Gully development and its controlling factors in the Loess Plateau of China using high spatial resolution imagery

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Abstract

Gully erosion damages land resources and is one of the most significant sources of sediment to streams. The purpose of this paper is to investigate the dynamics of gully development and its primary influencing factors on the loess plateau, China. Thirty small catchments were selected from Caijiachuan basin on the eastern hilly loess plateau in western Shanxi province to compare gully development (changes of the area and perimeter of the valley region from 2003 to 2010), based on high-resolution remote sensing data (QuickBird image) and GIS. The results showed that the rate of valley area increased change from 0.12% to 1.30% per year and the rate of valley perimeter increases by between −0.89% and 1.28% per year, sidewall erosion occurs in our study area, except gully headward erosion. Pearson correlation analysis indicated that topographic factors are the main factors inducing bank gully development for catchments with lower vegetation coverage in the inter-valley area. Vegetation coverage exceeding 60% in the inter-valley area can significantly reduce gully processes. Gullies developed most rapidly in catchments with multiple land use of farmland, grassland and forestland, compared with those dominated by grassland and forestland .

Keywords: gully development；QuickBird imagery；catchment scale

1. Introduction

Gullies have been defined as channels whose width and depth do not allow for normal tillage (FAO, 1965). Gully processes have a three-dimensional nature affected by a wide array of factors and processes. Gully erosion damages land resources and leads to a loss of crop yields (Valentin et al., 2005). Gully erosion represents an important sediment source on a catchment scale, contributing on average 50–80% of sediment production by water erosion (Poesen et al., 2002). However, gully erosion rates are difficult to assess, particularly at the catchment scale. The major contribution of remote sensing to gully erosion assessment has been the visual interpretation of aerial photography. Gully boundary line was delineated from aerial photographs and gully retreat rates are assessed using multi-temporal comparison (Daba et al., 2003; Vandekerckhove et al., 2003). Some research has shown that high resolution remote sensing can be used to extract the gully boundary line and assess the gully development. Vrieling et al. (2007) used a panchromatic QuickBird image to validate permanent erosion gullies obtained from optical ASTER imagery. Li et al. (2012) used QuickBird images in 2003 and 2010 to compare changes of the area and perimeter of the gully region and the headcut development rate of gully in the eastern hilly loess plateau of China. In another aspect, vegetation restoration can result in a reduction of erosion-induced sediment yield in gullies (Li et al., 2003; Chen and Cai, 2006; Martinez-Casasnovas et al., 2009). This paper aimed to assess the gully development using high spatial resolution imagery (QuickBird image) and focus on the rates of bank gully retreat, change of gully area and the factors leading to gully development in the Loess Plateau of China.

2. Study area, data and methods

The study area, Caijiachuan basin (39.33 km^2) is located on the eastern Loess Plateau (36°14′–36°18′ N, 110°40′–110°48′ E). The elevation ranges ranging from 905 to 1580 m and 525.7 mm over the period of 2003–2010. Thirty small catchments were selected to analyze the development of gullies and its main influencing factors. In the study area, a large number of bank gullies exist on both sides of the main channel. The gully boundary line in 2003 and 2010 was extracted from QuickBird images by visual interpretation (Fig. 1).

QuickBird images acquired on Oct.21, 2003 and Oct.11, 2010 (blue, green, red and NIR of 2.44 m resolution, and PAN data of 0.61m resolution). The gully boundary line in 2003 and 2010 was extracted from QuickBird images by visual interpretation. Fusion of panchromatic and multispectral images was performed to create a 0.61m pan-sharpened image with ERDAS IMAGINE 9.2. Each individual bank gully development leads to a change of valley area. In other words,

