

Soil Erosion Is Influenced by Grain for Green Policy in Loess Plateau Area of Northern Shaanxi, China

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Abstract: Grain for Green Policy (GGP), one of China's important ecological construction and protection policies, have been made remarkable achievements since implementation in 1999. The purpose of this work is to assessment of soil erosion influenced by GGP, which implementation is lead to great change of land use and vegetation cover, using RUSLE model on the basis of land use, MODIS NDVI, DEM and precipitation data in Loess Plateau area of northern Shaanxi, northwest of China. Result showed: (1) GGP implementation in northern Shaanxi was mainly during 1999-2003 and the area of returning farmland in the period accounted for 81.28% of the total area from 1999 to 2008. (2) Farmland in northern Shaanxi and slope $>25^\circ$ was decrease 4.94% and 4.84%, respectively, while grassland was increase 4.04% and 4.05%, respectively. The change of decreasing farmland and increasing grassland was mainly from 2000 to 2005 in northern Shaanxi and slope $>25^\circ$. (3) Farmland was convert into woodland and grassland, which led to increasing of vegetation NDVI. Especially, the vegetation NDVI value of farmland in slope $>25^\circ$ was increase larger than whole area of northern Shaanxi from 2000 to 2010. (4) The change area of soil erosion in northern Shaanxi and slope $>25^\circ$ was decrease in 1 degree, while was increase in other degrees from 2000 to 2010. But when recalculated by rainfall erosivity in 2000, the change area of soil erosion in northern Shaanxi and $>25^\circ$ was increase in 1 degree, while was decrease in other degrees from 2000 to 2010. Vegetation cover change induced by GGP was reduce soil erosion, but due to rainfall erosivity increased, soil erosion was show increase trend in northern Shaanxi and slope $>25^\circ$.

Keywords: Land Use Change, MODIS NDVI, Rainfall Erosivity, Loess Plateau

1. Introduction

Grain for Green Policy (GGP) is one of the major ecological protection and construction policies in China. GGP pilot implementation involve 1897 county-level administrative units since 1999, and those counties included in loess plateau area of northern Shaanxi province are key counties of construction. By 2010, the area of returning farmland to forest was $906.30 \times 10^4 \text{ hm}^2$, afforestation of barren hills was $1533.97 \times 10^4 \text{ hm}^2$, new forest conservation was $246.81 \times 10^4 \text{ hm}^2$, total food subsidies was 322.79×10^8 (\$1=¥6), and subsidies of living cash amounting was 43.74×10^8 [1]. With the implementation of GGP, forest cover rate has been improved, and GGP has achieved significant environment benefits [2].

Loess Plateau area in northern Shaanxi province is a serious soil erosion area, and the key area of GGP implementation. Affected by GGP, ecological environment has been improved obviously, vegetation cover increased, land use structure adjusted, a large area of arable land on steep slopes has been

converted into forest or grassland, soil nutrients has been recovered and soil erosion decreased in northern Shaanxi [3,4]. Implementation of GGP was lead to reduction of arable land, promotion of rural surplus labor to non-agricultural industries, and improved of rural household's economic structure [5]. By the impact of GGP, total arable land of grain output was declined but grain yield of per unit area was increased [6,7]. Overall, ecological environment – human social system had been changing in many aspects by GGP. By the continued implementation of GGP, issues of implementation were highlighted by scholars [8].

Vegetation cover are important factors affecting soil erosion [9, 10, 11]. The goal of GGP implementation in northern Shaanxi is to reduce soil erosion. Relevant regulations and laws required the farmland which has serious soil erosion, important ecological status but low grain production, should be included in GGP plans and is prohibited reclamation in slope $>25^\circ$ area. Therefore, even though the policy does not explicit propose, but the arable land especially in slope $>25^\circ$ should be the main target of GGP [4, 12]. The purpose of this work is to assessment

of soil erosion influenced by GGP, which implementation is lead to great change of land use and vegetation cover, using RUSLE model on the basis of land use, MODIS NDVI, DEM and precipitation data in Loess Plateau area of northern Shaanxi, northwest of China.

2. Materials and Methods

2.1. Study Area

Loess plateau area in northern Shaanxi include Yulin and Yan'an, which contain 25 counties and locate in

107°15'56"E-111°13'10"E and 35°21'56"N-39°35'06"N (Figure.1), while Mu Us Sand land along the edge of northern Yulin. By the end of 2011, the total population of the area is 554.64×10^4 , and the total land area is $80\,624\text{km}^2$. The climate is temperate continental monsoon climate, and the average temperature is 9.5°C . Annual average rainfall and the average sunshine are 506.5mm and 2540h/a, respectively, and frost-free period is 194d. The whole territory belongs to the Yellow River watershed, and the main tributary is Wuding River and Yanhe River, etc [13].

