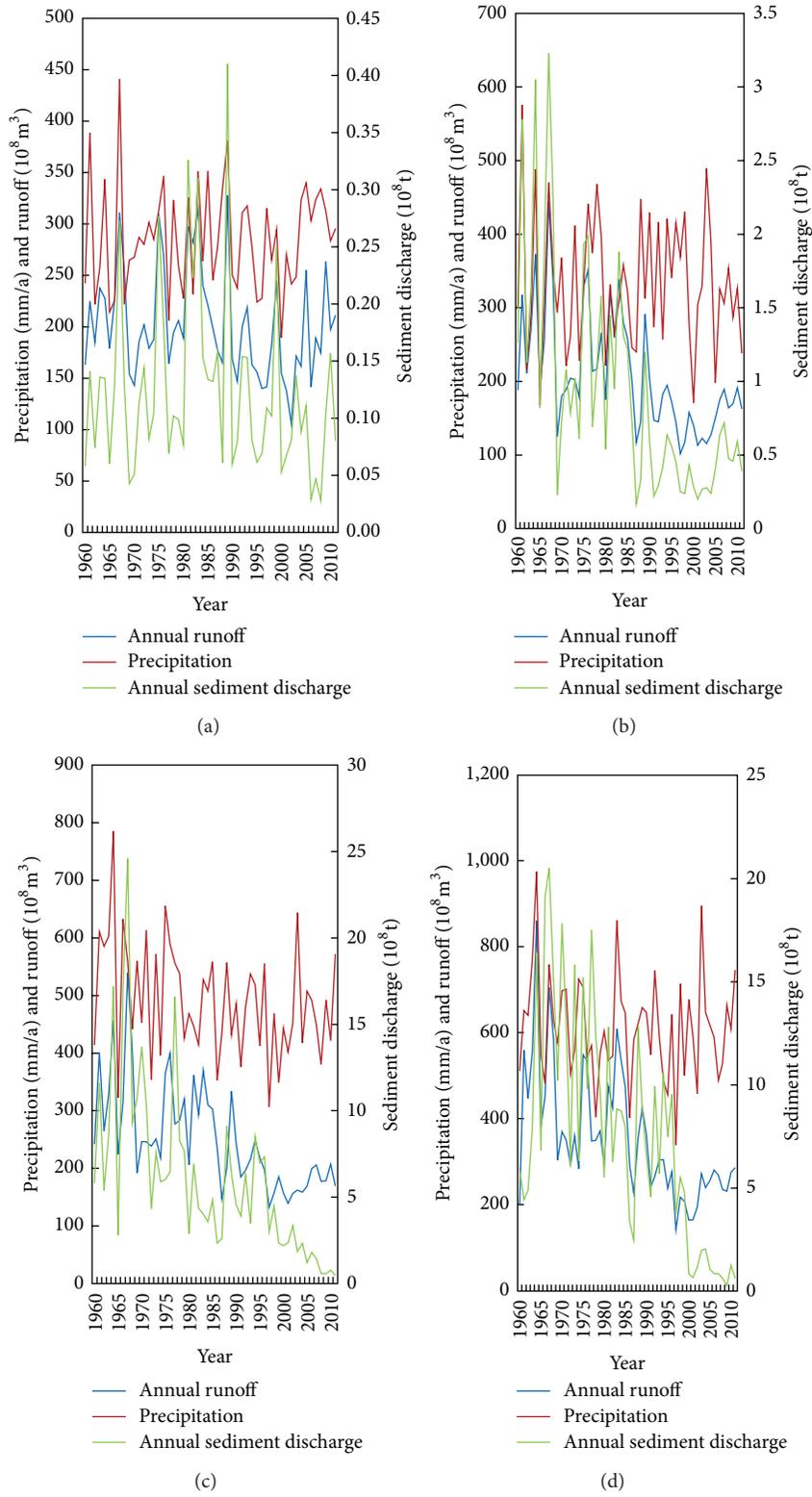


FIGURE 3: Changes of annual precipitation, runoff, and sediment discharge during the past 50 years (1960–2010) ((a) Tangnaihai, (b) Toudaoguai, (c) Longmen, and (d) Huayuankou).