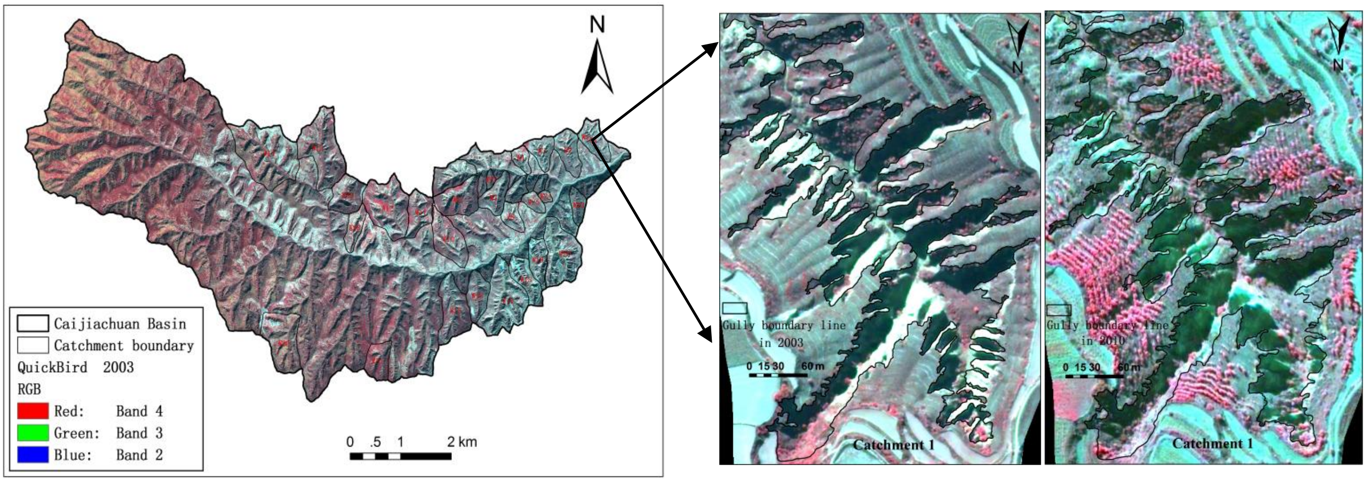

Fig.1. Location and QuickBird image of study area

the change of valley area could be considered as the sum of growth of all bank gullies for each catchment. DEM of 5m resolution was used to extract slope gradient information. Based on the NDVI, vegetation coverage was calculated according to the following equation (Qi et al., 2000):

$$fc = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soi}} \qquad (1)$$

in which, fc is vegetation coverage, $NDVI$ is the NDVI value in pixel, $NDVI_{soil}$ is the NDVI value of bare soil, and $NDVI_{veg}$ is the $NDVI$ value of pure vegetation. And we extracted the pixels in which the vegetation coverage exceeded 60% in thirty small catchments and their inter-valley regions, respectively. Land use types were classified by visual interpretation into farmland, grassland, forestland and others. According to land use types in 2003, thirty small catchments were classified into three types: multiple land use of farmland, grassland and forestland with the proportion of farmland in the small catchments larger than 15%; T2: grassland is predominant with a proportion larger than 50%; T3: dominated by forestland with its proportion being larger than 50% (Fig. 2).

3. RESULTS AND DISCUSSION

From 2003 to 2010, the values for valley area increase rate change from 0.12% to 1.30% per year, and the rate of valley perimeter change by between −0.89% and 1.28% per year. 60% of the valley perimeter of 30 catchments increased by 0–1.28% per year, while for 40% of them there was a decrease by −0.89% to 0% per year. The disappearance of some narrow inter-gully area, which was obvious on the images, accounted for the decrease of valley perimeter (Fig. 3). It means that sidewall erosion occurs in our study area, exceptgully headward erosion. The rate of valley area increase was related to land uses with increases of 0.53%, 0.52% and 0.28% per year for catchment type 1, catchment type 2 and catchment type 3, respectively. Gullies developed most rapidly in catchments with multiple land use of farmland, grassland and forestland, compared with those dominated by grassland and forestland.

Pearson correlation analysis indicated that topographic factors are the main factors inducing bank gully development for catchments with lower vegetation coverage in the inter-valley area. For catchment type 1 (T1) with multiple land use, there are significant positive correlations between the rate of valley area increase and the inter-valley area ratio (R_{int}) and slope gradient of the inter-valley area (S_{int}) ($p<0.01$). For catchment type 2 (T2) with >50% grassland, apart from R_{int} and S_{int}, the rate of valley area increase was significantly correlated with the proportional change of area with vegetation coverage exceeding 60% in the inter-valley region from 2003 to 2010 (C_{g60}) at the level of 0.05. For catchment type 3 (T3) with >50% forestland, the rate of valley area increase is not correlated significantly to R_{int} and S_{int} but to C_{g60} significantly at the level of 0.01 (Table 1). Previous studies clearly showed that aboveground vegetation could reduce gully incision by concentrated flow, but few studies have demonstrated what level of vegetation coverage in the inter-valley region will be the most beneficial for controlling gully-system expansion. Through above analysis, we suggest that vegetation coverage exceeding 60% in the inter-valley region is efficient for increasing the drainage area needed for gully development, and can be the objective for vegetation restoration in the gully and hilly Loess Plateau.

