Environ Monit Assess (2018) 190: 736
https://doi.org/10.1007/s10661-018-7120-6

Assessment of potential changes in soil erosion using remote sensing and GIS: a case study of Dacaozi Watershed, China

Jun Huang

Received: 27 May 2018 / Accepted: 12 November 2018 / Published online: 20 November 2018

Abstract Soil erosion is a major global environmental problem. Therefore, a method of calculating potential soil erosion is necessary for soil and water resource management, as well as for assessing the risk of soil erosion. This study aimed to develop a simple method for calculating potential soil erosion change (PSEC) by combining the Universal Soil Loss Equation (USLE) and a Geographic Information System (GIS). The USLE model includes a rainfall erosivity factor (*R*), soil erodibility factor (*K*), cover management factor (*C*), slope gradient factor (*S*), length factor (*L*), and the supporting practice factor (*P*). Using a measured patch of soil and water conservation as the experimental unit, weather and soil data were combined to calculate *R* and *K*. Remote sensing images were used to extract vegetation cover (*VC*) and calculate *C*, while digital elevation models were used to extract and calculate *S* and *L*; land use maps were used to determine the *P* of each patch. The PSEC of each patch was then calculated according to the results of the above mentioned six factors. Finally, the PSEC of the entire study area was calculated on the basis of a patch area weighting method, which was validated in the Dacaozi Watershed in China, where a 1-year soil and water conservation project was implemented, beginning in November of 2013. In this study, the PSEC of the Dacaozi Watershed in May of 2017 was calculated, accounting for approximately 3 years of project implementation. The results showed that the average *VC* increased by 21.6% after 3 years of project implementation, whereas *C* decreased by 46.4%. The value of *P* did not change significantly from before to after project implementation. The average *S* decreased from 22.6 ± 12.1° to 21.3 ± 10.6°, and *S* decreased by 6.8%. In contrast, *L* increased by 33.3%. On the whole, the PSEC in the Dacaozi Watershed was 0.3925 and the potential soil erosion decreased by 60.75% after 3 years of conservation.

Keywords Geographic Information System · Universal Soil Loss Equation · Remote sensing · Unmanned aerial vehicle · Soil and water conservation

J. Huang
Pearl River Hydraulic Research Institute, Pearl River Water Resources Commission, Ministry of Water Resources, Guangzhou 510611, China

J. Huang (✉)
Soil and Water Conservation Monitoring Center of Pearl River Basin, Pearl River Water Resources Commission, Ministry of Water Resources, Guangzhou 510611, China
e-mail: hjnwsuaf@qq.com

Introduction

Catchments or watersheds are the fundamental units for the management of land and water resources (Moore et al. 1993; Liu 2005). The Food and Agriculture Organization of the United Nations has identified catchments or watersheds as planting units for administrative purposes to conserve soil and water resources (Honore 1999; Khan 1999). The severity of potential soil erosion is the direct embodiment of the effectiveness of soil and water conservation efforts and is the basis of technical policies for soil and water conservation. However, calculation of the absolute amount of soil loss is known to be difficult and its accuracy is relatively low because soil erosion is an extremely dynamic physical process. Therefore, a quantitative method for calculating potential soil erosion change (PSEC) is necessary and important for the management of land and water resources.

The mapping of soil erosion by integrating remote sensing and Geographic Information System (GIS) data has long been studied, and this method can identify areas that are potentially at risk for extensive soil erosion and provide information on the estimated severity of soil loss at various locations (Vittala et al. 2008; Pradhan et al. 2012; Khadse et al. 2015). Millward and Mersey (1999) integrated the Revised Universal Soil Loss Equation (RUSLE) with GIS to model potential erosion for soil conservation planning within the Sierra de Manantlán Biosphere Reserve, Mexico. Mati et al. (2000) used the USLE and data from erosion plots and reconnaissance surveys to predict soil erosion hazards in the Upper Ewaso Ng'iro North Basin of Kenya. They predicted that approximately 36% of the study area was at high risk for erosion and found that land use and management were the major factors associated with soil erosion. Le Bissonnais et al. (2002) developed a methodology for evaluating erosion risk at the national scale using GIS and found that the northern, western, and eastern parts of the Paris Basin were at high risk for soil erosion. Lee (2004) developed a method for evaluating the hazards of soil erosion using GIS, remote sensing, and the USLE and verified it at Boun, Korea. Youssef et al. (2009) performed GIS-based geomorphological hazard mapping of the Red Sea area between Safaga and Quseir, Egypt, and the results provided suggestions for measures to mitigate probable hazards in the area. Based on GIS and field survey data, Cai et al. (2000) and Shi et al. (2002) developed conservation-oriented watershed management strategies for the Wangjiaqiao Watershed in China and provided a simple and practical tool for soil conservation planning and other land management practices. Xu and Shao (2006) used the RUSLE to calculate the soil erosion of the Maotiao Watershed in China using GIS and proposed strategies for watershed governance. Zhang et al. (2007) quantitatively calculated soil erosion in Miyun County, Beijing using Land Satellite Thematic Mapper (Landsat-TM) data, GIS, and the USLE. Finally, Qin et al. (2009) studied soil erosion intensity and its relationship with environmental factors in the Simianyaogou Watershed, located on the Loess Plateau of China, using GIS and the RUSLE.

