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Original Research

Temporal-Spatial Variation Characteristics of Soil Erosion in the Pisha Sandstone Area, Loess Plateau, China

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Abstract

Soil erosion in the Pisha sandstone area of the Loess Plateau in China has become a severe environment issue that has raised concerns globally. The projects of ecological restoration in this area and their impact on soil erosion have been analyzed using the unmanned aerial vehicle remote sensing system (UAVRSS) and the revised universal soil loss equation (RUSLE) in the Two-Tiger Valley Basin in 2013 and 2015. Our findings show that:

1) The volume of soil erosion and average soil erosion modulus decreased from 126.24 t year^{-1} and 6465.295 t km^{-2} year^{-1} to 114.7 t year^{-1} and 6333.19 t km^{-2} year^{-1} between 2013 and 2015, respectively.

2) Spatial-temporal variations of soil erosion are extremely significant. All erosion grades recorded different degrees of decline across the study period, except for the level of severe erosion.

3) There is a significant positive correlation between slope degree and soil erosion. When the slope degree was <5°, the soil erosion modulus was 51.355 t km^{-2} year^{-1}, accounting for only 0.87 % of total erosion in this area. When the slope degree was >35°, the soil erosion modulus attained 2574.413 t km^{-2} year^{-1}, and the erosion amount accounted for 43.52% of total erosion. Although anti-erosion and the promotion of plant growth measures have achieved noticeable ecological benefits, the present situation of preventing and controlling soil and water loss is still severe.

Keywords: soil erosion, temporal-spatial changes, UAVRSS, Pisha-sandstone area

Introduction

Environmental problems present in the Loess Plateau ecosystem, such as vegetation destruction, soil degradation, water and soil loss, have become increasingly serious with an increase in global climate change. As a result, a series of social and economic problems have arisen, with ecological security in this area having widespread concern [1]. The Pisha sandstone area is widely distributed in the Yellow River watershed at the junction of Shanxi, Shaanxi, and Mongolia provinces. This area has been referred to as having "the world's most soil and water loss" and being termed as

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suffering from "environmental cancer" [2]. Although the Pisha sandstone area accounts for only 2% of the Loess Plateau, sediment discharged from this area accounts for 25% of the total sediment of the Yellow River. The volume of sediment lost from this area is having a serious impact on the implementation of sustainable development in this region. As part of China's Twelfth Five-Year Plan, erosion control was initiated in 2013 in the Pisha sandstone area. This investigation integrates previous soil and water conservation results in the area, evaluates the eco-environmental benefits obtained from an anti-erosion project, and provides a scientific basis for soil and water loss control planning.

Currently a wide number of theoretical and empirical investigations on soil erosion have been undertaken. Theoretical studies have resulted in the formulation of inherent driving mechanisms of soil erosion with the construction of a soil erosion model framework [3-4]. Investigations have also been undertaken analyzing the influential factors of soil erosion from a theoretical analysis [5-6], erosion assessment and prediction [7-11], soil erosion process simulation, and measures of anti-erosion and the promotion of plant growth [12-14]. Empirical research has also been used, for example to assess soil erosion on a watershed scale [15-16]. Taguas et al. [17] simulated the spatial distribution of water erosion using a sediment delivery distributed (SEDD) model across a small watershed in a Spanish olive orchard, and Elmouden et al. [18] evaluated spatial-temporal soil erosion in the Souss Massa River basin in Morocco.

Previous research on soil erosion in the Pisha sandstone area has focused on analysis of anti-erodibility [19], morphological characteristics [20], patterns of land use [21], and the evaluation of eco-environmental quality [22]. However, investigations have rarely analyzed the spatial-temporal evolution of soil erosion after the implementation of anti-erosion and the promotion of plant growth in this area. The majority of studies have focused on large- and medium-scale soil erosion, such as in the administrative area or in river basins [23-24]; small-scale studies on soil erosion have rarely been undertaken. As large- and medium-scale investigations on the differences of climate, hydrogeology, vegetation cover, and human activities on spatial heterogeneity of soil erosion only provide limited applicability, it is therefore important to examine small-scale soil erosion changes.

