Evaluation and optimization of the Grain for Green project based on the effect of soil conservation: A case study of Yan'an, China

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May 5, 2020

Abstract

Quantitative evaluation of soil conservation effects (SCE) of ecological policies at the macro level is not only a summary of past ecological recovery experience but also an effective way to explore the optimization of future ecological policies. As a famous ecological policy, "Grain for Green" (GFG) carried out in the Loess Plateau of China has significantly reduced soil erosion in this region. However, it is unclear whether the implementation of this policy has achieved the optimal SCE, which is an important issue in the GFG evaluation. The concept of soil conservation potential (SCP) was proposed in this study. Taking Yan'an, China as an example, the influence of GFG on soil erosion control was evaluated by comparing the total amount of soil erosion reduction and the SCP under certain the GFG intensity. On this basis, the future measures of GFG optimization were proposed. The result shows that the implementation of GFG in the past does not take into account the local SCP, and there is a significant spatial mismatch between the GFG implementation intensity and the SCP, resulting in the waste of resources and low policy efficiency. If this problem was fully considered in ecological restoration planning, a "win-win" result of improving governance effect and reducing input cost could be achieved. Finally, the suggestion of establishing the GFG dynamic input mechanism was put forward for the formulation and optimization of relevant ecological policies in the future.

1 Introduction

To curb and restore the deteriorating ecological environment, Chinese government has introduced a series of ecological policies since the end of the 20th century (Yin et al., 2010). Grain for Green (GFG) is one of the most famous ecological policies. The GFG was to restore and improve the ecological environment quality at the expense of reducing the cultivated land that contracted by farmers. Since it was directly related to the interests of farmers, the evaluation of the implementation effect of GFG has been widely concerned (Bullock and King, 2011). Studies have shown that the implementation of GFG had promoted ecosystem services in relevant areas, such as the increase of vegetation coverage (Xiao, 2014), decrease of soil erosion (Lü et al., 2012), raised carbon sink (Wang et al., 2018), and enhanced per unit yield of cultivated land (Zhang et al., 2019). Due to the positive externalities brought by the improvement of ecosystem services, the surrounding regions can also benefit from the GFG (Wu et al., 2019). In addition, the GFG has also made positive contributions to the improvement of social and economic benefits such as poverty reduction and employment promotion (Peng et al., 2007; Bullock and King, 2011). On the contrary, some researchers also put forward negative views on the GFG, because large-scale afforestation was suspected of consuming too much soil moisture, which hurt soil conservation, soil quality, and biodiversity (Cao et al., 2009; Jiang et al., 2016; Jia et al., 2017). Despite different opinions on the evaluation of GFG, some researchers also pointed out the existing problems and the areas for improvement, the positive benefits, and the impacts generated by GFG were more generally recognized (Bryan et al., 2018; Chen et al., 2019).

In the Loess Plateau, the direct purpose of GFG was to control soil erosion, which was the most prominent ecological problem in the area (Wang et al., 2001; Qiu et al., 2002; Zhang et al., 2019). The causes of soil erosion included the evolution of regional natural characteristics and external interference factors such as human activities (Yang et al., 2003; Chen et al., 2019), among which the latter was more common in developing countries (Millward and Mersey, 1999; Onyando et al., 2005; Adimassu et al., 2017). From 1955 to 1989, about 56.6% of the Loess Plateau had an average annual soil loss of 2500 t·km^{-2}or more, which was considered to be a moderate or above erosion level (Wang and Jiao, 2002). Serious soil erosion not only endangered the economic and social development and ecological environment security within the region but also caused a significant negative impact on the nearby areas (Chen et al., 2008). Since the implementation of GFG in the Loess Plateau, the soil conservation effects (SCE) has been significantly improved and soil erosion has been controlled to a certain extent through adjustment and optimization of land use structure, improvement of vegetation coverage and engineering measures (Deng et al., 2012; Wang et al., 2016).

In recent years, researchers have carried out detailed studies on the benefits of soil conservation brought by the GFG from different perspectives, mainly including empirical model and field observation. An empirical model was often used to analyze soil erosion at different stages and evaluate the SCE, such as USLE (Fu et al., 2011), SWAT (Yang et al., 2018), WATEM/SEDEM (Li et al., 2019), etc. On the basis, some researchers simulated soil erosion in different situations, thus expanding the application space of the empirical model (Hessel et al., 2003; Zhou et al., 2006; Han et al., 2016). Field observation was to use the data of river runoff, sediment content and sediment transport obtained from public release or experiments to analyze the impact of GFG on soil erosion in specific areas, especially at the river basin scale and made feasible suggestions (Gao et al., 2018; Yang et al., 2018; Deng et al., 2019). In general, the current evaluation on the impact of GFG on soil erosion focuses on the overall treatment effect, that is, the comparative analysis of the amount of soil erosion reduction before and after the implementation of GFG (Sun et al., 2014; Zhang et al., 2016). However, at the present stage of GFG, more attention should be paid to the coordination between the GFG investment and the SCE, so as to analyze whether the implementation of GFG is efficient or not. Theoretically, the GFG should be mainly invested in areas where there is a large gap between the current status of soil erosion and the theoretical minimum level of soil erosion, in order to obtain the optimal SCE. However, the existing research methods are unable to quantify this gap, so it is difficult to analyze the investment of GFG in different regions. This is not conducive to the effective evaluation of the GFG implementation in the past, but also hurts the formulation of more reasonable soil conservation plans in the future.