Many previous studies focused on calculating the amount of potential soil erosion have been based on pixel information from remote sensing images. However, this method and its results may not accurately reflect the true physical situation because remote sensing image resolutions range from several meters to tens of meters. Furthermore, the unit of calculation in this method is the remote sensing image element. The element is usually square or rectangular and obviously cannot be consistent with the actual patch of soil and water conservation measures. Therefore, we attempted to improve the representation of potential soil erosion using remote sensing and GIS, taking a soil and water conservation measured patch as the calculation unit. The results can better represent the actual situation on the ground. The objectives of this study were to propose a simple method for evaluating PSEC that accurately reveals the real physical situation by using a soil and water conservation measured patch as the calculation unit, and to validate this method in the Dacaozi Watershed, Guizhou Province, China. The results could provide valuable strategies for predicting soil erosion and for soil and water resource management.

Materials and methods

Study area

The Dacaozi Watershed is located in the town of Zhudong, Pan County, Guizhou Province, China (Fig. 1). The watershed lies between the latitudes of 25.617° N and 25.667° N and longitudes of 104.683° E and 104.750° E and covers an area of 16.26 km^2. The ecological environment is under heavy stress, with great land use pressures, serious soil loss, and a shortage of surface water resources. A 1-year soil and water conservation project was implemented in the Dacaozi Watershed in November of 2013. Before the project, areas exhibiting soil loss accounted for 90.86% of the total area. The proportions of cultivated land and forest land were 27.22% and 52.18%, respectively. The main commercial and food crops in the Dacaozi Watershed were flue-cured tobacco, corn, and potatoes.

Data source

The remote sensing image, taken prior to project implementation, was generated by the Chinese high-resolution remote sensing satellite Gaofen-1 in July 2013. Detailed parameters of Gaofen-1 can be found in a previous study by Li et al. (2015). The resolution of the remote sensing image from Gaofen-1 is 2 m. Previous altimetric data from before project implement were obtained from the design data of the soil and water conservation project.

A DJI Phantom 4PRO, which is a kind of unmanned aerial vehicle (UAV), was used to complete the image data collection of Dacaozi on May 22, 2017. It is made by DJI Innovation Technology Co. Ltd. in Shenzhen, China, and its detailed parameters are available on the website: http://www.dji.com/phantom-4-pro/info. The flight height of the UAV was 400 m, and the weather conditions were good, with maximum visibility during the flight period. Hence, the obtained UAV-image data were highly consistent with the physical situation on the ground. Based on oblique photogrammetry, Agisoft PhotoScan® v. 1.4.3 software was used to obtain the orthophoto and the digital elevation model of the Dacaozi Watershed, following geometric processing, multi-view matching, triangulated irregular network construction, and automatic texturing.

Universal Soil Loss Equation-based model

The Universal Soil Loss Equation (USLE) is widely used to estimate the annual soil loss for hillslopes at various scales (Wischmeier and Smith 1978), and its expression is as follows:

$$A = RKLSCP \tag{1}$$

where A, R, K, L, S, C, and P denote the average annual soil loss (t ha^{-1} year^{-1}), rainfall erosivity factor (MJ mm ha^{-1} h^{-1} year^{-1}), soil erodibility factor (t ha h ha^{-1} MJ^{-1} mm^{-1}), slope length factor, slope gradient factor, cover management factor, and the supporting practice factor. The P equals to 1 under no support practice conditions, and it can be ignored in this calculation.

Potential soil erosion change index

Taking a soil and water conservation project as an example, the potential soil erosion before implementation of the project is denoted as A_b, and the potential soil erosion after implementation is denoted as A_a. Thus, the PSEC for the study area can be expressed as

$$\mathrm{PSEC} = 1 - A_a / A_b \tag{2}$$

Obviously, a PSEC value greater than or equal to zero indicates an increased or unchanged potential erosion in the study area, respectively. This can provide useful insights for the assessment of potential erosion risk and for land and soil resource management. Substituting Eq. (1) into Eq. (2), the following detailed equation for calculating PSEC can be obtained:

$$\mathrm{PSEC} = 1 - (R_a K_a L_a S_a C_a P_a) / (R_b K_b L_b S_b C_b P_b) \tag{3}$$

Soil erodibility is well known as a physical property of soil. For a given region and over a shorter research period, the physical and chemical properties of soils will not change significantly, and thus soil erodibility will not change by much. If there are no extreme rainfall events, the rainfall characteristics of a region will also not change significantly, and thus annual rainfall erosivity will not change greatly. Therefore, the rainfall erosivity and soil erodibility factors can be considered to be unchanged over relatively short research periods. That is, $R_a \approx R_b$ and $K_a \approx K_b$, and Eq. (3) can be simplified as follows:

$$\mathrm{PSEC} = 1 - (L_a S_a C_a P_a) / (L_b S_b C_b P_b) \tag{4}$$

Equation (4) is suitable and convenient for situations such as those of the study area, where basic meteorological and soil data are lacking, and the study period is relatively short (3 to 5 years).

Calculation of USLE parameters

Calculation of rainfall erosivity

Rainfall erosivity (R) is defined as the potential ability of rain to cause erosion, and it is given as the product (EI_{30}), the total energy of rainfall (E), and the maximum 30-min intensity (I_{30}) (Wischmeier and Smith 1958; Foster et al. 1981). The long-time