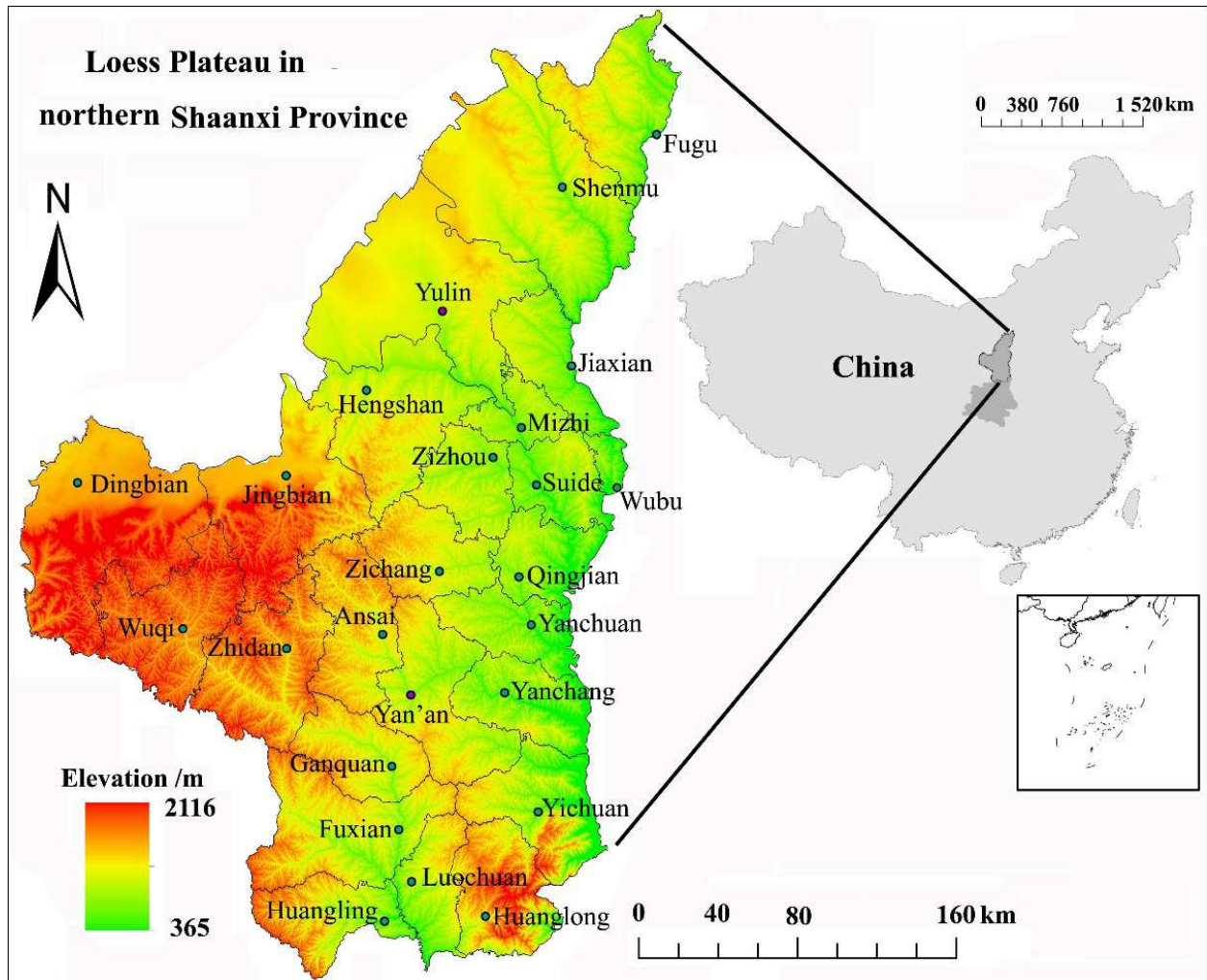


Figure 1. Study area.

Precipitation in study area is focus on the summer and autumn, which account for 80% of annual precipitation, and which also the important reasons of soil erosion in northern Shaanxi, China. Yulin and Yan'an are the mainly area of GGP implementation in Shaanxi province. According to the statistical yearbook of Shaanxi province (1999-2008), the area of returning farmland to forest in northern Shaanxi is $472.1 \times 10^3\text{hm}^2$ from 1999 to 2008, accounting for 41.14% of total area of returning farmland to forest in Shaanxi province [13].