Based on the Revised Universal Soil Loss Equation (RUSLE), the soil conservation potential (SCP) model was established. The SCP model quantifies the difference between the current situations of soil erosion in different regions and at different times and the theoretical minimum level of soil erosion, calculates the range of improvement for soil erosion control, and provides a reference for the future investment planning of GFG. At the same time, the model can also evaluate the implementation effect of GFG in the past, and summarize experience and deficiencies. The significance of the SCP model lies in that it not only solves the theoretical defect of evaluating the GFG effect based on the amount of soil erosion reduction in previous studies, but also optimizes the input allocation of GFG, and strives to achieve the optimal implementation efficiency of GFG, so as to provide new ideas for researchers and decision-makers.

Yan'an, located in the northern part of Shaanxi province, China, was taken as study area in this study. According to the SCP model, the GFG investment and the SCE produced by the GFG in different regions were evaluated, the reasons for the mismatches in spatial locations of the two and the relationship with the SCP were analyzed, and the problems existing in the implementation of GFG at the present stage were discussed. Then the key implementation areas of GFG in the future were defined through the calculated SCP, and the dynamic input mechanism to achieve the optimal input efficiency was proposed. Finally, the optimization design of the future GFG in Yan'an was carried out.

2 Study area

Yan'an belongs to Shaanxi Province and is located in the central of the Loess Plateau of China, with a total area of about 37,000 km^2 (Figure 1). In 2018, the resident population of Yan'an was about 2.5294 million, and the urbanization rate reached 62.31%. The terrain of Yan'an is high in the northwest and low in the southeast, with an average elevation of about 1,200m. Yan'an has a typical temperate continental monsoon climate with concentrated precipitation. Special geological and climatic conditions are important factors that cause soil erosion in this city. In recent years, due to the implementation of GFG, the vegetation coverage in Yan'an has significantly improved, and soil erosion has also been significantly controlled (Government Website of Yan'an, 2019).

[Figure 1 near here]

3 Material and methods

3.1 Data sources and preprocessing

The precipitation data used in this study were from the Climate Forecast System Reanalysis (CFSR) (https://globalweather.tamu.edu), which provides daily meteorological indicators for specific latitudes and longitudes, selected from 1 January 1979 to 31 December 2013. The soil data were obtained from the Harmonized World Soil Database (HWSD) (http://webarchive.iiasa.ac.at/Research/LUC/), which was in a grid format with an original resolution of approximately 30 arc seconds. The topography data were provided by Geospatial Data Cloud site, Computer Network Information Center, Chinese Academy of Sciences (http://www.gscloud.cn). ASTER GDEM V2 version of the original elevation data was selected, and the original spatial resolution was 30 m. Elevation data can be used to extract slope in ArcGIS 10.2. The land use data were derived from the interpretation of remote sensing images. According to the research needs, Landsat 5 TM images in 2000 and Landsat 8 OLI_TIRS images in 2015 were selected as the base map for interpretation. The source of remote sensing images data was the same as topography data, and the original spatial resolution was 30m. Land use status in 2000 and 2015 were obtained through manual interpretation (Zhang et al., 2018). The enhanced vegetation index (EVI) data from 2000 to 2016 were obtained from synthetic vegetation index product MOD13Q1 V6 with an original resolution of 250m (Didan, 2015), and the average EVI from the 97th to 289th days (plant growth season) of each year is considered the year's EVI (Xu et al., 2020). The population data were from the Statistical Yearbook of Yan'an (http://data.cnki.net), and the resident population of each county in 2015 were selected as the calculation standard.

It should be noted that, (1) all data were presented in grids with a resolution of 90m $\times$ 90m, (2) the area with a slope below 6° was ignored because the GFG was hardly carried out in such an area (Zhang et al., 2019).

3.2 Study methods

3.2.1 Revised Universal Soil Loss Equation (RUSLE)

RUSLE is an empirical model for estimating soil erosion, which has been widely used in current situation evaluation, risk estimation, simulation and prediction (Prasannakumar et al., 2012; Panagos et al., 2015; Zare et al., 2017). The specific form is shown in equation (1).

$A = 100 \times R \times K \times L \times S \times C \times P$ (1)

Where A is average annual soil loss per unit area ($\mathrm{t \cdot km^{-2} \cdot a^{-1}}$); R is rainfall and runoff erosivity factor ($\mathrm{MJ \cdot mm \cdot hm^{-2} \cdot h^{-1} \cdot a^{-1}}$),$K$ is soil erodibility factor ($\mathrm{t \cdot hm^{2} \cdot h \cdot hm^{-2} \cdot MJ^{-1} \cdot mm^{-1}}$),$L$ is slope length factor, S is slope steepness factor,C is cover and management factor, these factors are calculated from equation (2) ~ (6) (Table 1); P is support practice factor, which is assigned according to land use type (Mallick et al., 2014; Kumar et al., 2014) (Table 2).