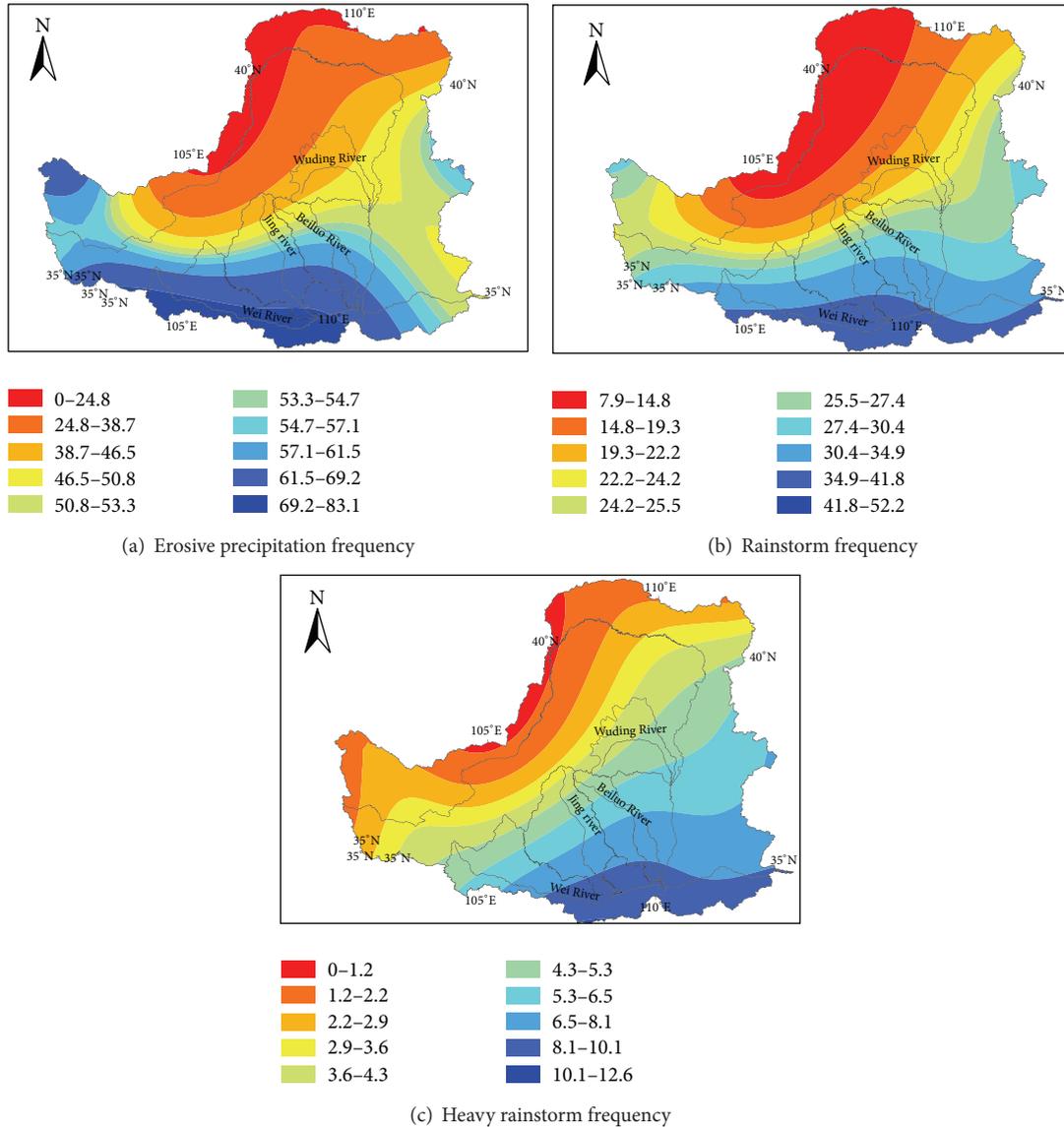


FIGURE 4: Frequency of different rainfall types ((a) erosive precipitation, (b) rainstorm, and (c) heavy rainstorm).