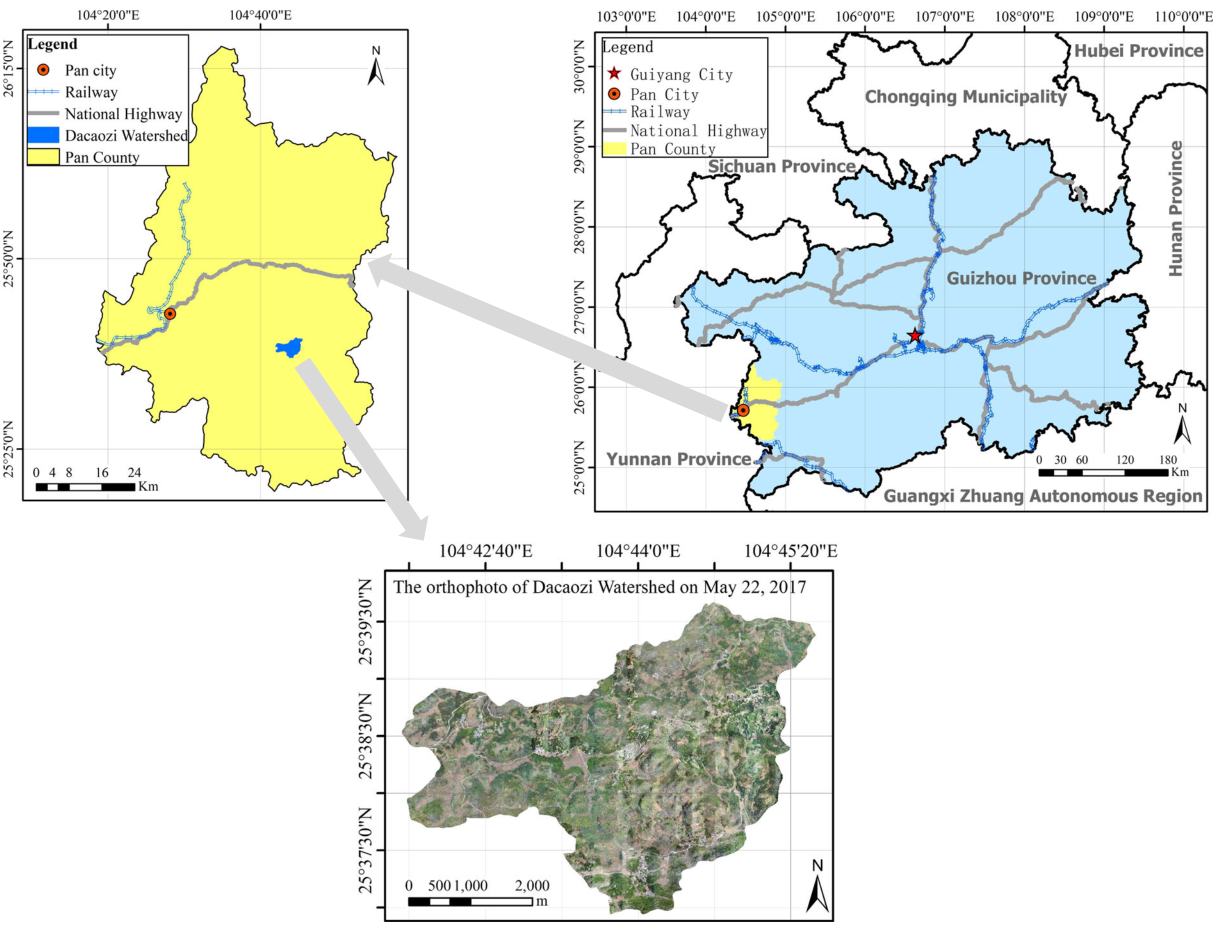

Fig. 1 Location of the study region in Pan County, Guizhou Province, China

average annual R can be calculated according to the following equation:

$$R=\frac{1}{n}\sum_{j=1}^{n}\left(\sum_{i=1}^{m}EI_{30}\right) \quad (5)$$

where n is the number of calculated years and m is the number of rainfall events during the study period.

Calculation of soil erodibility

The soil erodibility (K) factor reflects the vulnerability of the soil to detachment and transport caused by rainfall and runoff. The Erosion/Production Impact Calculator (EPIC) model provides a detailed method for computing K for a specific soil type (Sharpley and Williams 1990). The equation is as follows:

$$K=\left(0.2+0.3e^{-0.0256san\left(1-\frac{san}{100}\right)}\right)\cdot\left(\frac{sil}{sil+cla}\right)^{0.3}\cdot\left(1-\frac{0.25oc}{oc+e^{3.72-2.95oc}}\right)\cdot\left(1-\frac{0.7sn}{sn+e^{22.9sn-5.51}}\right) \quad (6)$$

Here, san, sil, cla, and oc denote the percentage contents of sand, silt, clay, and organic carbon, respectively, and $sn = 1 - (san / 100)$.

Calculation of cover management

Vegetation cover and plantation systems have a large impact on runoff and erosion yield, and the cover management (C) factor varies with changes in vegetation cover (VC). Vegetation cover is firstly calculated according to Eq. (7), and then C can be determined using Eq. (8), based on the results of VC. According to the previous study by Wang et al. (2015), the Visible-Band Difference Vegetation Index ($VDVI$) is used to calculate the vegetation index from remote sensing or UAV images.

$$VDVI = (2b_{green} - b_{red} - b_{blue}) / (2b_{green} - b_{red} - b_{blue}) \quad (7)$$

Here, b_{green}, b_{red}, and b_{blue} are the reflectivity or pixel values for the green, red, and blue bands in remote sensing or UAV images. The raster calculator module in ArcGis v. 10.2 can be used to calculate the average VC for each patch based on $VDVI$ data. Then, using Eq. (8), the C value can be calculated (Cai et al. 2000).

$$C = \begin{cases} 1 & VC = 0 \\ 0.6508 - 0.3436(VC) & 0 < VC \leq 78.3\% \\ 0 & VC > 78.3\% \end{cases} \quad (8)$$

Calculation of the slope gradient and length

The slope gradient factor (S) is a key factor affecting soil erosion. Based on the digital elevation model, the average slope gradient (θ) for each patch can be obtained using the surface analysis module in ArcGis v. 10.2. Equation (9) may then be employed to calculate S (Liu et al. 1994).