Unmanned aerial vehicle remote sensing system (UAVRSS) integrate unmanned aerial vehicles, remote sensing, radio communications, GPS differential positioning, and inertial measurement unit (IMU) inertial navigation and other technologies to quickly obtain information on a target object/area. Compared with traditional remote sensing technologies, UAV low-altitude remote sensing has significant advantages

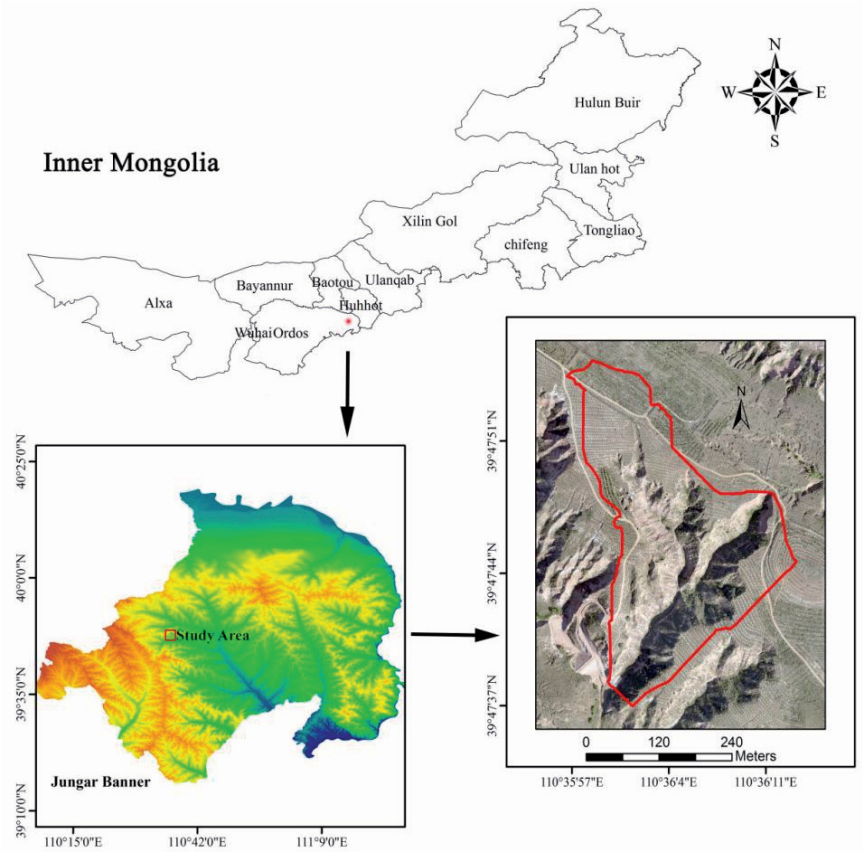

Fig. 1. UAV remote sensing image and geographical location of the study area.

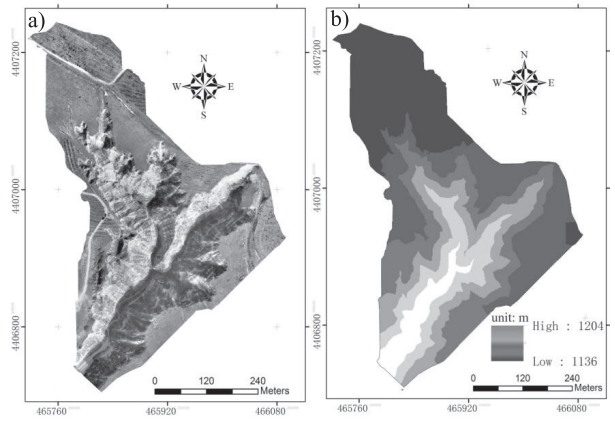

Fig. 2. Digital orthophoto map a) and digital elevation model b) of the study area, 2013.

in terms of spatial-temporal resolution, cloud impact, and economic cost [25]; this technique has seen an increase in use recently. UAVRSS is used in this study to evaluate the benefits of controlling soil erosion and obtaining high-resolution topography and image data in the study area. The revised universal soil loss equation is then used to evaluate the spatial-temporal evolution of soil erosion during the implementation of anti-erosion and the promotion of plant growth measures in a small-scale pattern. Results from this study will provide theoretical and technical support for managing soil and water conservation planning and comprehensive management in the Pisha sandstone area.

Material and Methods

Study Area

The Two-Tiger Valley Basin in the Pisha sandstone area (39°47′37.48″~39°47′54.92″N, 110°35′58.9″~110°36′14.84″E) (Fig. 1), located in Nuanshui town, Jungar Banner, Ordos, Inner Mongolia, is situated in the pilot area to examine plant growth as erosion control. This area has a typical arid and semi-arid continental climate, and has an annual flood season spanning June to September. The study area is fragmented and densely covered with ditches and valleys, many of which are deep and have V-shaped channels. The factors affecting soil erosion are normally water, wind, gravity, coverage, freeze-thaw, and properties of Pisha sandstone, etc., of which unsteadiness of stone is the most different factor from other areas. Relevant research [26] shows that Pisha sandstone is rich in extremely active components like CaO, K_2O, and Na_2O. The properties of unsteadiness have led the area to be more vulnerable to external erosion and having the greatest impact on the local environment. The selected study area is believed to be representative for similar environments undergoing soil erosion, thus our results will be applicable in other areas.