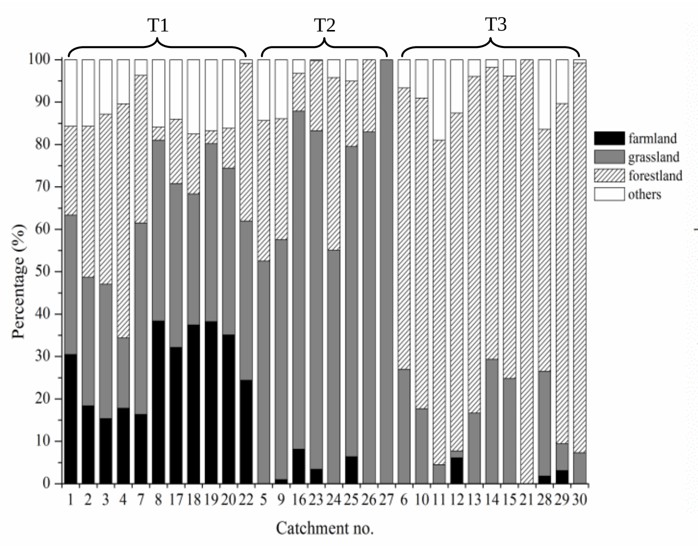

Fig. 2.The percentage of land use in the 30 catchments in 2003

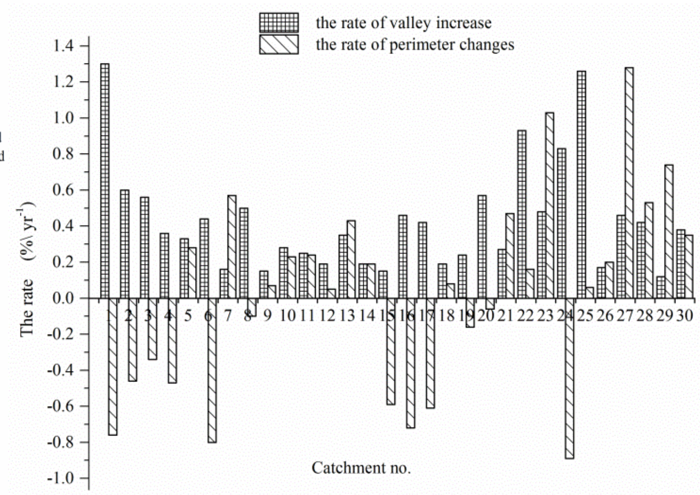

Fig. 3.The rate of gully development in 30 catchments

Table1 Correlation coefficients between the rate of valley area increase and the influencing factors for different types of catchments

Catchment types	R_{int} (ha/ha)	S_{int}(m/m)	C_w(%)	C_g (%)	C_{w60} (%)	C_{g60} (%)
T1 (*n* =11)	0.755 [a]	0.777 [a]	−0.406	−0.245	−0.355	−0.336
P	0.007	0.007	0.215	0.467	0.285	0.312
T2 (*n* = 8)	0.813 [b]	0.710 [b]	−0.480	−0.602	−0.574	−0.707 [b]
P	0.014	0.049	0.229	0.115	0.137	0.050
T3 (*n* = 11)	−0.422	−0.132	0.004	−0.245	−0.213	−0.639 [b]
P	0.196	0.699	0.992	0.710	0.530	0.034
Total (*n* = 30)	0.570 [a]	0.683 [a]	−0.304	−0.277	−0.506 [a]	−0.535 [a]
P	0.001	0.000	0.102	0.138	0.004	0.002

[a] $p<0.01$,[b]$p<0.05$;

R_{int} is the inter-valley area ratio in 2003; S_{int} is the slope gradient of inter-valley area; C_w is the proportional change of the average vegetation coverage in catchment; C_g is the proportional change of the average vegetation coverage in the inter-valley; $C_{w60}$is the proportional change of area with vegetation coverage exceeding 60% in catchment from 2003 to 2010; C_{g60} is the proportional change of area with vegetation coverage exceeding 60% in inter-valley region from 2003 to 2010.

T1: multiple land use of farmland, grassland and forestland with the proportion of farmland in the small catchments larger than 15%; T2: grassland is predominant with a proportion larger than 50%; T3: dominated by forestland with its proportion being larger than 50%.

4. Conclusions

The change of valley area was considered as the sum of growth of all bank gullies for each catchment and the distance between each gully head in 2003 and 2010 as the gully retreat distance. In the thirty investigated catchments, and the rate of valley area increase in each catchment ranged from 0.12% to 1.30% per year, and the rate of valley perimeter increases by between −0.89% and 1.28% per year. Sidewall erosion occurs in our study area, except gully headward erosion. The gully area increased more quickly in catchments where the proportion of farmland is larger than 15% (0.53% per year) and in catchments dominated by grassland (0.52% per year) than in catchments dominated by forestland (0.28% per year). The correlation analysis indicated that topographic factors were the main ones for inducing bank gully development for catchments with lower vegetation coverage in the inter-valley area, and topography effects on gully development decreased as the vegetation coverage increased. Vegetation coverage exceeding 60% in the inter-valley area can significantly reduce gully erosion rate, so we suggest that vegetation coverage exceeding 60% can be the objective for vegetation restoration to soil and water loss conservation in the gully and hilly Loess Plateau.

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