$$S = \begin{cases} 10.8\sin\theta + 0.03 & \theta < 5^\circ \\ 16.8\sin\theta - 0.50 & 5^\circ \leq \theta < 10^\circ \\ 21.9\sin\theta - 0.96 & \theta \geq 10^\circ \end{cases} \quad (9)$$

The USLE defines slope length as the horizontal distance from the starting point to the intercepted or break point of runoff (Wischmeier and Smith 1965, 1978). The equation for calculating the slope length factor (L) can be obtained as follows:

$$L = (len/22.13)^{1/(1+t)} \quad (10)$$

where len is the slope length (m) and $t = (\sin\theta/0.0896)/(3\sin\theta^{0.8} + 0.56)$. Using the hydrological analysis module in ArcGis v. 10.2, the maximum water flow in a pixel (denoted as mn) and the non-cumulative slope length (len_n) for each patch equals the product of mn and the pixel edge length. Here, the effect of upland water flow on erosion was not considered.

The cumulative slope length (len_c) for each patch is calculated as follows: assuming there are n patches of water flowing into the calculated patch and that the maximum len_n among the n patches is len_{nmax}, len_c of the calculated patch can be determined using the following equation:

$$len_c = (\lambda_{out}^{m+1} - \lambda_{in}^{m+1}) 22.13^{-m} / (\lambda_{out} - \lambda_{in}) \quad (11)$$

where $\lambda_{out} = len_{nmax} + len_{n\_cal}$, $\lambda_{out} = len_{nmax}$. The non-cumulative slope length of the calculated patch in meters is denoted as len_{n_cal}. For each patch, the slope length equals the sum of the non-cumulative and cumulative slope lengths, $len = len_n + len_c$.

Calculation of the supporting practice

The supporting practice (P) factor is a ratio that incorporates the effects of conservation practices, such as contouring and terracing to protect soil (Renard et al. 1997). This value ranges from 0 to 1. Information on P from various land use/cover classes and slope gradients was collected through a field survey. Here, we referenced previous studies (Wischmeier and Smith 1978; Wang and Jiao 1996; Shi et al. 2002) and generated a land use map of the Dacaozi Watershed, for which the parameters are presented in Table 1.

Land use type classification

Land use type is a key factor in soil erosion calculations. In this study, we combined the unsupervised classification method of eCognition Developer v. 8.0 and a method of manual random sampling by visual inspection to complete land use type classification. First, eCognition Developer v. 8.0 was used to classify the initial land use types. We then manually extracted a certain percentage of samples that were used to evaluate the accuracy of the land use type classification; the extraction ration was 25%

Table 1 Supporting practice factor (P) values

Land use/cover		Values of the supporting factor
Road		0
Building		0
Cultivated land	Gradient < 5°	0.30
	Gradient = 5~10°	0.40
	Gradient > 10°	0.45
Forest land		1.00

for one kind of land use type. If the accuracy was greater than 95%, the results of land used type classification could be accepted. Otherwise, eCognition Developer v. 8.0 was used to reclassify the land use type. Notably, the parameter of the split scale in eCognition Developer v. 8.0 is very critical, and has a significant effect on the accuracy of land use type classifications, and multiple tests are needed to determine the optimal value.

Technical route

Remote sensing images and digital elevation models of the study area before and after the implementation of the soil and water conservation project were collected. The eCognition Developer v. 8.0 software was used to extract the measured patch, and individual measurements for soil and water conservation were taken for each patch. The programs ArcGis v. 10.2 and ENVI v. 5.1 were used to calculate the values of the six factors for each patch, and then the value of PSEC for each patch was calculated according to Eq. (3) or (4). Finally, the comprehensive value of PSEC for the entire study was calculated. The schematic representation is presented in Fig. 2.

Results and discussion

Extracting measured patches

In order to calculate the PSEC value based on the patch unit, geographic attributes, such as the area, longitude and latitude, and shape, of these patch vector files before and after soil and water conservation project implementation must be identical. Therefore, we acquired a recent UAV image as the benchmark for land use classification, and used eCognition Developer v. 8.0 software to generate the patch vector file. After several repeated attempts, when the split scale (F) of 300 could be achieved as the optimal value, the extraction accuracy was deemed satisfactory. A total of 26,519 measured patches were produced, as shown in Fig. 3, including 7079 patches of arable land, 18,894 patches of woodland, 451 patches of buildings, and 95 patches of roads. The accuracy of the land use type classification for the patches was 85.33% after verification through visual inspection. Based on the vector file with the above patches, we examined land use type attributes and modified errors based on the remote sensing image from