It is obvious that there were time lags between rainfall and runoff, runoff, and sediment transportation in the observed stations. For example, precipitation peak was on the 18th day at Tangnaihai station in 1967, the nearest runoff began to increase on the 22nd day, and the runoff peak was on the 35th day; in 1976, the peaks of runoff were about 4–8 days late compared to that of precipitation.

Differences between precipitation and runoff and sediment increased from upstream to downstream in the mainstream of upper and middle Yellow River, although precipitations fluctuated at around a certain level. And sediment decreased much more than runoff. Higher precipitation of these cities (Tangnaihai, Toudaoguai, Longmen, Tongguan, and Huayuankou) which locate from the upper of Yellow River to lower of it corresponded to higher runoff and sediment from 1960 to 2010. Correlation between precipitation and runoff is positive ($r = 0.565$, $p < 0.01$), and it is

much more obvious during 1960 and 1990. In 1960s and 1970s, change of runoff was mainly caused by fluctuation of rainfall. With development of society and increase of human activities, factors influencing runoff increased, and the coupling relationship between rainfall and runoff has become more complex. Moreover, annual runoff increases from upstream to downstream as well as annual precipitation.

Although annual precipitation fluctuates during the study period, annual runoff sediment discharge decreased obviously. However, runoff peaks correspond with rainfall events, especially for rainstorm (daily rainfall is larger than 50 mm/d). Sediment discharge does not display well correlations with precipitation; as a result, sediment discharge (soil erosion) is mainly influenced by vegetation, land cover, and human activities. The relationship of rainstorm and runoff can correspond well. In July of 1977 at Pingliang, there was a rainstorm which lasted for 19 hours and covered 33200 km².

TABLE 1: Parameters configuration of Erosive Landform Evolution Index (ELEI).

Parameters of Erosive Landform Evolution Index	Weihe River	Jinghe River	Beiluo River	Wudinghe River
Gully				
Gully density (km/km ²)	0.13	0.15	0.15	0.13
Runoff (10 ⁸ m ³)	64.62	16.01	8.16	10.86
Sediment discharge (10 ⁸ t)	2.94	2.08	0.68	0.92
RDLS				
0–20	0.44%	0.23%	0.61%	1.67%
20–75	5.81%	1.01%	3.96%	37.30%
75–300	29.82%	52.36%	58.94%	53.12%
300–600	42.31%	44.49%	36.45%	7.85%
600–max	21.62%	1.91%	0.04%	0.06%
Runoff (10 ⁸ m ³)	64.62	16.01	8.16	10.86
Sediment discharge (10 ⁸ t)	2.942	2.083	0.682	0.916
Slope (°)				
0~5	24.32%	16.69%	19.12%	57.46%
6~15	38.14%	40.77%	41.05%	27.89%
16~25	23.98%	32.75%	29.54%	11.94%
26~35	9.56%	6.24%	8.85%	2.31%
36~40	2.20%	2.92%	0.88%	0.22%
41~45	1.08%	0.30%	0.31%	0.09%
46~max	0.73%	0.34%	0.24%	0.09%
Runoff (10 ⁸ m ³)	64.62	8.16	16.01	10.86
Sediment discharge (10 ⁸ t)	2.942	0.682	2.083	0.916
ELEI				
Gully length (km)	9334.05	3501	5865.51	4414.58
RDLS (km ² , 20–600 m)	48825.22	26755.75	44496.04	29713.77
Slope (km ² , 0–25°)	54150.01	24294.27	40790.31	29417.45

Its rainfall was 255 mm, and the maximum peak flow was 5220 m³/s. In August of 1984 at Zhengning, there was a rainstorm which lasted for 6 hours and covered 423 km², and the maximum peak flow was 586 m³/s. In May of 1985 at Zhenyuan, the rainstorm lasted for 2.5 hours and covered 480 km² with 359 mm precipitation, the maximum peak flow of which was 1260 m³/s. In July of 1996 at Qingyang, the rainstorm lasted for 19.5 hours and covered 33150 km² with 257.2 mm precipitation, and the maximum peak flow was 4680 m³/s.