Data Resource

Digital elevation model (DEM) (Fig. 2a), digital orthophoto map (DOM) (Fig. 2b), land use types, soil types, and daily precipitation data across the research area (2013 and 2015) were used in this study.

All data sources are shown in Table 1. All feature layers were converted into a Gaussian projection coordinate system to be a convenience to calculating, with a grid resolution of 1 m.

Methods

The universal soil loss equation (USLE), first proposed by Wischmeier and Smith [27], can be used to predict annual average soil loss due to surface and gully erosion. The United States Department of Agriculture (USDA) improved the suitability of this equation to form a revised universal soil loss equation (RUSLE) [28]. In this study, the soil loss equation was calculated as:

$$A = R \times K \times L \times S \times C \times P \quad (1)$$

…where A is the average annual soil erosion modulus t km^{-2} year^{-1}; R is the erosive factors for rainfall-runoff MJ mm km^{-2} h^{-1}year^{-1}; K is the soil erodibility factor t h MJ^{-1}mm^{-1}; is the slope length factor;is the slope steepness factor; C is the vegetation cover in the management factor; and P is the soil and water conservation factor. Parameters L, S, C, and P are all

Table. 1 Research data and sours.

Data type	Directions	Data source
DOM	1:1000 UAV data	UAV remote sensing
DEM	1 m resolution DEM data	UAV remote sensing
Meteorological data	daily rainfall data	Meteorological station
Soil type data	1: 1000 soil type data	Visual interpretation and field research
Land use type data	1:1000 Land use type data	Visual interpretation and field research
Basic geographic data	30 m resolution DEM	National Earth Systems Science Data Sharing Infrastructure

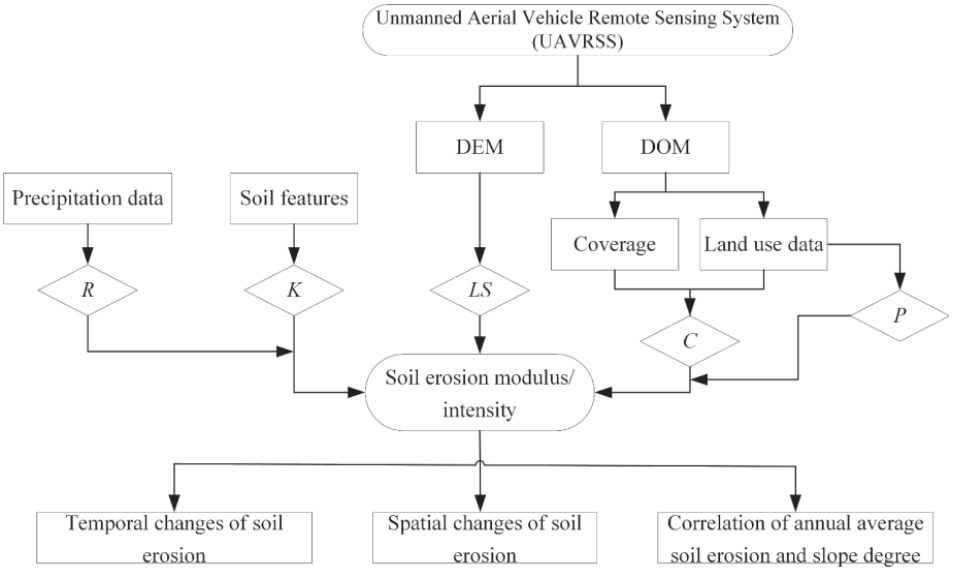

Fig. 3. The technical route of calculating soil erosion.

dimensionless. Fig. 3 is the flow chart of the entire methodology.

Rainfall Erosivity Factor (R)

The rainfall erosivity factor is the main dynamic factor resulting in soil erosion. Due to a lack of detailed data such as rainfall and intensity of rainfall, this study uses the calculation method of rainfall erosivity factor based on daily precipitation data proposed by Zhang et al. [29]. This method has been widely used to calculate erosion on the Yellow River Plateau due to a lack of detailed rainfall data. We chose daily rainfall greater than 12 mm as the valid values. The equations used are:

$$R_{\text{Half-month}} = \alpha \sum_{k=1}^{m} (R_k)^{\beta} \quad (2)$$

$$\beta = 0.8363 + (18.177 / P_{d12}) + (24.455 / P_{y12}) \quad (3)$$

$$\alpha = 21.586 \beta^{-7.1891} \quad (4)$$

…whereis R_k the daily precipitation on the *kth* day of the half month, and P_{y12} is the mean annual rainfall erosivity. The Half-month rainfall erosivity was calculated according to this equation and recorded as monthly rainfall erosivity. It should be noted that, due to the extremely small study area, the rainfall