[Table 1 near here]

[Table 2 near here]

3.2.2 Soil conservation potential (SCP)

In this study, the SCP was defined as the difference between the current value and the theoretical minimum value of soil erosion per unit area of a region, reflecting the improvement space of soil erosion control in a region. According to the RUSLE, in order to control soil erosion, the values of the above factors must be effectively controlled. In fact, precipitation condition is difficult to manipulate because it is nearly constant over a short period. It takes a lot of capital to artificially influence soil properties and topographic conditions, so it is uneconomical to change the behavior of these factors. Vegetation cover and land use types are directly affected by the implementation of GFG, and they are also important factors affecting soil erosion. Therefore, in the calculation of SCP, C factor and P factor will be introduced into the model as the main variables.

The soil erosion amount when the C factor and P factor in region i reach the ideal state is defined as the theoretical minimum soil erosion level of the region (A_{i0}), and the soil erosion calculated from the actual values of Cfactor and P factor in the year t was defined as the soil erosion level (A_{it}) of the region in the year$t$. Then the formula of SCP can be defined as equation (7).

$$\mathrm{AP}_{\mathrm{it}} = A_{\mathrm{it}} - A_{i0} = R_i \times K_i \times L_i \times S_i \times (C_{\mathrm{it}} \times P_{\mathrm{it}} - C_{i0} \times P_{i0})(7)$$

AP_{it} represents the SCP of region i in year t . R_i , K_i ,L_i , and S_i are respectively the rainfall and runoff erosivity factor, soil erodibility factor, slope length factor and slope steepness factor of region$i$. C_{it} and C_{i0} are respectively the values of the cover and management factor of region$i$ in year t and in the ideal state. Among them, theEVI corresponding to C_{i0} comes from the theoretical maximum value of vegetation restoration obtained by constructing similar habitat units based on the spatial sliding window, and references for specific calculation methods (Zhang et al., 2019; Xu et al., 2020). P_{it} and $P_{i0}$are respectively the values of the support practice factor of region$i$ in year t and in the ideal state. Among them, the land use types corresponding to P_{i0} are defined based on the standard of ensuring 1 mu (1/15 hm^2) of grain ration field per capita. Based on the resident population data of each county or district of Yan'an in 2015, the scale of grain ration fields to be reserved in each county or district was calculated, and the reserved grain ration fields should occupy the lowest part of the originally cultivated land slope. Finally, the remaining cultivated land will be converted to forest. The layers of each factor are shown in Figure 2.

[Figure 2 near here]

According to the definition and calculation method of SCP, it can be considered that if a region has higher SCP, it indicates that the gap between the current soil erosion level and the theoretical minimum soil erosion level in the region is more obvious, so the GFG investment in the region should be higher, thereby enhancing the effectiveness of soil erosion control.

In addition, this study uses village-level administrative districts as statistical units for calculation results, thereby enhancing data analysis and visualization.

4 Results and analysis

4.1 Evaluation of the SCE after the implementation of GFG

As shown in Figure 3, in general, the average annual amount of soil erosion in Yan'an decreased from 4884.49 $\mathrm{t{\cdot}km^{-2}{\cdot}a^{-1}}$ in 2000 to 4087.57 $\mathrm{t{\cdot}km^{-2}{\cdot}a^{-1}}$ in 2015. This result shows that the effect of GFG on soil conservation is significant. The implementation of GFG has improved the level of vegetation coverage, curbed the increasingly serious soil erosion in Yan'an, and improved the effect of soil conservation.

[Figure 3 near here]

From the spatial perspective, compared with 2000, in 2015, the area with an average annual soil erosion of more than 8000 $\mathrm{t{\cdot}km^{-2}{\cdot}a^{-1}}$ almost completely disappeared. The scale of the region between 5000 and 8000 $\mathrm{t{\cdot}km^{-2}{\cdot}a^{-1}}$ has been significantly reduced. At the same time, the average annual soil erosion between 2500 and 5000 $\mathrm{t{\cdot}km^{-2}{\cdot}a^{-1}}$ increased significantly. The above results show that, since the implementation of GFG, the soil erosion in Yan'an has been significantly reduced on the whole, while the differences between different regions have been gradually narrowed, and some areas with serious soil erosion have achieved remarkable results in the treatment.

4.2 Spatial distribution relationship between the SCE and the GFG intensity

Figure 4a provides the spatial distribution of GFG intensity (the ratio between the area of cultivated land converted to forest or grassland and the area of original cultivated land in a region) in Yan'an, which shows significant spatial agglomeration. The high-intensity areas of GFG are concentrated in Wuqi, Baota, Zichang, and Luochuan. The low-intensity areas are mainly distributed in Ansai, Huanglong, Yanchang, and Ganquan. It can be seen that this agglomeration is controlled by the county boundaries. This is because, in China, the formulation and implementation of related measures of the GFG are based on counties, so there can be significant differences in the intensity of GFG among counties. Figure 4b shows the SCE produced by GFG in Yan'an. It can be found that its spatial distribution also has an obvious agglomeration effect. The areas with obvious SCE are mainly distributed in the east, south, and Ansai in the north. While counties such as Wuqi, Zhidan, and Baota have achieved certain results in soil conservation, they are not as obvious as in other regions.