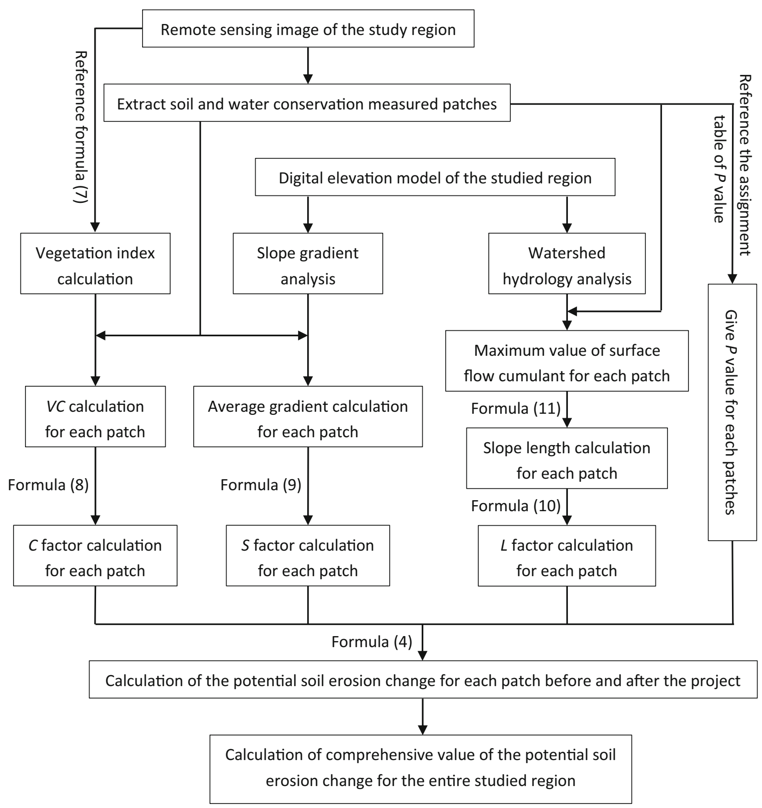

Fig. 2 Schematic of the methods used in this study. The vegetation cover, cover management factor, slope gradient factor, slope length factor, and supporting practice factor are denoted as *VC*, *C*, *S*, *L*, and *P*, respectively

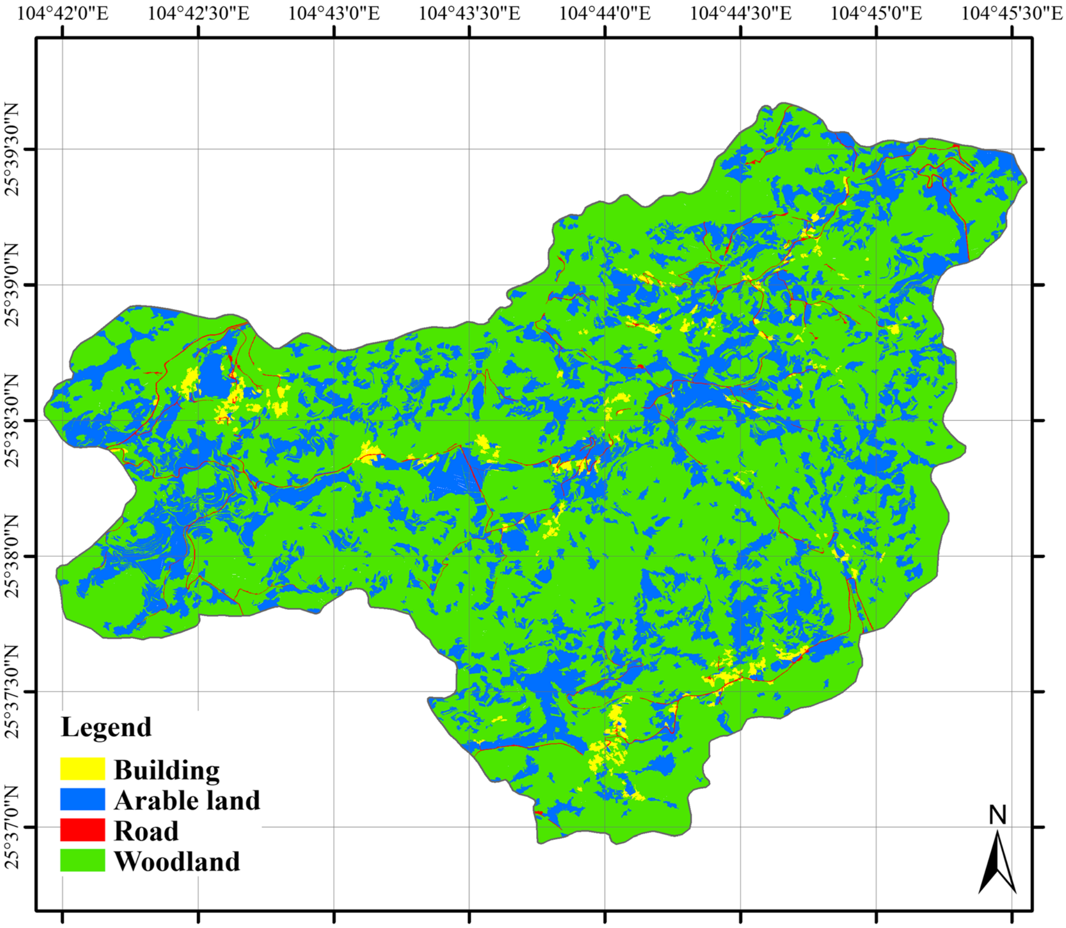

Fig. 3 Land use classification of the Dacaozi Watershed in 2017

Gaofen-1 through visual inspection. Before implementation of the project, there were 6697 patches of arable land, 19,276 patches of woodland, 451 patches of buildings, and 95 patches of roads.

Factor calculation

Figure 4a, b shows the results of the *C* factor in the Dacaozi Watershed before and after project implementation. The average *VC* and mean *C* factor were 60.1% ± 25.7% and 0.60 ± 0.26 before project implementation and 74.1% ± 2 9.4% and 0.322 ± 0.416 after project implementation, respectively. Vegetation cover increased by 21.6% and *C* decreased by 46.4%. An analysis of variance revealed that changes in both *VC* and *C* were significant ($p < 0.01$). The proportion of patches with *VC* over 80% substantially increased, from 46 to 59% before and after project implementation.

Figure 4c, d shows the variation in the *P* factor in the Dacaozi Watershed before and after project implementation. The results of the analysis of variance showed that the average value of *P* significantly reduced was from 0.834 ± 0.279 to 0.828 ± 0.278 before and after project implementation, respectively, indicating a significant decrease ($p < 0.01$). The mean slope in the Dacaozi Watershed also decreased from 22.6 ± 12.1° to 21.3 ± 10.6° before and after project implementation, respectively. The proportion of patches with slopes over 25° substantially decreased, from 40 to 35% before and after project implementation. This is very important for reducing soil erosion and water loss. Correspondingly, values of the *S* factor were 7.3 ± 4.0 and 6.8 ± 3.6 before and after project implementation, as shown in Fig. 4e, f.