2.2. Materials

The data used in this research include: (1) 1:100 000 vector land use map of northern Shaanxi in 2000, 2005 and 2010 year, comes from the project "Remote sensing survey and evaluation of ecological environment change in China (2000-2010)". Land use map in 2010 was classified by environmental satellite images, while TM images were used in 2000 and 2005. Geographic coordinates of land use map is GCS_WGS84, and projection is Albers ellipsoid with central longitude 105° . Classification system of land use map include

7 primary classifications and 30 secondary classifications. (2) Vector county administrative boundary map of northern Shaanxi. (3) ASTER GDEM data with 30m resolution of northern Shaanxi. The dataset was provided by Geospatial Data Cloud, Computer Network Information Center, Chinese Academy of Sciences (<http://www.gscloud.cn>). (4) Daily rainfall data of 7 stations from 1991 to 2010 is collected from China Meteorological Data Sharing Service System (<http://cdc.nmic.cn>). The station is Dingbian, Yulin, Hengshan, Suide, Wuqi, Yan'an and Luochuan. (5) Soil map of northern Shaanxi with scale of 1:500 000. (6) MODIS NDVI 13Q1-Level 3 images data of vegetation index with 250m resolution of northern Shaanxi in 2000, 2005 and 2010. (7) Shaanxi statistical yearbook from 2001 to 2011.

2.3. Methods

The Revised Universal Soil Loss Equation (RUSLE) is used to calculate soil erosion of northern Shaanxi. RUSLE is represented as follows [14]

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

where A is the amount of the average soil loss ($\text{t} \cdot \text{hm}^{-2} \cdot \text{a}^{-1}$); R is the rainfall erosivity factor ($\text{MJ} \cdot \text{mm} \cdot \text{hm}^{-2} \cdot \text{h}^{-1} \cdot \text{a}^{-1}$); K is the soil erodibility factor ($\text{t} \cdot \text{hm}^{-2} \cdot \text{h} \cdot \text{hm}^{-2} \cdot \text{MJ}^{-1} \cdot \text{mm}^{-1}$); L is the slope length factor; S is the slope factor; C is the vegetation cover factor and P is the erosion control practice factor.

$$K = \left(0.2 + 0.3 \exp \left(0.0256M \left(1 - \frac{F}{100} \right) \right) \right) \cdot \left(\frac{F}{N+F} \right)^{0.3} \cdot \left(1.0 - \frac{0.25T}{T + \exp(3.72 - 2.95T)} \right) \cdot \left(1.0 - \frac{0.7\delta}{\delta + \exp(-5.51 + 22.9\delta)} \right) \quad (5)$$

where, M , F , N is mass fraction of sand, silt and clay, respectively, %; T is mass fraction of soil organic carbon, %; $\delta = 1 - M/100$. The K value is need to change into the international system of units through multiplied by 0.1317, $\text{t} \cdot \text{hm}^{-2} \cdot \text{h} / \text{hm}^2 \cdot \text{MJ} \cdot \text{mm}$.

2.3.3. Topographical Factor (LS)

Slope and slope length (LS) are topographical factor, which mainly reflecting the effects of topography on soil erosion. L is calculated by DEM according to [21] proposed formula and S is calculated by the formula proposed by [22] and [23]. The formula is expressed as follows:

$$L = (\lambda / 22.13)^\alpha \quad (6)$$

$$\alpha = \beta(\beta + 1), \quad \beta = (\sin\theta / 0.0896) / (3.0(\sin\theta)^{0.8} + 0.56) \quad (7)$$

$$S = \begin{cases} 10.8 \sin\theta + 0.03, & \theta < 9\% \\ 16.8 \sin\theta - 0.50, & 9\% \leq \theta < 14\% \\ 21.9 \sin\theta - 0.96, & \theta \geq 14\% \end{cases} \quad (8)$$

where λ is the slope length; α is the slope length index; θ is the slope (%) extract by DEM.

2.3.4. Vegetation Cover Factor (C)

C factor is vegetation index, which is calculated based on MODIS NDVI data, the formula is expressed as follows [24,25]:

$$AVHRR \text{ NDVI} = 0.18 \text{ MODIS NDVI} + 0.131 \quad (9)$$

2.3.1. Rainfall Erosivity Factor (R)

R factor is the indicator for evaluating the impact of rainfall on soil separation and transportation, and is used to estimate by rainfall parameters. Annual rainfall erosivity is calculated by daily rainfall data proposed by [15,16]:

$$R_i = \alpha \sum_{j=1}^k P_j^\beta \quad (2)$$

$$\alpha = 21.586\beta^{-7.1891} \quad (3)$$

$$\beta = 0.8363 + 18.144P_{d12}^{-1} + 24.455P_{y12}^{-1} \quad (4)$$

where R_i is the rainfall erosivity of i th year, $\text{MJ} \cdot \text{mm} \cdot \text{hm}^{-2} \cdot \text{h}^{-1} \cdot \text{a}^{-1}$; k is the number of days with erosive rainfall in one year, d; and P_j is the erosive rainfall of j th day, mm. The standard rainfall leading to soil erosion is $\geq 12\text{mm/d}$, otherwise is calculated by 0 value [17]. α and β are characteristic parameters, and P_{d12} is annual average daily rainfall with daily rainfall $\geq 12\text{mm}$, mm, while P_{y12} is average annual rainfall of rainfall $\geq 12\text{mm}$, mm.