[Figure 4 near here]

Although the above two indicators have their specific spatial distribution law, the correlation between them is not significant, and the correlation coefficient is only -0.12. By comparing Figure 4a and 4b, it can be found that Wuqi, Baota, Zichang and other places with higher GFG intensity have lower SCE. Yanchuan, Yanchang, and Yichuan, where the SCE are obvious, have less GFG intensity. This situation reflects the mismatch between the GFG intensity and the SCE in spatial distribution. That is, the SCE is not necessarily better in areas with relatively high GFG investment. Considering that the main purpose of GFG in this region is soil conservation, it can be considered that the current GFG does not achieve optimal input allocation.

As mentioned earlier, the optimal allocation of GFG investment should be concentrated in regions with greater SCP. Therefore, we compared the SCP before GFG (Figure 4c) with the GFG intensity (Figure 4a). It was found that the matching degree of SCP and GFG at the spatial level was low, and the correlation coefficient was only -0.05, which was obviously inconsistent with the theoretical analysis. Considering that the GFG is mostly implemented at the county level, the SCP before GFG and the GFG intensity of all counties in Yan'an were ranked and compared. As shown in Table 3, the ranking difference of most counties is large, which further validates their inconsistencies. Taking Wuqi as an example, the county has the least SCP before GFG. While its GFG intensity ranks the 3rd, indicating that the GFG intensity in Wuqi has far exceeded the reasonable range of soil conservation. On the contrary, Yanchuan, Yanchang, and Yichuan in eastern Yan'an, which have the greatest SCP before the GFG and should have the highest GFG intensity theoretically. However, the GFG intensity rankings are far from the SCP, which indicates that the implementation of GFG in these areas needs to be improved. These results indicate that the previous GFG investment did not take into account the SCP, not only failed to achieve the optimal SCE, but also caused a waste of resources. If the GFG investment can be formulated and adjusted according to the SCP in each region, the implementation efficiency of GFG can be greatly improved, so as to achieve better SCE.

[Table 3 near here]

To better illustrate the above point, we calculated the ratio of the GFG area and the soil erosion reduction (RGS) from 2000 to 2015. Comparing the GFG areas in several counties under the premise of achieving the same SCE (Table 4). Obviously, the RGS of Wuqi (1.836) is much higher than that of Yanchang (0.105), Yichuan (0.196), and Yanchuan (0.307). That is, under the premise of achieving the same SCE, the GFG investment in Wuqi needs to be higher. The result indicates that if the focus of GFG investment can be placed on counties with great SCP, the investment cost of GFG will be significantly reduced, thereby saving capital and resources.

[Table 4 near here]

4.3 The GFG strategy based on the SCP

The main purpose of the GFG is to control soil erosion and enhance the SCE. Therefore, in combination with the above analysis, the focus of GFG investment should be arranged in regions with high SCP in the future to obtain the maximum benefits. As for the future development direction of GFG in Yan'an, in this study, the future GFG investment is divided into 3 levels based on the SCP in 2015. Table 5 and Figure 5 provide the classification and spatial distribution of the levels. For different levels, the practical GFG investments strategy should be adopted.

[Table 5 near here]

[Figure 5 near here]

High-level regions are concentrated in the east, north and south of Yan'an. These regions have the most range for soil erosion control. Through the GFG, the best SCE will be achieved. Therefore, priority needs to be given in policy formulation to increase the GFG investment in these regions. The distribution of mid-level regions is similar to that of high-level regions, but the scope is wider. The implementation of GFG is still feasible in these regions. In the process of formulating strategies, it is necessary to pay attention to the overall coordination between mid-level and high-level regions, so as to generate economies of scale and reduce costs. Low-level areas are mainly distributed in the middle and northwest. For these areas, the SCE produced by intensive artificial vegetation restoration is not obvious, the GFG investment in these areas should be gradually reduced in the future. The focus should be shifted to the natural restoration, management and maintenance of vegetation.

5 Discussion and implications

5.1 Evaluation of the GFG implementation

In the Loess Plateau of China, the primary goal of GFG is to curb the increasingly severe soil erosion, thereby reducing the sediment content in the Yellow River. As an ecological policy, the GFG has had a positive and far-reaching impact on the ecological environment in relevant regions over the past 20 years. Yan'an is considered to be one of the cities with the most serious soil erosion in the Loess Plateau. The vegetation restoration brought by GFG has significantly controlled soil erosion in the city. However, the research in this paper shows that although the GFG plays an obvious role in soil conservation, there are problems of policy dislocation and low efficiency in the specific implementation process. In some areas, the implementation of GFG has cost a lot, but the SCE is very limited. This not only exposes the external manifestation of local government's one-sided pursuit of vegetation restoration effect in the process of policy implementation but also reflects the failure of the superior government to make sufficient analysis and judgment on the key implementation regions of GFG in the process of macro-control. The result is an imbalance in input and output, and a waste of resources and capital. These problems need to be adjusted and changed in the future. It also shows that the implementation of GFG in the future still has great significance.