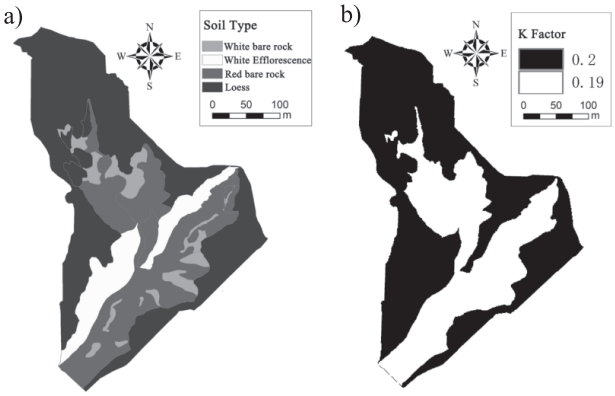

Fig. 4. Soil type a) and *K* factor b) maps of the study area.

Table 2. Soil organic matter content and soil particle size distribution.

Soil type	Soil organic matter	Coarse sand	Silt	Clay
Pisha-sandstone (White bare rock)	0.09	64.95	34.8	0.24
Slope wash (White)	0.21	67.612	31.94	0.44
efflorescence (Red)	0.18	55.94	43.78	0.28
Pisha sandstone (Red bare rock)	0.11	54.47	45.35	0.19
Loess	0.21	41.46	57.45	1.08

Note: coarse sand: 50-2000 μm; silt: 2-50 μm; clay: 0.001-2 μm

erosivity factor was calculated by daily precipitation data from a single station.

Soil Erodibility Factor (K)

The soil erodibility factor (K) is affected by the inherent characteristics of the soil, with soil features mainly including: soil texture, structure, soil permeability, and clay mineral properties. In this study we used the erosion productivity impact calculator (EPIC) model. The K value (Fig. 4b) was obtained using data for characteristics of the soil (Table 2) and soil type distribution (Fig. 4a) in the study area.

Slope Steepness (S) and Slope Length (L)

Slope steepness and slope length are the basic geographical factors that reflect the impact of topography on soil erosion. Considering the actual situation of the study area, we used the calculation equation of the LS factor in RUSLE to obtain the LS factor for the whole study area (Fig. 5). The calculation equation was:

$$\begin{cases} S = 10.8 \times \sin\theta + 0.03 & \theta < 5^\circ \\ S = 16.8 \times \sin\theta - 0.05 & 5^\circ \le \theta < 14^\circ \\ S = 21.91 \times \sin\theta - 0.96 & \theta \ge 14^\circ \end{cases} \quad (5)$$

$$L = \left(\lambda / 22.1\right)^m \quad \left[m = \begin{cases} 0.2 & (\theta \le 1^\circ) \\ 0.3 & (1 < \theta \le 3^\circ) \\ 0.4 & (3 < \theta \le 5^\circ) \\ 0.5 & (\theta \ge 5^\circ) \end{cases} \right] \quad (6)$$

…where θ is the slope extracted by DEM (°); λ is the slope length extracted from DEM (m); L is the slope length factor; S is the slope steepness factor; and m is the slope steepness and slope length index (the value of m in study area being 0.5). According to results from the DEM, having a grid size of 1 m, slope steepness and slope length factor were obtained by extracting the terrain parameters. Further details of this method can be found in Zhang et al. [30].

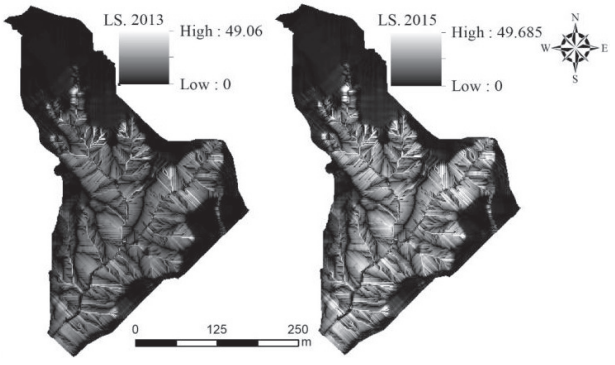

Fig. 5. *LS* factor maps of the study area in 2013 and 2015.