2.3.2. Soil Erodibility Factor (K)

K factor affected by many factors, is the indicator to evaluate soil erosion probability when rainfall erosivity is occurred [18, 19]. K value is calculated by EPIC model [20] as follows:

$$C = \exp(-\alpha \cdot \frac{AVHRR \text{ NDVI}}{\beta - AVHRR \text{ NDVI}}) \quad (10)$$

where α and β are parameters with the value of 2 and 1, respectively. C value is calculated by AVHRR NDVI data, which need to covert MODIS NDVI into AVHRR NDVI.

2.3.5. Erosion Control Practice Factor (P)

P factor is calculated by the following formula proposed by [26]:

$$P = 0.2 + 0.03S \quad (11)$$

where S is the slope extracted by DEM (%).

3. Results

3.1. GGP on Land Use Change

3.1.1. Decreased Area of GGP Implementation in Northern Shaanxi

The area of returning farmland to forest or grassland of Shaanxi province and northern Shaanxi region including Yan'an and Yulin city was obtained by statistical yearbook of Shaanxi province from 2000 to 2011, and the result showed in Figure.2.

GGP implementation was occurred mainly during 1999-2008, and statistical yearbook of Shaanxi province was not recorded about the area of returning farmland to forest or grassland after 2009. From 1999 to 2008 of GGP

implementation, the area of returning farmland was about 11476.2km² in Shaanxi province, where the area of returning

farmland in northern Shaanxi (Yulin and Yan'an) was 4721km², accounting for 41.14%.

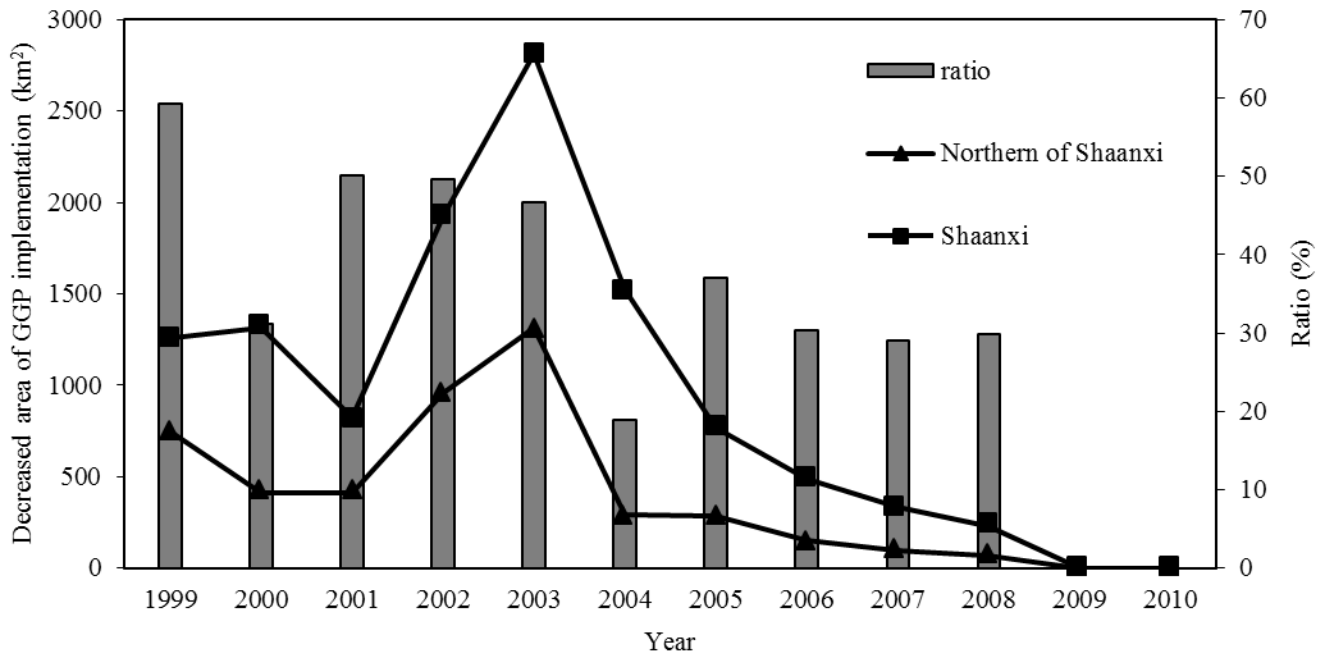


Figure 2. Decreased area of GGP implementation in Shaanxi province and northern Shaanxi.

The process of area change can be divided into 2 stages. The first stage was from 1999 to 2003 with increasing trend of area of returning farmland in Shaanxi province and northern Shaanxi, and the ratio of returning farmland area in northern Shaanxi accounting for Shaanxi province was higher than 40% (except in 2000). The second stage was from 2003 to 2008 with decreasing trend of area of returning farmland in Shaanxi province and northern Shaanxi, and the ratio of returning farmland area in northern Shaanxi accounting for Shaanxi province was about 30% (except in 2004).