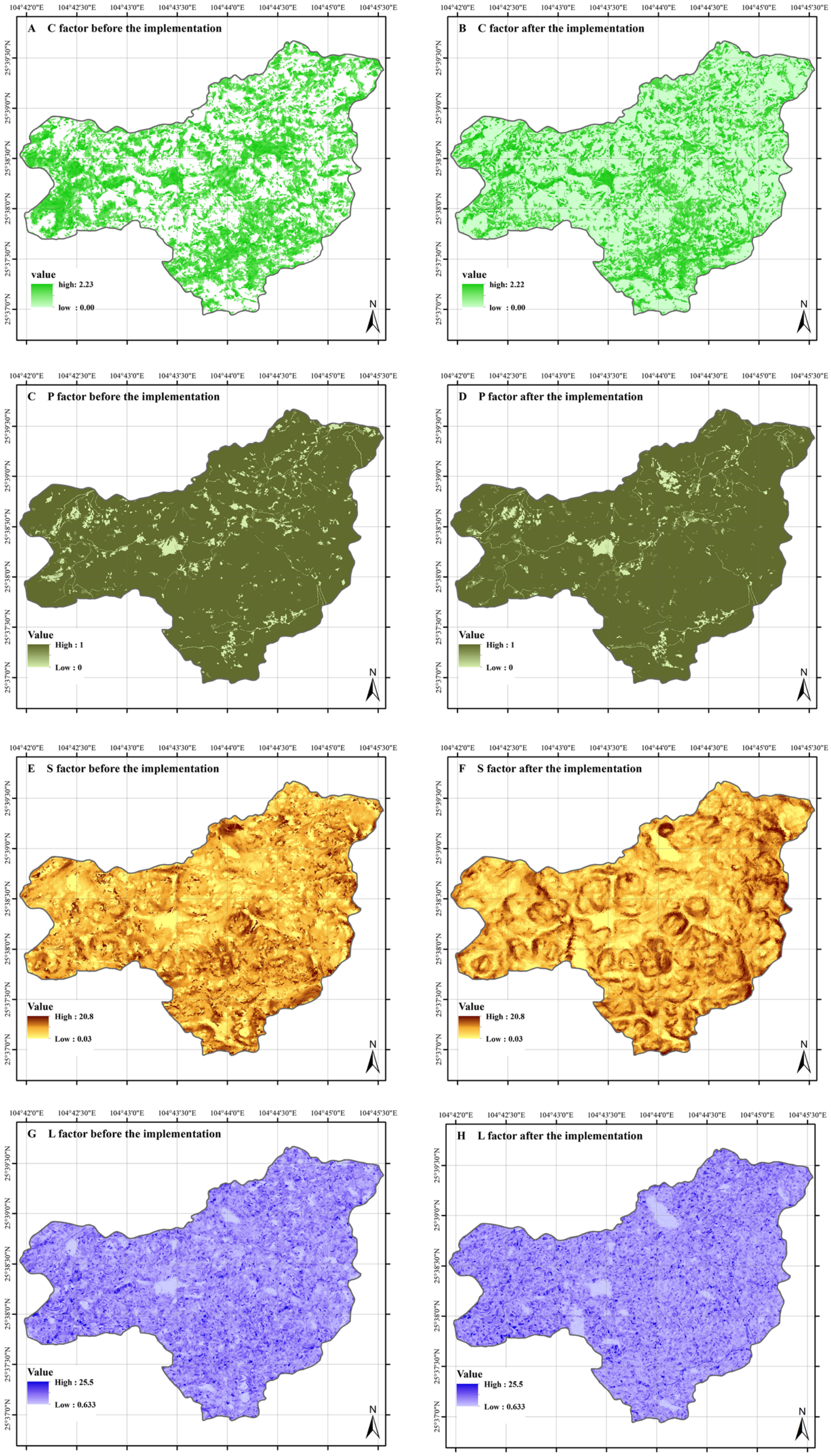

Fig. 4 **a**–**h** Digital raster maps of *C*, *P*, *S*, and *L* of the study area before and after the project implementation

Changes in both the slope and S were significant ($p < 0.01$).

Figure 4g, h shows the L of the Dacaozi Watershed before and after project implementation. Before the project, the average slope length was 260.8 ± 192.7 m but it increased to 414.7 ± 258.2 m after the project, which can be attributed to the implementation of engineering measures. Averages of the L significantly increased from 5.1 ± 2.8 to 6.8 ± 3.1 before and after project implementation ($p < 0.01$), respectively, showing an increase of 33.3%.

Determination of PSEC

Based on the raster data of L, S, C, and P before and after implementation of the soil and water conservation project in the Dacaozi Watershed, as shown in Fig. 4, we calculated the product of the four factors for each patch before and after the project implementation. The average product values were 16.8 ± 26.4 and 9.8 ± 19.2 before and after project implementation for all 26,519 patches, as shown in Fig. 5. The average product showed a declining trend and indicated that the soil and water conservation project played an important role in reducing soil erosion and water loss. On this basis, the PSEC value for each patch was calculated according to Eq. (4). The comprehensive value of PSEC in the Dacaozi Watershed was then calculated as 0.3925, using a patch area weighting method. That is, the potential soil erosion in Dacaozi was decreased by 60.75% after project implementation.