Cover Management Factor (C)

In this study, the vegetation distribution was initially interpreted before the vegetation data was divided into 1 × 1 m grids. The proportion of vegetation in each grid was then calculated to provide vegetation coverage f in 2013 and 2015 (Fig. 6a). The value of C was calculated according to the following equation (Fig. 6b):

$$C = \begin{cases} 1 & 0 \le f < 0.1\% \\ 0.6508 - 0.3436 \times \lg(f) & 0.1\% \le f < 78.3\% \\ 0 & f \ge 78.3\% \end{cases} \quad (7)$$

Soil and Water Conservation Support Practice Factor (P)

The soil factor and water conservation measures reflect the impact of anti-erosion measures on soil. The results of this analysis range from 0 to 1, with 0 indicating almost no erosion and 1 indicating soil erosion occurring due to no soil factor or water conservation measures having been implemented. According to the results of previous studies [31], the P factors of the study area in 2013 and 2015 were determined based on

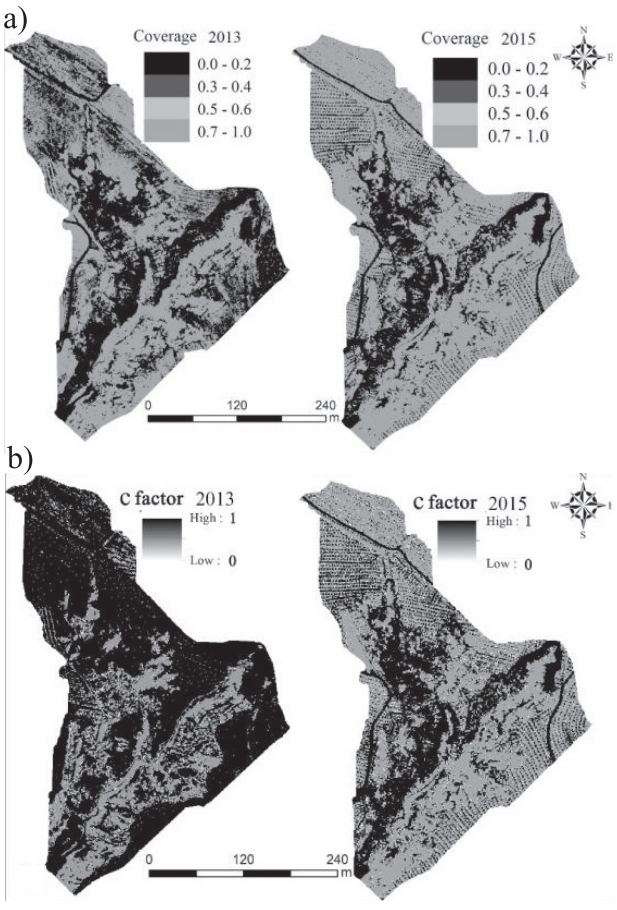

Fig. 6. Coverage a) and C factor b) maps of the study area in 2013 and 2015.

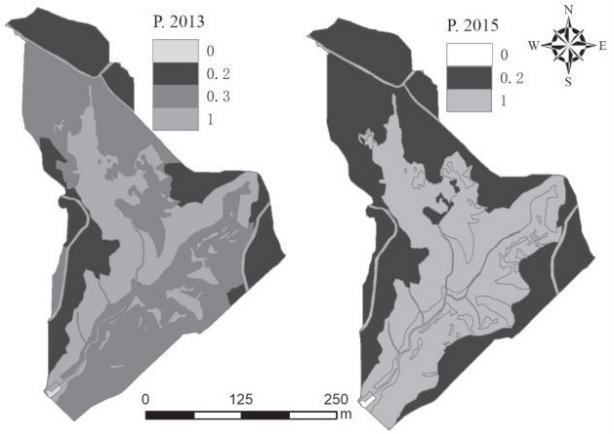

Fig. 7 *P* factor maps of the study area in 2013 and 2015.

the different conditions of land use in the study area (Fig. 7).

Results and Discussion

The RUSLE model was used to calculate the raster layer of each erosion factor in the study area and the raster calculator tool was used to multiply each soil erosion factor to obtain the pattern of soil erosion in 2013 and 2015. We quantitatively analyzed the inter-annual variation of the soil erosion modulus to evaluate positive influence of anti-erosion and the promotion of plant growth measures in the study area.

Temporal Changes of Soil Erosion

To investigate temporal changes in soil erosion intensity (between 2013 and 2015), we used standard "SL190-2007" [32] to divide the soil erosion modulus with the grid unit of 1 × 1 m into six grades (micro-degree to severe). The raster calculator tool in ArcGIS 10.4 was then used to calculate the distribution of erosion amount in 2013 and 2015 (Table 3).