Overall, GGP implementation in northern Shaanxi was mainly during 1999-2003, and the area of returning farmland

in the period accounting for 81.28% of the total area during 1999-2008.

3.1.2. Land Use Change

Land use type in northern Shaanxi was woodland, grassland and farmland, which three land types accounting for more than 90% of the total land area. Woodland and grassland were show an increasing trend and the percentage increased from 20.21% to 20.73%, from 44.74% to 48.78%, respectively, during 2000-2010, while farmland showed decreasing trend and the percentage decreased from 25.16% to 20.22% (Figure.3a).

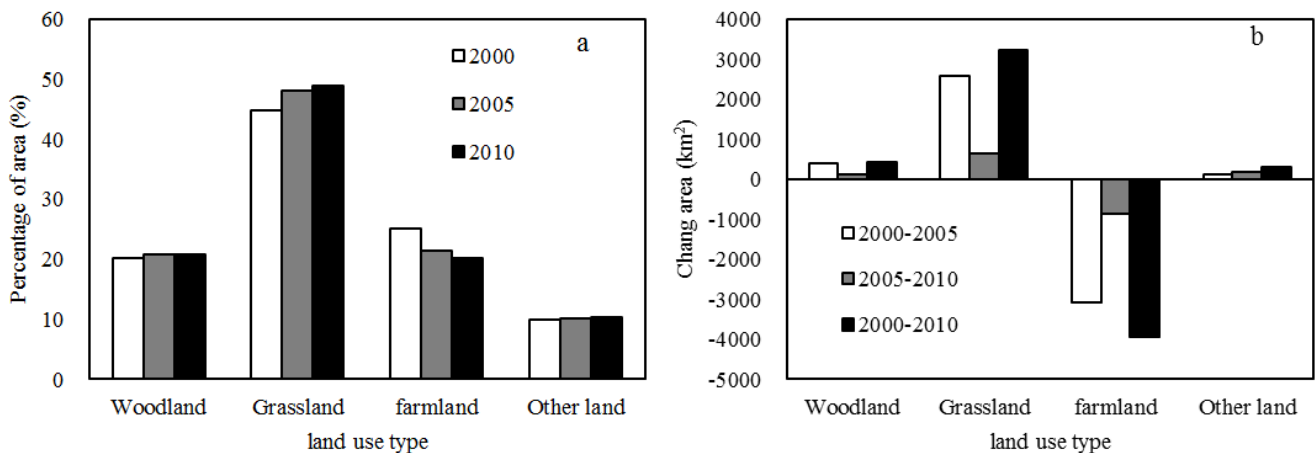


Figure 3. Land use structure (a) and change area (b) in different stage of northern Shaanxi.

Woodland, grassland and farmland were the largest types of land use change. The area of woodland and grassland were increase 412.35km² and 3229.71km², respectively, from 2000

to 2010, while farmland was decrease 3948.16km² (Figure.3b). The change rate of woodland, grassland and farmland were 0.52%, 4.04% and -4.94%, respectively, during 2000-2010.

The most intense period of land use change was from 2000 to 2005 in northern Shaanxi. In the period of 2000-2005, the change area of woodland, grassland and farmland were 377.49km², 2583.13km² and -3081.71km², respectively, and accounting for 91.55%, 79.98% and 78.05% of the total change area of 2000-2010, respectively.