5.2 Innovation and advantages of the SCP model

The innovation of this study is the SCP model with vegetation coverage as the core. The model describes the difference between the soil erosion level in different regions at different times and the theoretical minimum soil erosion level, reflecting the extent of improvement and spatial difference of soil erosion control. And, it not only inherits the evaluation criteria of absolute quantity reduction commonly used in the evaluation system of SCE but also provides a theoretical basis for the investment of GFG. The greater SCP is, the greater the gap between the current situation of soil erosion and the ideal situation is, and the higher intensity of GFG should be. On the other hand, if the SCP is small, it indicates that the current situation of soil erosion is close to the ideal situation, and relatively low GFG investment should be given. The advantage of this approach is that corresponding GFG strategies can be developed for different regions to control costs and improve the effectiveness of governance and policy implementation. The proposal and application of this model provide the public with a further understanding of the relationship between the GFG and soil conservation and provide a new way of thinking for the optimization of GFG in the future.

5.3 Establish the dynamic investment mechanism of the GFG

The SCP, the GFG investment and the SCE are not isolated states, but constitute a complete system together, and there are dynamic circulation characteristics between each other. Specifically, the SCP calculated by the theoretical model can provide decision-makers with the investment intensity of GFG in different regions for a while in the future, to achieve the economical and intensive utilization of resources and reduce the cost of policy implementation. The investment of GFG will inevitably reduce the amount of soil erosion in the region and produce a certain SCE. At the same time, the dynamic change of SCE and the interference of external factors will modify the SCP accordingly, so as to provide a reference for the key input direction of the GFG in the next stage (Figure 6). Through the continuous circulation among the three, the ideal SCE is finally achieved.

[Figure 6 near here]

Therefore, in order to optimize the GFG, it is suggested to establish the GFG dynamic investment mechanism. In the future formulation of the GFG plan, an appropriate implementation period should be set on the basis of full consideration of the SCP. Considering the time delay of vegetation growth and development, this period should have a large time span. After the implementation period is reached, the new SCP is calculated, and based on this adjustment, the implementation plan for the next stage is formulated.

6 Conclusion

This study took Yan'an as the research object, and evaluated the effects and existing problems of soil conservation in different regions since the implementation of the GFG. By constructing the SCP model and exploring the relationship between the GFG investment and the SCE in some counties, the causes of problems were analyzed. On this basis, suggestions were made for the implementation of GFG in the future. The conclusions of the study are as follows.

(1) Since the implementation of GFG, soil erosion in Yan'an has been effectively controlled. Especially in regions with serious soil erosion, the SCE is more significant. However, due to insufficient theoretical research in the early stage, the implementation of the policy appears blind. The imbalance of input and output in some areas leads to the failure of soil conservation to achieve the optimal effect.

(2) As a theoretical innovation, the SCP model not only explains the low efficiency of previous policies but also simulates the investment difference of GFG under the same SCP, thus providing a new idea for the optimization of future GFG.

(3) The SCP for Yan'an in 2015 was calculated by using the SCP model. According to this, three investment levels of GFG were divided, and corresponding optimization schemes were formulated for different levels.

(4) A dynamic circulation for the optimization of the ecological policy is proposed based on the analysis of the relationship among the SCP, the GFG investment.

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Table

TABLE 1 Calculation method of each factor in RUSLE

Factor	Equation	Description	Reference
R	$R = \sum_{i=1}^{12} 1.735 \times 10^{\left[1.5lg\left(\frac{P_i^2}{P}\right)-0.08188\right]}$ (2)	Pi: mean monthly rainfall (mm) P: mean annual rainfall (mm)	Prasannakumar et al. (2011)
K	$K = 0.1317 \times K_1 \times K_2 \times K_3 \times K_4$ (3) And, $K_1 = 0.2+0.3exp\left\{-0.0256SD\left[1.0-\left(SI/100\right)\right]\right\}$ $K_2 = \left[SI/\left(CL+SI\right)\right]^{0.3}$ $K_3 = 1.0-\left\{0.25C/\left[C+exp\left(3.72-2.95C\right)\right]\right\}$ $K_4 = 1.0-\left\{0.7SN/\left[SN+exp\left(-5.51+22.9SN\right)\right]\right\}$	*SD:* sand fraction (%) *SI:* silt fraction (%) *CL:* clay fraction (%) *C:* organic carbon fraction (%) *SN:* $1-SD/100$	Yang et al. (2003)
L&S	$L = (\lambda/22.13)^m$ (4) $S = \begin{cases} 10.8sin\theta + 0.03 & \theta < 9\% \\ 16.8sin\theta - 0.50 & \theta \geq 9\% \end{cases}$ (5) And, $m = \beta/\left(1+\beta\right)$ $\beta = sin\theta/\left[3\left(\sigma\iota\nu\vartheta\right)^{0.8}+0.56\right]$	λ*:* horizontal projection slope length *m:* variable slope length exponent *β:* a factor that varies with slope gradient *ϑ:* slope angle (%).	McCool et al. (1989) Zhang et al. (2013)
C	$C = \begin{cases} 1 & 0 \leq FVC \leq 4.9\% \\ 0.221-0.595lgFVC & FVC \geq 4.9\% \end{cases}$ (6) And, $FVC = \left(EVI-\mathrm{EVI}_{\mathrm{min}}\right)/\left(\mathrm{EVI}_{\mathrm{max}}-\mathrm{EVI}_{\mathrm{min}}\right)$	*FVC:* the fractional vegetation cover EVI_{min} and EVI_{max}*:* the minimum and maximum EVI values of the whole study area during the study period	Liu et al. (1999)