Frequency of low intensity rainfall was higher than that of high intensity rainfall, and frequency of the same intensity rainfall is higher in downstream than that of upstream. The average annual precipitation increases from northwest to southeast, and the minimum annual precipitation (46.80 mm/a) is in Linhe, Inner Mongolia, and the maximum annual precipitation (1262.3 mm/a) is in Huashan, Shaanxi. Overall, high rainfall (more than 720 mm/a) region mainly concentrates in south of Shaanxi province, and the low rainfall (less than 250 mm/a) is in Inner Mongolia, Ningxia province, and northwest of Gansu province. The tendency of average decade precipitation is consistent with that of average annual precipitation which increases from northwest (138 mm) to southeast (819 mm). In the typical reach of the Yellow River, sediment discharge and annual runoff of specific stations which are

close to downstream are larger than others. It indicates that (a) the downward trend of sediment discharge in upstream catchment is more significant than that in downstream basins for the same grade tributaries and (b) the trend of annual runoff in downstream catchment is more significant than that in upstream basin. The trend of sediment discharge is similar to that of runoff which increases from upstream to downstream.

4.2. Coupling Analysis of Soil Erosion and Landforms Evolution in the Loess Plateau. Tectonic movements in Quaternary formed the basic topography in Loess Plateau. Based on the above analysis of rainfall, runoff, and sediment transport, we can observe that peaks of runoff and sediment discharge are consistent with rainfall peak with time lags, and time lags of runoff and sediment discharge became longer in downstream than that in upstream for a normal distribution rainfall.

As indicated in methodology section, the higher values of Erosive Landform Evolution Index (ELEI) represent late stage of landform erosion. Table 1 displays parameters configuration of Erosive Landform Evolution Index (ELEI). By using the PCA method, we can easily get a comprehensive factor to stand for the three landform factors (gully length, RDLS, and slope). Before the PCA process, we standardized the data of three landform factors because of the difference of

TABLE 2: The proportion of covariance and first principal values of landform and climatic factors.

(a)							
PRIN number	Eigenvalue	Difference	Proportion	Cumulative			
Landform factors							
1	2.9524	2.9051	0.9841	0.9841			
2	0.0473	0.0470	0.0158	0.9999			
3	0.0003		0.0001	1.0000			
Climatic factors							
1	2.7813	2.6352	0.9271	0.9271			
2	0.1461	0.0734	0.0487	0.9758			
3	0.0726		0.0242	1.0000			
(b)							
Basins	Weihe River	Wudnghe River	Beiluoh River	Jinghe River	Fenhe River	Qinhe River	Yanhe River
Landform factors	2.7176	0.1526	-0.3206	1.3861	0.1233	-1.9096	-2.1495
Climatic factors	3.3354	-0.3999	-0.4694	0.9867	-0.7555	-1.3332	-1.3640

TABLE 3: The estimation parameters of the regression modeling.

Variable	Parameter estimate	Standard error	<i>t</i> value	<i>p</i> value
Comprehensive factor of erosive landform				
Intercept	0	0.270	0	1.00
E_e	0.953	0.004	150.87	<0.003

the units. The results of PCA (Table 2) show that the proportion of first principal is 98.41% which has significant correlation with the three landform factors. So we choose the first principal components as the comprehensive factor of erosion landform; higher PRIN values mean higher development of the erosion landform. Furthermore, with the PCA results we build (2) between the first PRIN and landform factors. The equation indicates that the three landform factors have positive correlation with the comprehensive landform factor:

$$Y_e = 0.576X_1 + 0.575X_2 + 0.582X_3, \quad (p < 0.05). \quad (2)$$

In the equation, the Y_e is the comprehensive factor of erosion landform, X_1 is the standardized value of gully length, X_2 is the standardized value of waviness, and X_3 is the standardized value of slope.