3.1.3. Land Use Change in Slope >25°

Land use type in slope >25° of northern Shaanxi was

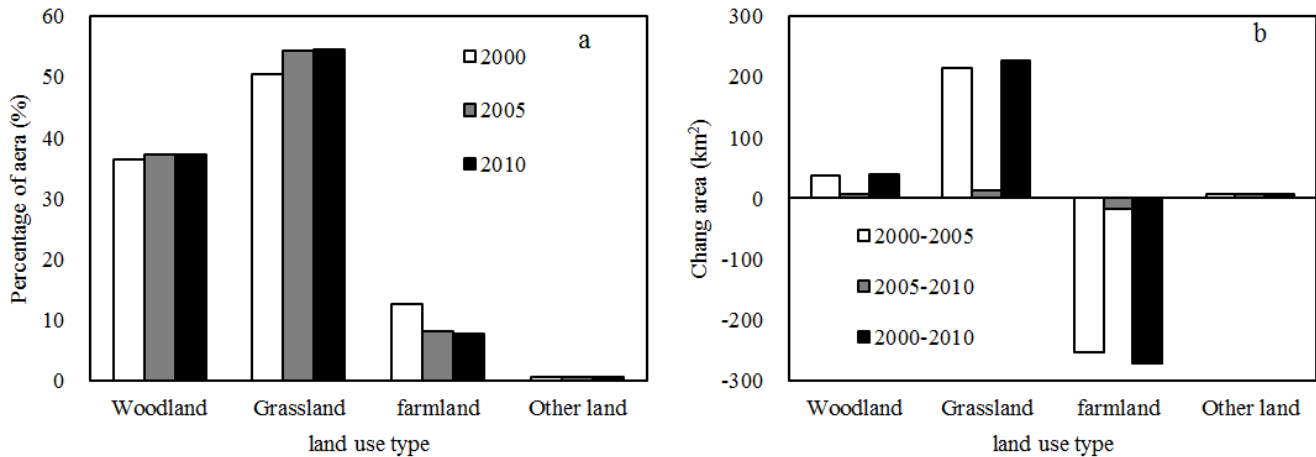


Figure 4. Land use structure (a) and change area (b) in different stage of slope >25° in northern Shaanxi.

Woodland, grassland and farmland were the largest types of land use change in slope >25°. The area of woodland and grassland were increase 39.51km² and 226.90km², respectively, from 2000 to 2010, while farmland was decrease 270.67km² (Figure.4b). The change rate of woodland, grassland and farmland were 0.70%, 4.05% and -4.84%, respectively, during 2000-2010.

The most intense period of land use change in slope >25° was from 2000 to 2005 in northern Shaanxi. In the period of 2000-2005, the change area of woodland, grassland and farmland were 38.41km², 213.65km² and -254.04km², respectively, and accounting for 97.21%, 94.16% and 93.86%

woodland, grassland and farmland, which three land types accounting for more than 99% of the total land area in slope >25°. Woodland and grassland were show an increasing trend and the percentage increased from 36.47% to 37.17%, from 50.50% to 54.55%, respectively, during 2000-2010, while farmland showed decreasing trend and the percentage decreased from 12.59% to 7.75% (Figure.4a).

of the total change area of 2000-2010, respectively.

3.2. GGP on Vegetation Cover Change

Large changes of land use were happened in northern Shaanxi by GGP implementation, which also lead to changes of vegetation cover. Land use and vegetation NDVI data were used to extract vegetation NDVI value corresponding to 2000, 2005 and 2010 of farmland area in 2000 in northern Shaanxi and slope >25°, and the value of vegetation NDVI of changed and unchanged area of farmland in 2000. Results show in Table 1.

Table 1. Vegetation NDVI value in different area.

Type	2000	2005	2010	2000-2005	2000-2010	2000-2010(%)
Farmland area	2000	0.4111	0.5053	0.0942	0.1512	36.78
	Unchanged during 2000-2010	0.4152	0.5034	0.0882	0.1413	34.03
	Changed during 2000-2010	0.3947	0.5129	0.5859	0.1912	48.44
Farmland area in slope >25°	2000	0.4074	0.5197	0.1123	0.1782	43.74
	Unchanged during 2000-2010	0.4035	0.5024	0.0989	0.1595	39.53
	Changed during 2000-2010	0.4135	0.5468	0.1333	0.2075	50.18

The direct effect of GGP implementation was lead to a significant reduction of farmland converting to woodland and grassland, thereby vegetation NDVI value increased. The vegetation NDVI value of farmland area in 2000 showed increasing trend from 2000 to 2010, with an increase of 0.1512 which accounting for 36.78% of 2000. In the farmland area of 2000, the vegetation NDVI of farmland unchanged area was increase 0.1413 with 34.03% while of farmland changed area increased 0.1912 with 48.44% (Table 1). Therefore, the vegetation NDVI of changed area of farmland in 2000 was

increase larger than the vegetation value of unchanged area, which was influenced by GGP implementation.

The vegetation NDVI value of farmland area in slope >25° in 2000 showed increasing trend from 2000 to 2010, with an increase of 0.1782 which accounting for 43.74% of 2000. In the farmland area of slope >25° in 2000, the vegetation NDVI of farmland unchanged area was increase 0.1595 with 39.53% while of farmland changed area increased 0.2075 with 50.18% (Table 1).