TABLE 2 P factors for different land use types

Land use types	P values	Land use types	P values
Cultivated land (α¡6°)	0.5	Forest	1
Cultivated land (6°[?]α¡10°)	0.6	Grassland	1
Cultivated land (10°[?]α¡15°)	0.7	Water	0
Cultivated land (15°[?]α¡20°)	0.8	Construction land	0
Cultivated land (20°[?]α¡25°)	0.9	Unused land	1
Cultivated land (α[?]25°)	1		

TABLE 3 Ranking and comparison of the SCP before GFG and the GFG intensity in various counties

County	The SCP before GFG ($t\cdot km^{-2}\cdot a^{-1}$)	Rank	GFG intensity	Rank	Difference
Ansai	1522.564	4	0.256	12	-8
Baota	1232.594	8	0.694	1	7
Fuxian	1129.961	10	0.330	9	1
Ganquan	865.670	12	0.275	11	1
Huangling	1195.142	9	0.427	8	1
Huanglong	1261.420	7	0.236	13	-6
Luochuan	1262.177	6	0.595	4	2
Wuqi	822.888	13	0.633	3	10
Yanchang	2138.511	1	0.316	10	-9
Yanchuan	1638.593	3	0.476	7	-4
Yichuan	1665.547	2	0.566	5	-3
Zhidan	1048.796	11	0.476	6	5
Zichang	1263.172	5	0.662	2	3

TABLE 4 The RGS of several counties from 2000 to 2015

County	RGS	County	RGS
Wuqi	1.836	Yanchang	0.105
Yanchuan	0.307	Yichuan	0.196

TABLE 5 Corresponding relationship between the GFG investment level and the SCP

The SCP in 2015 ($t\cdot km^{-2}\cdot a^{-1}$)	The GFG investment level
More than 800	High-level
500 ˜ 800	Mid-level
Less than 500	Low-level

Figures

FIGURE 1 Location of the study area.

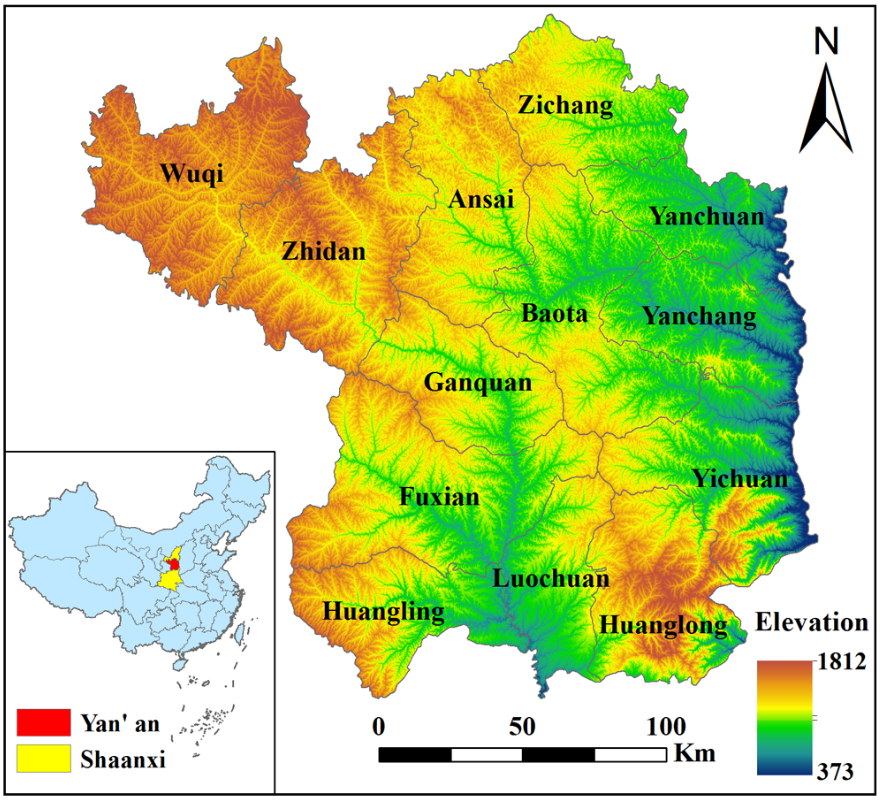
FIGURE 2 RUSLE factors in this study: (a) ˜ (c) R factor, K factor and LS factor; (d) ˜ (f) C factor in 2000, 2005 and the ideal state; (g) ˜ (i) P factor in 2000, 2005 and the ideal state.