It is well known that soil erosion is affected by many factors, and the processes underlying its change are highly nonlinear. Although there are many models for predicting soil erosion, it remains difficult to precisely calculate the amount of soil erosion in a given area. The development of GIS and the popularization of high-resolution remote sensing images have greatly facilitated the resolution of this problem. Many researchers have used GIS to study regional soil erosion based on high-resolution remote sensing images. However, in such research, the computing unit is still based on image pixels. Obviously, the pixel is a regular square or rectangle, making it difficult to remain consistent with the actual situation on the ground for land use classification and slope length calculations. That is to say, a calculation unit may contain multiple land use types, which is obviously problematic for ensuring the accuracy of calculation results. In addition, image resolution is usually a few meters to tens of meters, or even hundreds of meters, which will induce substantial errors into the calculation of soil erosion for smaller areas. In this study, we propose a simple method for calculating the PSEC in a region. This method does not use remote sensing image pixels as the calculation unit, relying instead on land use classification as the calculation unit. This method ensures that the land use type is the same in one computing unit. Hence, the results are obviously closer to the actual physical situation. Moreover, this method calculates

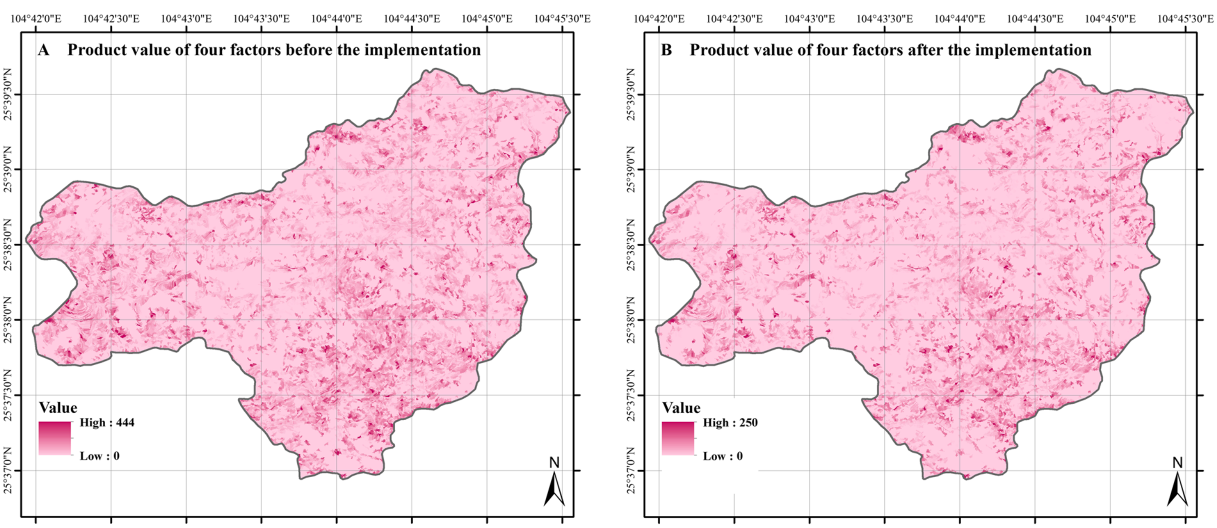

Fig. 5 Digital raster image of the product value of L, S, C, and P of the study area

changes in the potential soil erosion, which can reduce the error caused by system problems, such as the inconsistent resolution of data sources and model errors. The results of PSEC can also provide insights that are valuable for regional soil and water conservation.

In this case, the study period was relatively short and no extreme rainfall events occurred during this period. Thus, to reduce the computational effort, we assumed that the rainfall erosivity and soil erodibility factors did not change much during this period, and studies providing basic meteorological and soil data were lacking. Therefore, in the future, additional studies are needed for considering extreme rainfall events with variable rainfall erosivity and soil erodibility factors over the long term.

Conclusions

In this study, we proposed a simple method for calculating PSEC using an USLE-based model and GIS. It is noteworthy that this method took the measured patch as the calculation unit, which guaranteed that the soil and water conservation measurement type were the same. Thus, the calculated results may be more objective and truly reflect real-word PSEC.

The method was applied to the Dacaozi Watershed for evaluation. The results show that the average *VC* increased from 60.1% ± 25.7% before project implementation to 74.1% ± 29.4% after project implementation. The average value of *P* did not change much during the study period, being 0.834 ± 0.279 and 0.828 ± 0.278 before and after project implementation, respectively. The average value of *S* decreased from 22.6 ± 12.1° before project implementation to 21.3 ± 10.6° after project implementation. In contrast, the average value of *L* increased by 59.1% after project implementation. The PSEC value in the Dacaozi Watershed was 0.3925, and the potential soil erosion was reduced by 60.75% after project implementation.

Funding information This work was jointly supported by the Changjiang River Scientific Research Institute (CRSRI) Open Research Program [grant no. CKWV2016389/KY], the National Natural Science Foundation of China [grant no. 41501019], and the National Soil and Water Loss Monitor and Announcement [grant no. 1261520610101].

References

Cai, C. F., Ding, S. W., Shi, Z. H., Huang, L., & Zhang, G. Y. (2000). Study of applying USLE and geographical information system IDRISI to predict soil erosion in small watershed. *Journal of Soil and Water Conservation, 14*(2), 19–24 (in Chinese with English abstract).

Foster, G. R., McCool, D. K., Renard, K. G., & Moldenhauer, W. C. (1981). Conversion of the Universal Soil Loss Equation to SI metric units. *Journal of Soil and Water Conservation, 36*(6), 355–359.

Honore, G. (1999). *Our land, ourselves-guide to watershed management in India* (pp. 238). New Delhi: Government of India New Delhi.