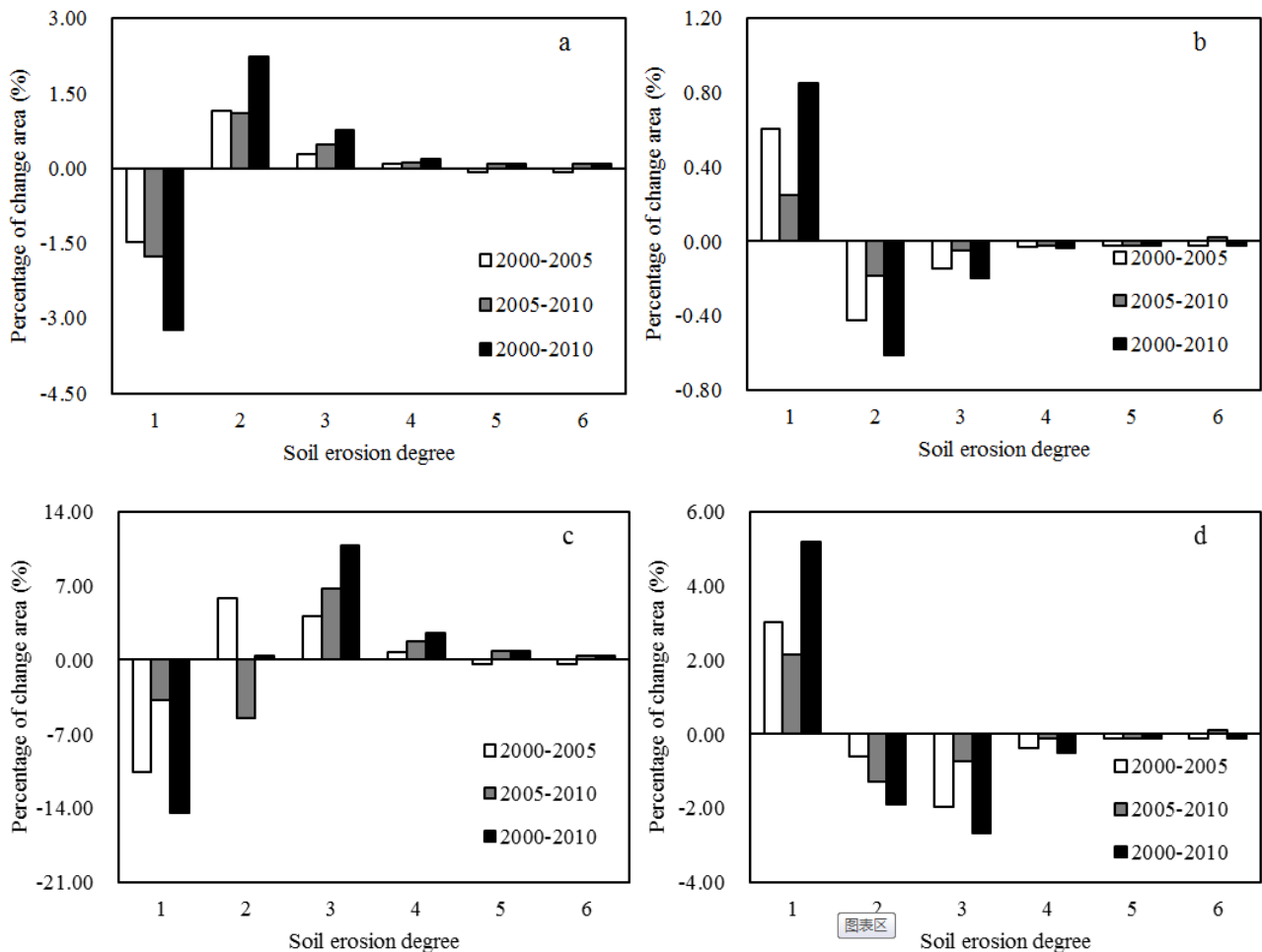
Overall, farmland was convert into woodland and grassland

from 2000 to 2010, which led to vegetation NDVI increase by GGP implementation. Especially, the vegetation NDVI value of farmland in slope $>25^\circ$ was increase more than whole area of northern Shaanxi.

3.3. GGP on Soil Erosion

The value of R , K , L , S , P and C was calculated by the formula mentioned in the context. R and C had different value in 2000, 2005 and 2010, so the amount of the average soil loss in northern Shaanxi and the area of slope $>25^\circ$ were obtained in 2000, 2005 and 2010. While for evaluating GGP on soil

erosion, the rainfall erosivity should be not considered. Therefore, the amount of the average soil loss in northern Shaanxi and the area of slope $>25^\circ$ were also obtained in 2000, 2005 and 2010 using the rainfall erosivity of 2000. Six soil erosion degree was divided according to the classify standard of soil erosion [27], that was 1, 2, 3, 4, 5, 6 degree with the amount of the average soil loss $<1000 \text{ t}\cdot\text{hm}^{-2}\cdot\text{a}^{-1}$, $1000\text{-}2500 \text{ t}\cdot\text{hm}^{-2}\cdot\text{a}^{-1}$, $2500\text{-}5000 \text{ t}\cdot\text{hm}^{-2}\cdot\text{a}^{-1}$, $5000\text{-}8000 \text{ t}\cdot\text{hm}^{-2}\cdot\text{a}^{-1}$, $8000\text{-}15000 \text{ t}\cdot\text{hm}^{-2}\cdot\text{a}^{-1}$, $>15000 \text{ t}\cdot\text{hm}^{-2}\cdot\text{a}^{-1}$, respectively. The percentage of change area in different degree during 2000-2005, 2005-2010 and 2000-2010 showed in Figure.5.