On the other hand, we also applied the same PCA process of calculation of the comprehensive factor of erosion landform, to calculate the comprehensive effect of erosion landform. By using the data of effects of erosion landform (Table 2), we obtain the comprehensive effect of erosion landform based on these erosion landform effects (runoff, sediment, and rainfall volume). The results (Table 2) indicate that the proportion of first principal is 92.71%, which means the first principal can explain all the erosion landform effects very well. Therefore, we select the first principal component as the comprehensive effect of erosion landform, and higher principal scores mean more influence on the erosion

landform. The equation of comprehensive effect of erosion landform is as follows:

$$E_e = 0.570Z_1 + 0.578Z_2 + 0.584Z_3, \quad (p < 0.05), \quad (3)$$

where the E_e is the comprehensive effect of erosion landform, Z_1 is the standardized value of runoff, Z_2 is the standardized value of sediment, and Z_3 is the standardized value of rainfall volume.

Finally, by using regression analysis, we can figure out the relationship between the comprehensive factor and comprehensive effect of erosion landform. Via the first principal scores of both comprehensive indexes (Table 2) in seven basins, we can calculate the relationship between these two indexes. The results (Table 3) show that the erosion landform comprehensive factor has the significant correlation ($p < 0.003$) with comprehensive effect of erosion landform, and the intercept of the model is not significant with erosion landform comprehensive factor ($p > 0.05$). Therefore we remove the intercept from the model.

Moreover, through the regression analysis we also obtain (4) between the erosion landform comprehensive factor and comprehensive effect. Meanwhile from the equation, we can also indicate that the erosion landform comprehensive factor has positive relationship with the effects of erosion landform. Therefore, the development level of erosion landform will increase as the effects values increase:

$$Y_e = 0.953E_e, \quad (p < 0.003). \quad (4)$$

In this equation, the Y_e is the comprehensive factor of erosion landform and the E_e is the comprehensive effect of erosion landform.

5. Conclusion

The aim of this study was to identify coupling relationship of soil erosion and landforms evolution under the background of climate change and human activities. Through mathematical statistics, regression analysis, and PCA method, it was found that the main effects of erosion landform are rainfall volume, runoff, and sediment in Chinese Loess Plateau. The results of PCA indicate that the erosion landform comprehensive factor is composed of the three landform factors, which are gully length, RDLS, and slope. It also shows that there is a significant positive relationship between erosion landform comprehensive factor and landform factors, and this means that these three factors can stand for erosion landform. Therefore, they can be used as evaluation factors of erosion landform. The results of multiregression analysis indicate that annual rainfall volume, runoff, and sediment are the main effects of erosion landform, and they drive the changes of landform in the Loess Plateau. Furthermore, both landform factors and erosion landform effects should be standardized before using them to build up the correlation model because standardization can reduce the influence of unequal units of these factors, which is a very important part in this modeling. Meanwhile, the regression results also show that there is also a significant positive linear relationship between the erosion landform comprehensive factor and its effects. As a result, the development level of erosion landform will increase as its effects' values increase. Thus, this study provides useful information on impacts of erosion landforms evolution and can be used to guide soil and water conservation and investigate landforms evolution.

Conflict of Interests

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

Acknowledgments

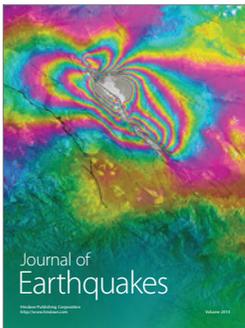
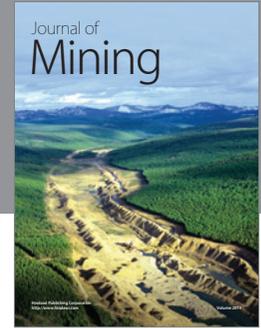
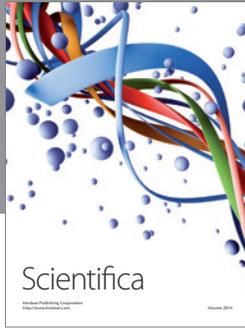
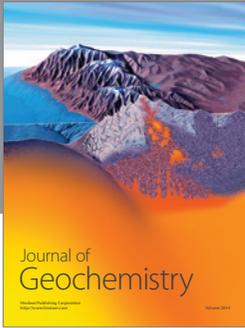
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