Soil erosion intensity levels (Table 3) by 2015 had the order of: micro-erosion (71.07 %), moderate erosion (11.65 %), mild erosion (9.99 %), intense erosion (5.93 %), very intensive erosion (1.24 %), and severe erosion (0.1 %). Between 2013 to 2015 the soil erosion amounts of micro-erosion decreased by 3.65 t (from 14.24 to 10.58). The soil erosion modulus of micro-degree and mild erosion decreased from 212.82 t km^{-2} year^{-1} and 1642.51 t km^{-2} year^{-1} to 154.95 t km^{-2} year^{-1} and 1648.54 t km^{-2} year^{-1}, and the soil erosion modulus of micro-erosion erosion decreased by 27.19 %. The soil erosion amounts of mild erosion and micro-erosion decreased 6.82 t year^{-1} from 2013 to 2015. Soil erosion modulus showed a decreasing trend, indicating that soil erosion in the study area was effectively controlled and the ecological environment significantly improved. This result is in accordance with soil erosion findings by Wang et al. [33] on the Loess Plateau.

The soil erosion modulus of moderate and strong erosion levels recorded only a slight change between 2013 and 2015. The soil erosion amounts of moderate and severe erosion levels in 2015 were 41.31 t year^{-1} and 34.85 t year^{-1}, the total proportion of two levels increased by 66.40 %, this recording the most severe soil erosion in the study area. The phenomenon appeared due to not being suitable for use and being locating in the wasteland area. This area has a broad steep slope and experiences severe gravity erosion. In addition, although biological measures have been implemented, due to the wide area of undeveloped forest the ecological and environmental benefits have not been fully exerted. Therefore, the moderate and intense erosion levels should be viewed as key areas for subsequent projects to reduce anti-erosion and promote engineering solutions. In 2015, the soil erosion modulus of extremely intense erosion and severe erosion were 10269.78 t km^{-2} year^{-1} and 16322.98 t km^{-2} year^{-1}, respectively, this being more

Table 3. Distribution of soil erosion intensity levels in 2013 and 2015

Soil erosion modulus /t km^{-2}year^{-1}	Erosion degree	2013			2015			2013-2015
		Erosion area /km^2	Soil erosion modulus /t km^{-2}year^{-1}	Total erosion /t km^{-2}	Erosion area /km^2	Soil erosion modulus /t km^{-2}year^{-1}	Total erosion /t km^{-2}	Variation of soil erosion /t km^{-2}
0~1000	micro	0.0669	212.82	14.24	0.0683	154.95	10.58	-3.65
1000~2500	mild	0.0104	1642.51	17.08	0.0096	1448.54	13.91	-3.17
2500~5000	moderate	0.0114	3677.74	41.93	0.0112	3688.79	41.31	-0.61
5000~8000	intense	0.0059	6124.55	36.13	0.0057	6114.10	34.85	-1.28
8000~15000	extreme	0.0013	10357.48	13.46	0.0012	10269.78	12.32	-1.14
>15000	severe	0.0002	16989.49	3.40	0.0001	16322.98	1.63	-1.77

Note: Soil erosion classification grading standard: micro-erosion: <1000 t km^{-2}year^{-1}; mild erosion: 1000-2500 t km^{-2} year^{-1}; moderate erosion: 2500-5000 t km^{-2} year^{-1}; intense erosion: 5000-8000 t km^{-2} year^{-1}; very extreme erosion: 8000-15000 t km^{-2} year^{-1}; severe erosion: >15000 t km^{-2} year^{-1}

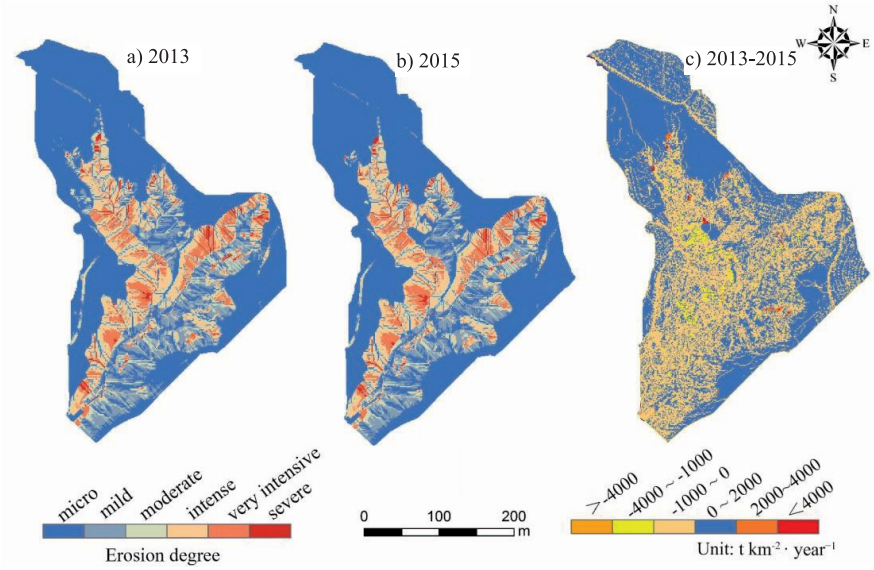

Fig. 8. Soil erosion grade and spatial change across the study area.

than 10-times greater than the allowable soil erosion modulus (1000 t km^{-2} year^{-1}). However, the amount of soil erosion was much lower than that recorded at the moderate and intense erosion levels due to being maintained at 1%. In addition, it should be noted that the average modulus of soil erosion in 2015 was as high as 6333.19 t km^{-2} year^{-1}, and that the severe erosion modulus was 16322.98.11 t km^{-2} year^{-1} – both results being significantly higher than the permissible value of soil erosion (1000 t km^{-2} year^{-1} for the northwest Loess Plateau; Ministry of Water Resources PRC, 2008).