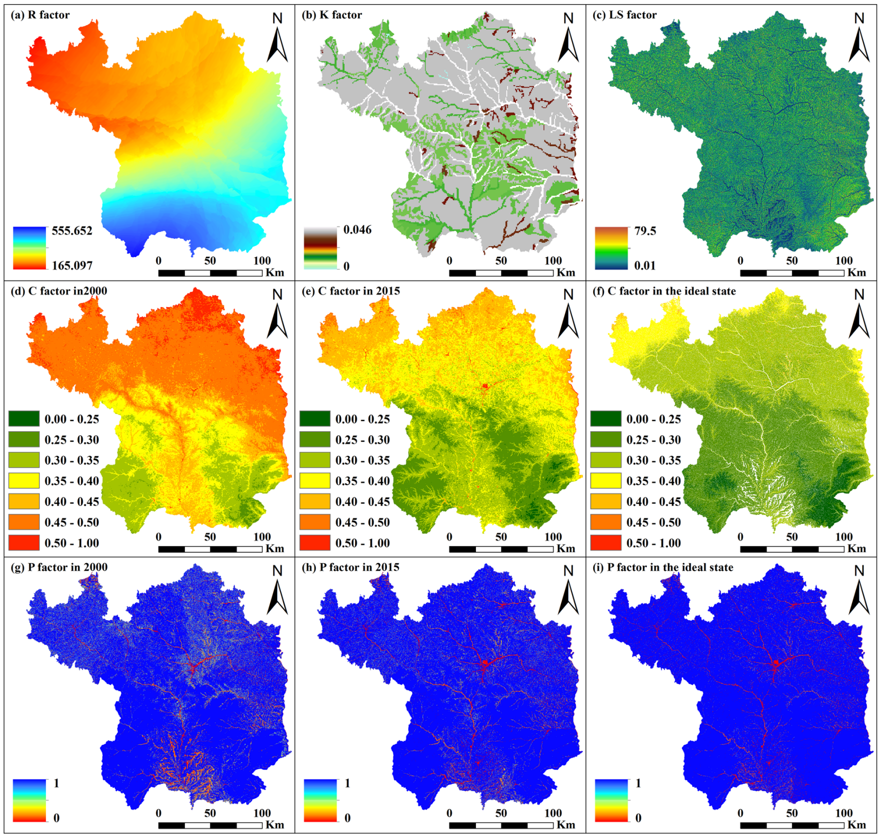
FIGURE 3 Average annual soil loss per square kilometer (t) in Yan'an for (a) 2000 and (b) 2015.

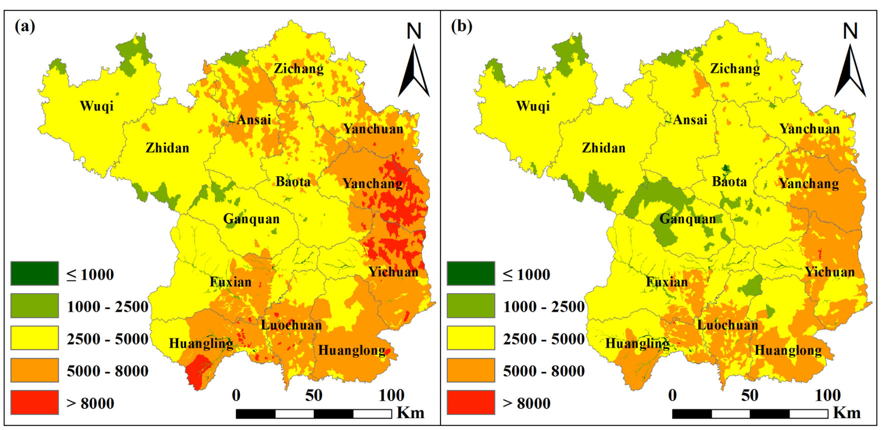
FIGURE 4 (a) The intensity of GFG; (b) the SCE from 2000 to 2015; (c) the SCP in 2000.

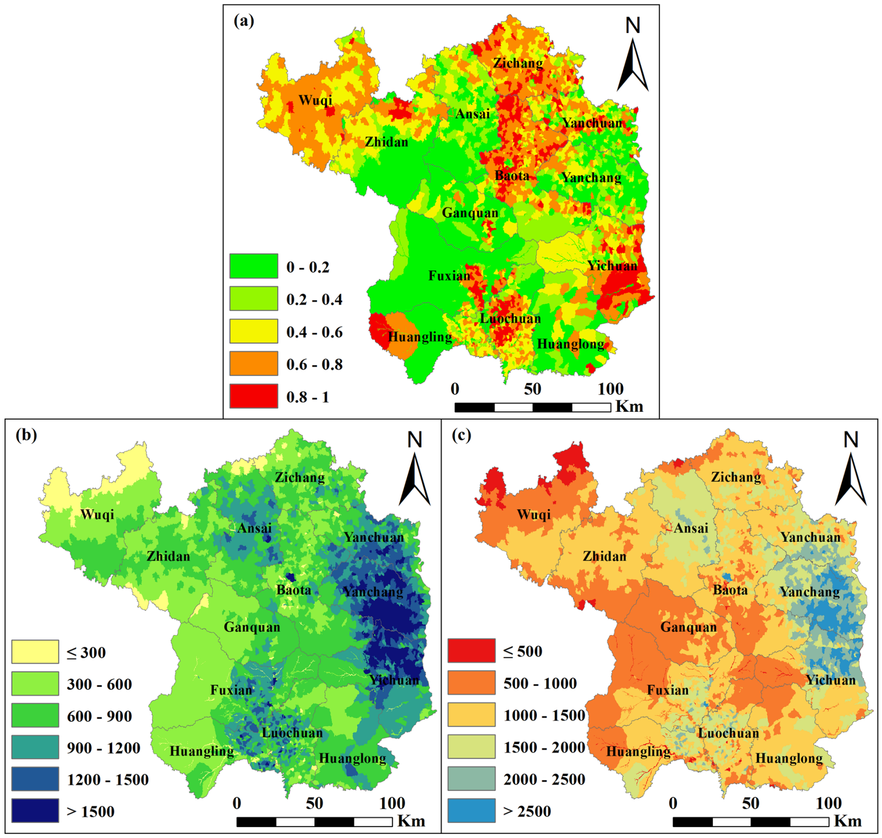
FIGURE 5 The GFG investment levels in different regions in the future.