1, $<1000 \text{ t}\cdot\text{hm}^{-2}\cdot\text{a}^{-1}$; 2, $1000\text{-}2500 \text{ t}\cdot\text{hm}^{-2}\cdot\text{a}^{-1}$; 3, $2500\text{-}5000 \text{ t}\cdot\text{hm}^{-2}\cdot\text{a}^{-1}$; 4, $5000\text{-}8000 \text{ t}\cdot\text{hm}^{-2}\cdot\text{a}^{-1}$; 5, $8000\text{-}15000 \text{ t}\cdot\text{hm}^{-2}\cdot\text{a}^{-1}$; 6, $>15000 \text{ t}\cdot\text{hm}^{-2}\cdot\text{a}^{-1}$. a and c were calculated by rainfall erosivity in 2000, 2005 and 2010, while b and d were recalculated by rainfall erosivity in 2000.

Figure 5. Change area of different soil erosion degree in the area of northern Shaanxi (a, b) and the area of slope $>25^\circ$ (c, d).

The percentage of change area of northern Shaanxi in 1 degree was decrease with 3.23%, while other degrees were increase with 2.24%, 0.76%, 0.18%, and 0.06% in 2, 3, 4, 5 degree, respectively, and the percentage of change area in 6 degree was not obviously from 2000 to 2010 (Figure.5a). When recalculated by rainfall erosivity in 2000, the percentage of change area of northern Shaanxi in 1 degree was increase with 0.85%, while other degrees were decrease with 0.61%, 0.20%, 0.04% and 0.01%, respectively, and the percentage of change area in 6 degree was also not obviously

from 2000 to 2010 (Figure.5b).

The percentage of change area in slope $>25^\circ$ of 1 degree was decrease with 14.46%, while other degrees were increase with 0.31%, 10.83%, 2.52% and 0.80%, respectively, and the percentage of change area in 6 degree was not obviously from 2000 to 2010 (Figure.5c). When recalculated by rainfall erosivity in 2000, the percentage of change area in 1 degree was increase with 5.17%, while other degrees were decrease with 1.89%, 2.70%, 0.51% and 0.07%, respectively, and the percentage of change area in 6 degree was also not obviously

from 2000 to 2010 (Figure.5d).

Overall, the change area of soil erosion in northern Shaanxi and slope $>25^\circ$ was decrease in 1 degree, while was increase in other degrees from 2000 to 2010. When recalculated by rainfall erosivity in 2000, the change area of soil erosion in northern Shaanxi and slope $>25^\circ$ was increase in 1 degree, while was decrease in other degrees from 2000 to 2010. Vegetation cover change induced by GGP was reduce soil erosion, but due to rainfall erosivity increased, soil erosion was show increase trend in northern Shaanxi and slope $>25^\circ$ area.

4. Conclusions

As an important ecological construction and protection policy, the implementation of GGP has played important role in ecological environment. In this paper, the impact of GGP on soil erosion was evaluated by land use, MODIS NDVI, DEM, precipitation, and vegetation cover data in northern Shaanxi and the area of slope $>25^\circ$. Result showed:

(1) GGP implementation in northern Shaanxi was mainly during 1999-2003 and the area of returning farmland in the period accounted for 81.28% of the total area from 1999 to 2008.

(2) Farmland in northern Shaanxi was decrease largely with 3948.16km², while grassland was increase largely with 3229.71km². The percentage of change area of farmland and grassland was 4.94% and 4.04%, respectively. The process of decreasing farmland and increasing grassland was mainly from 2000 to 2005. Farmland in the area of slope $>25^\circ$ was decrease largely with 270.67km², while grassland was increase largely with 226.90km². The percentage of change area of farmland and grassland was 4.84% and 4.05%, respectively. The process of decreasing farmland and increasing grassland was mainly from 2000 to 2005, too.

(3) Farmland was convert into woodland and grassland from 2000 to 2010, which led to vegetation NDVI increase. Especially, the vegetation NDVI value of farmland in slope $>25^\circ$ was increase larger than whole area of northern Shaanxi.

(4) The area of soil erosion in northern Shaanxi and slope $>25^\circ$ was decrease in 1 degree, while was increase in other degrees from 2000 to 2010. When recalculated by rainfall erosivity in 2000, the area of soil erosion in northern Shaanxi and slope $>25^\circ$ was increase in 1 degree, while was decrease in other degrees from 2000 to 2010. Vegetation cover change induced by GGP was reduce soil erosion, but due to rainfall erosivity increased, soil erosion showed increasing trend in northern Shaanxi and the area of slope $>25^\circ$.

This paper has many limitations. One of the limitations is soil erosion model with not detailed analysis in the process of research, but it is an important element. There are many methods and models to calculate rainfall erosivity, soil erodibility, topographical factor, vegetation cover factor and erosion control practice factor. Different choice of methods and models would produce different result in soil erosion. Moreover, the paper only estimated macro-scale soil erosion influenced by GGP in northern Shaanxi, but the results lack of validation by

hydrological sediment monitoring data. So soil erosion model and results validation need to further be improved.

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