These results indicate that annual soil erosion significantly decreased in the study area from 2013 to 2015. The results also show that the soil erosion modulus for all grades decreased to some extent, indicating that as parts of China's Twelfth Five-Year Plan the implementation of the anti-erosion and promotion of plant growth achieved a certain degree of ecological and environmental success, and that soil and water loss prevention and treatment has progressed. At the same time, due to the significant base of water and soil loss, the current situation of soil and water loss was still extreme and that the ecological environment is still very fragile. The positive impact of controlling soil and water loss in small watersheds of the Pisha sandstone area has some degree of finiteness, and the anti-erosion and promotion of plant growth is a long process.

Spatial Changes of Soil Erosion

Based on the six degrees of soil erosion, the spatial pattern of soil erosion changes in the study area were plotted and analyzed to identify any noticeable characteristics (Fig. 8). Results from this analysis show that soil erosion levels in the loess-covered area around the study area mainly consisted of mild and moderate erosion levels (Fig. 8 a and b), and that soil erosion levels mainly consisted of micro-erosion by 2015. This change in erosion levels indicated that the anti-erosion and promotion of plant growth measures extenuated the soil erosion conditions around the study area, and that the ecological environment improved to a certain extent. The reason for this change is due to the prevention and control of soil and water erosion, and to the restoration of vegetation (which mainly included Seabuckthorn and Mongolian pomfret). As a result, the area of land use pattern also had a dramatic change. The area of bare sandstone and sandy land decreased, and the proportion of grassland and shrubland increased sharply. In addition, eco-immigrants returned farmland to forests and grasslands within the basin, which was also an important factor for ecological restoration. Results for soil erosion levels (Fig. 8c) showed a gradual increase from the periphery to the center from 2013 to 2015. The soil erosion modulus around the study area decreased, and only partially improved in the central area (>2000 t km^{-2} year^{-1}). The majority of areas maintained their original status (-4000 ~ -1000 t km^{-2} year^{-1}), or became worse, indicating that the biological measures undertaken were not very effective in controlling soil and water loss in these areas.

The spatial pattern of soil erosion in the study area from 2013 to 2015 followed the trend of a rapid increase from the periphery to the center. A decrease was recorded for the periphery of the study area and it was basically unchanged in the central region. There are plural reasons for the significant spatial heterogeneity of soil erosion. Compared with the central area, the area surrounding the study area is covered by a few meters of loess with flat ground and suitable conditions for vegetation growth. However, the central area has many V-shaped valleys and the slope of this region has numerous changes, thus resulting in the bio-engineering measures not succeeding. In addition,

the combination of water and gravity erosion further aggravates soil erosion, indicating that the benefits of biological measures to control soil erosion have spatial heterogeneity. Our results suggest that the local population should take a variety of prevention measures according to the different local conditions. Finally, Seabuckthorn-based anti-erosion measures were applied in the loess area around the study area. This measure has played an effective role in protecting the soil and significantly reducing soil and water loss in some areas.

Correlation of Annual Average Soil Erosion and Slope Degree

As soil erosion from different slopes has a wide variety, identifying the correlation between slope and erosion modulus is very important for the area of anti-erosion. Because it can help us identify the areas with severe soil erosion and make appropriate measures for soil and water conservation in areas with large changes in slope. Soil erosion at different slope grades (annual average slope degree) was calculated by DEM and soil erosion data in the study area. The average slopes of 2013 and 2015 were then divided into six levels using the reclassification tool. Finally, based on the average soil erosion and slope data in 2013 and 2015, the soil erosion modulus at different slopes was obtained using zonal statistical methods (Table 4).