Khadse, G. K., Vijay, R., & Labhasetwar, P. K. (2015). Prioritization of catchments based on soil erosion using remote sensing and GIS. *Environmental Monitoring and Assessment, 187*(6), 333.

Khan, M. A. (1999). Water balance and hydrochemistry of precipitation components in forested ecosystems in the arid zone of Rajasthan, India. *Hydrological Sciences Journal, 44*(2), 149–161.

Le Bissonnais, Y., Montier, C., Jamagne, M., Daroussin, J., & King, D. (2002). Mapping erosion risk for cultivated soil in France. *Catena, 46*(2), 207–220.

Lee, S. (2004). Soil erosion assessment and its verification using the Universal Soil Loss Equation and Geographic Information System: a case study at Boun, Korea. *Environmental Geology, 45*(4), 457–465.

Li, J., Chen, X., Tian, L., Huang, J., & Feng, L. (2015). Improved capabilities of the Chinese high-resolution remote sensing satellite GF-1 for monitoring suspended particulate matter (SPM) in inland waters: radiometric and spatial considerations. *ISPRS Journal of Photogrammetry and Remote Sensing, 106*, 145–156.

Liu, Z. (2005). Retrospect and prospect on integrated management of soil conservation in small river basins. *China Water Resources, 22*, 17–18 (in Chinese with English abstract).

Liu, B. Y., Nearing, M. A., & Risse, L. M. (1994). Slope gradient effects on soil loss for steep slopes. *Transactions of ASAE, 37*(6), 1835–1840.

Mati, B. M., Morgan, R. P. C., Gichuki, F. N., Quinton, J. N., Brewer, T. R., & Liniger, H. P. (2000). Assessment of erosion hazard with the USLE and GIS: a case study of the Upper Ewaso Ng'iro North Basin of Kenya. *International Journal of Applied Earth Observation and Geoinformation, 2*(2), 78–86.

Millward, A. A., & Mersey, J. E. (1999). Adapting the RUSLE to model soil erosion potential in a mountainous tropical watershed. *CATENA, 38*(2), 109–129.

Moore, I. D., Gessler, P. E., Nielsen, G. A., & Peterson, G. A. (1993). Soil attribute prediction using terrain analysis. *Soil Science Society of America Journal, 57*, 443–452.

Pradhan, B., Chaudhari, A., Adinarayana, J., & Buchroithner, M. F. (2012). Soil erosion assessment and its correlation with landslide events using remote sensing data and GIS: a case study at Penang Island, Malaysia. *Environmental Monitoring and Assessment, 184*(2), 715–727.

Qin, W., Zhu, Q. K., & Zhang, Y. (2009). Soil erosion assessment of small watershed in Loess Plateau based on GIS and

RUSLE. *Transactions of the Chinese Society of Agricultural Engineering, 25*(8), 157–163.

Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K., & Yoder, D. C. (1997). Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). In K. G. Renard, G. R. Foster, G. A. Weesies, D. K. McCool, & D. C. Yoder (Eds.), *Agriculture handbook* (pp. 1–251) Washington.

Sharpley, A. N., & Williams, J. R. (1990). *EPIC-Erosion/ Productivity Impact Calculator: 1. Model documentation*. Washington (DC): USDA Agricultural Reaserch Service.

Shi, Z. H., Cai, C. F., Ding, S. W., Li, C. X., & Li, T. W. (2002). Soil conservation planning at small watershed level using GIS-based Revised Universal Soil Loss Equation (RUSLE). *Transactions of the Chinese Society of Agricultural Engineering, 18*(4), 172–175 (in Chinese with English abstract).

Vittala, S. S., Govindaiah, S., & Gowda, H. H. (2008). Prioritization of sub-watersheds for sustainable development and management of natural resources: an integrated approach using remote sensing, GIS and socio-economic data. *Current Science, 95*(3), 345–354.

Wang, W. Z., & Jiao, J. Y. (1996). Qutantitative evaluation on factor influencing soil erosion in China. *Bulletin of Soil and Water Conservation, 16*(5), 1–20 (in Chinese with English abstract).

Wang, X. Q., Wang, M. M., Wang, S. Q., & Wu, Y. D. (2015). Extraction of vegetation information from visible unmanned aerial vehicle images. *Transactions of the Chinese Society of Agricultural Engineering, 31*(5), 152–159 (in Chinese with English abstract).

Wischmeier, W. H., & Smith, D. D. (1958). Rainfall energy and its relationship to soil loss. *Eos, Transactions American Geophysical Union, 39*(2), 285–291.

Wischmeier, W. H., & Smith, D. D. (1965). *Predicting rainfall-erosion losses from cropland east of the Rocky Mountains*. Washington DC: Soil Conservation Service, USDA.

Wischmeier, W. H., & Smith, D. D. (1978). *Predicting rainfall erosion losses-a guide to conservation planning*. Washington DC: US Government Printing Office.

Xu, Y. Q., & Shao, X. M. (2006). Estimation of soil erosion supported by GIS and RUSLE: a case study of Maotiaohe Watershed, Guizhou Province. *Journal of Beijing Forest University, 28*(4), 67–71 (in Chinese with English abstract).

Youssef, A. M., Pradhan, B., Gaber, A. F. D., & Buchroithner, M. F. (2009). Geomorphological hazard analysis along the Egyptian red sea coast between Safaga and Quseir. *Natural Hazards and Earth System Sciences, 9*(3), 751–766.

Zhang, Y. Q., Gong, H. L., Zhao, W. J., & Li, X. J. (2007). Quantitative evaluation and spatial analysis of soil erosion in Miyun County base on GIS and USLE. *Research of Soil and Water Conservation, 14*(3), 358–362,364 (in Chinese with English abstract).