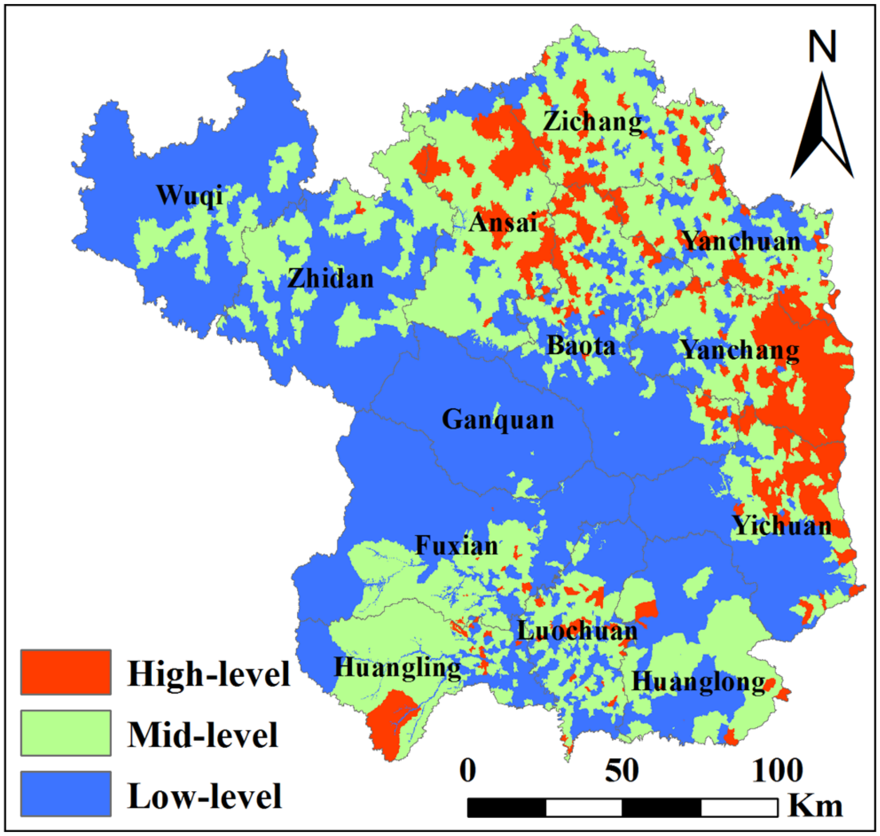
FIGURE 6 Cyclic relationship between the SCP, the GFG investment and the SCE.


N
Wuqi
Zhidan
Ansai
Zichang
Yanchuan
Baota
Yanchang
Ganquan
Fuxian
Yichuan
Luochuan
Huangling
Huanglong
Elevation
1812
373
0
50
100
Km
Yan' an
Shaanxi


(a) R factor
555.652
165.097
(b) K factor
0.046
0
(c) LS factor
79.5
0.01
(d) C factor in2000
(e) C factor in 2015
(f) C factor in the ideal state
0.00 - 0.25
0.25 - 0.30
0.30 - 0.35
0.35 - 0.40
0.40 - 0.45
0.45 - 0.50
0.50 - 1.00
(g) P factor in 2000
(h) P factor in 2015
(i) P factor in the ideal state
1
0
N
0 50 100 Km


(a)
(b)
N
Wuqi
Zhidan
Zichang
Ansai
Yanchuan
Baota
Yanchang
Ganquan
Yichuan
Fuxian
Luochuan
Huangling
Huanglong
≤ 1000
1000 - 2500
2500 - 5000
5000 - 8000
> 8000
0 50 100 Km


(a)
N
Wuqi
Zhidan
Ansai
Zichang
Yanchuan
Baota
Yanchang
Ganquan
Fuxian
Yichuan
Luochuan
Huangling
Huanglong
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1
0 50 100
Km
(b)
≤ 300
300 - 600
600 - 900
900 - 1200
1200 - 1500
> 1500
(c)
≤ 500
500 - 1000
1000 - 1500
1500 - 2000
2000 - 2500
> 2500



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