Annual average soil erosion modulus at different slope degrees is shown in Table 4. Results indicate that the area of slope <5° occupies 29.2% of the total study area, and that the area having a slope >25° accounts for 48.1%, a result that shows that the gradient of the ground surface changes dramatically. The reason for this dramatic change is due to the surface of the study area being subject to perennial hydraulics, gravity, and wind erosion. In addition, the intrinsic rigidity of the Pisha sandstone and the large area of exposed rock are also important reasons for surface crushing. Analysis of the relationship between slope and soil erosion in the study area shows that:

1) Micro-erosion is present at 0 < slope < 15°; mild erosion is present at 15° < slope < 35°; and slopes > 35° show moderate levels of erosion. The degree of soil erosion at each slope level is at or below moderate erosion levels, indicating an improvement of soil erosion to some extent. This result is due to the implementation of prevention and control measures for soil and water loss, combined with the reduction of human activities in the area and the improvement of the environmental quality caused by local populations moving to cities.
2) Although the area with 0<slope<15° accounts for 45.6% of the whole study area, soil erosion amount is only 5.4 t year^{-1}, this being 0.49% of total erosion. This finding is a product of the most obvious ecological and environmental benefits of soil and water conservation measures.
3) When 15°<slope<25°, the modulus of soil erosion accounting for 1024.615 km^{-2} year^{-1}, accounted for 17.32 % of the total area. The degree and scale of soil erosion gradually increased.
4) The modulus of soil erosion for slopes >25° accounted for 73.44 % of the whole area, with soil erosion accounting for more than 90% of the whole area. This finding shows that this slope degree is the area where soil erosion is the most concentrated.
5) The modulus of soil erosion for slopes >35° is as high as 2574.413 t km^{-2} year^{-1}, accounting for 43.52% of total erosion. Soil erosion attains its peak value at this slope degree, indicating this is where the most drastic soil erosion occurs. These results show that with an increase in slope degree, soil erosion modulus also increases. A significant positive correlation between slope and soil erosion modulus exists. In addition, the spatial change pattern of slope degree in the study area from 2013 to 2015 followed a decrease trend in the periphery and it was basically unchanged or slightly increased in the central region. The slope grew by an average of 0.74° in the study area from 2013 to 2015. The slope changes mainly concentrated on the degree of 15-25° and 25-35°, and the variation of slope degree was 2.08° and 1.81°, respectively. It is shown that the slope factor is the main factor affecting soil erosion in the Two-Tiger Valley watershed. This conclusion is similar to the conclusion drawn by related scholars on soil erosion in the Loess Plateau. Therefore the formulation of control strategies for soil erosion in

Table 4. Soil erosion modulus on different slopes in the study area.

Slope degree	Area /km^2	Erosion modulus /[t/km^2·a]	Erosion modulus ratio (%)	Erosion amount [t/a]	Erosion amount ratio (%)	Erosion degree
0-5°	0.028	51.355	0.87	1.44	0.13	micro-degree
5-8°	0.008	118.771	2.01	0.95	0.09	micro-degree
8-15°	0.008	376.622	6.37	3.01	0.27	micro-degree
15-25°	0.006	1024.615	17.32	6.15	0.55	mild
25-35°	0.115	1769.659	29.92	203.51	18.32	mild
>35°	0.348	2574.413	43.52	895.90	80.64	moderate

the Pisha-sandstone area must take full account of the gradient factor of topography.

Conclusions

This investigation analyzed the spatial-temporal evolution of soil erosion and revealed a correlation between soil erosion and slope factors in the Two-Tiger Valley in the Pisha sandstone region, with the following main conclusions:

1) Results from this study showed an obvious temporal-spatial variation of soil erosion between 2013 and 2015 in the Pisha sandstone area, Loess Plateau, China. Results for the spatial analysis showed the modulus of soil erosion around the study area to gradually decrease while the central area remained unchanged. This finding demonstrated that the positive effect of the anti-erosion and the promotion of plant growth measures had a strong spatial difference. Temporal results, in addition to the extreme erosion recorded at the site, showed different degrees of soil erosion reduction over time. Compared with 2013, soil erosion modulus and erosion levels in 2015 were generally lower, indicating that the anti-erosion and the promotion of plant growth measures was beneficial to soil and water conservation.
2) The series of biological and engineering measures from 2013 to 2015 resulted in a significant increase of surface vegetation coverage in the study area and subsequently an improvement in the regional ecological environment. However, it should be stressed that the average modulus of soil erosion was still as high as 6499.86 t km^{-2} $year^{-1}$ in 2015 – far beyond the limits of soil erosion permitted by the state. The proportion of moderate and intense erosion attained 66.40%, with soil erosion being the dominant process in the Two-Tiger Valley watershed.
3) There was a significant positive correlation between slope degree and soil erosion modulus. When the slope degree was >25°, the soil erosion level was moderately eroded and the modulus of soil erosion accounted for 73.44% of the total area. Thus, the interval of slope >25° was the area with the most soil and water loss, this being dominated by gravity erosion. These areas are important for future anti-erosion and the promotion of plant growth measures. In addition, soil erosion control should include topographic factors, with soil and water conservation strategies developed in close consideration of local conditions.

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