

Impact of fractional vegetation cover change on soil erosion in Miyun reservoir basin, China

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Abstract It is well known that soil erosion at the watershed scale is the result of interactions between various factors. Among these environmental factors, vegetation is the most important and plays a major role in the soil erosion process. The impact of fractional vegetation cover change (FVCC) on soil erosion in non-contributing areas is a heavily discussed topic. In this paper, the fractional vegetation cover (FVC) in 2002 and 2005 was calculated by using a backpropagation neural network based on remote sensing (RS) data. Then the impacts of FVCC on sediment loads at the outlets of two Miyun reservoir sub-basins were evaluated by integrating RS and geographic information system with statistical analysis. The Miyun reservoir basin (MRB) is characterized by hilly and mountainous topographies and seasonal rainy weather. The primary goal of this paper is to gain a better understanding of FVCC, its driving forces, and its impact on regional soil erosion. We discuss spatiotemporal variations in precipitation and soil erosion, identify which factors contribute to those variations, analyze the influences of FVCC on climate change and human activities and, finally, conclude that changes in FVC and climate regimes are primary factors for soil erosion in MRB. We also discuss how

sediment loads may be used to quantitatively separate biophysical and anthropogenic influences and to identify critical thresholds that might have dramatic consequences for the watershed ecosystem. These findings should be quite helpful for sensible watershed development and management planning.

Keywords Fractional vegetation cover change analysis · Soil erosion · BP neural network · Miyun reservoir basin

Introduction

The sediment production at the watershed scale is a result of interactions between various factors (Woodward and Foster 1997; Yang and Liang 2004; Chakrapani 2005). Among these environmental factors, vegetation is the most important due to its role in the soil erosion process (Wei et al. 2002; Cai and Li 1998; Yu et al. 1997; Sun 1989; Li et al. 1998; Wu and Zhao 2001). Vegetation can minimize kinetic energy by intercepting raindrops with leaves, while strong root distribution can improve soil structure, enhance soil infiltration capability, slow runoff velocity, and reduce the sediment transport capacity of surface runoff (Wei et al. 2002). Fractional vegetation cover (FVC) is often used to assess the degree of water and soil conservation (Zhang et al. 2002).

Due to the limitations of observation and the experimental method, research into the relationships between vegetation and soil erosion is primarily conducted on runoff plots and at the sample scale (Wu and Zhao 2001). However, at the basin scale, sediment production is a complex process involving interactions between many factors, such as climate, FVC, soil erosion rate, and others. Previous studies have shown that the fractional vegetation

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cover change (FVCC) affects not only sediment sources and the rate of soil erosion (Woodward and Foster 1997), but also the total amount of sediment produced by soil erosion (Yang and Liang 2004). Moreover, rapid FVCC will also affect the basin runoff sediment yield. It has been demonstrated that the variation of FVC is the key factor affecting both regional soil erosion and changes in erosion (Syvitski 2003). In addition to the impacts of FVCC and human activities, climate change is another driving force behind changes in basin soil erosion.

The Miyun reservoir, on Chaobaihe River, is the main surface source of drinking water for the 14.93 million inhabitants of Beijing, the capital of China. Water and soil losses from agricultural, pastoral, and forestry lands are the main causes of sediment entering the reservoir. These processes may impact the safety of the Beijing water supply and the operation and life span of the reservoir (Zhou and Wu 2005; Sun et al. 2011, 2012; Yao et al. 2011). In terms of erosion, the soils are under a serious risk due to hilly topography, soil conditions facilitating water erosion (i.e., fine texture, low organic matter, and poor plant coverage due to semi-arid climate), and inappropriate agricultural practices (e.g., excessive soil tillage and cultivation of steep lands). These widespread problems threaten the sustainability of agricultural productivity in the Miyun reservoir basin (MRB), where diverse, economically important crops are produced. To protect the water quality, it is necessary to reduce soil erosion and improve the environment upstream of Miyun reservoir (Yang et al. 2005; Tang et al. 2013). Because of the large areas that suffered or are suffering from soil erosion, determining the impact of FVCC on soil erosion is very important for improving endangered areas and deciding which types of conservation measures to apply.

With the development of remote sensing (RS) and geographic information system (GIS) technology, FVC can be obtained more conveniently and effectively and its change can be tracked. At present, satellite image-processing technology has been used in a range of different scales to detect surface FVCC. Through these techniques, researchers can make spatial and temporal comparisons of biophysical parameters. In recent years, computer simulation models have been increasingly used for regional estimates of soil erosion and sediment transport.

In this paper, a backpropagation (BP) neural network is used to map FVC in 2002 and 2005. The results are compared with values measured in the field. The study area was also divided into two sub-basins and the mean FVC of each sub-basin in each year was calculated. The annual sediment loads of each sub-basin were obtained from two hydrological stations. By combining these datasets, the objective of this study is to examine the spatial distributions of FVC in MRB and FVCC during 2002 and 2005, as

well as to quantify the relationship between FVCC and changes in regional sediment loads over the same years. Ultimately, the goal is to determine the main factors that influence changes in regional sediment loads.

Materials and methods

Description of the study area

The MRB is located in the northern area of Beijing (Fig. 1) between 40°19′–41°38′ N and 115°25′–117°35′ E, with an area of about 15,788 km². The northwestern portion of the study area is gently mountainous, while the southeastern portion is mainly hilly and partially plain. The elevation varies between 150 and 1,800 m above sea level.

The weather conditions in the area reflect typical continental monsoon climate with 488.9 mm average annual precipitation. Precipitation generally decreases from southeast to northwest and falls primarily between July and September. The annual average temperatures in the upper and lower watersheds are 9 and 25 °C, respectively.

In this region, the soil layer is thin. According to the Chinese soil taxonomy (Chinese Soil Taxonomy Research Group 1995), the main soil taxa are mountain meadow soil, brown forest soil, and cinnamon soil. The average annual soil erosion measured at the reservoir (Chinese River Sediment Bulletin 2006) is 12–16 ton/ha and the yearly quantity transported in bedload is about 5.72 million tons. The region suffers severe soil erosion and is considered a priority area for soil conservation in China in the twenty-first century (Chinese River Sediment Bulletin 2006).

Satellite data

In total, four scenes of Landsat 5 TM images and four scenes of Landsat 7 ETM+ images at a spatial resolution of 30 m were used to estimate the FVC in this study (Table 1).

Sediment loads data

Sediment loads data were obtained from two hydrological stations. Because the hydrological stations are on the Chaohe River and Baihe River, the MRB was divided into two sub-basins, the Chaohe sub-basin and the Baihe sub-basin (Table 2).

The sediment loads data from the Chinese River Sediment Bulletin 2002–2005 is shown in Table 3. Because the sediment loads data from each hydrological station are that of the entire upstream basin, the data were not interpolated, the results were used as the annual sediment discharge of each sub-basin.

Fig. 1 Location of the study area

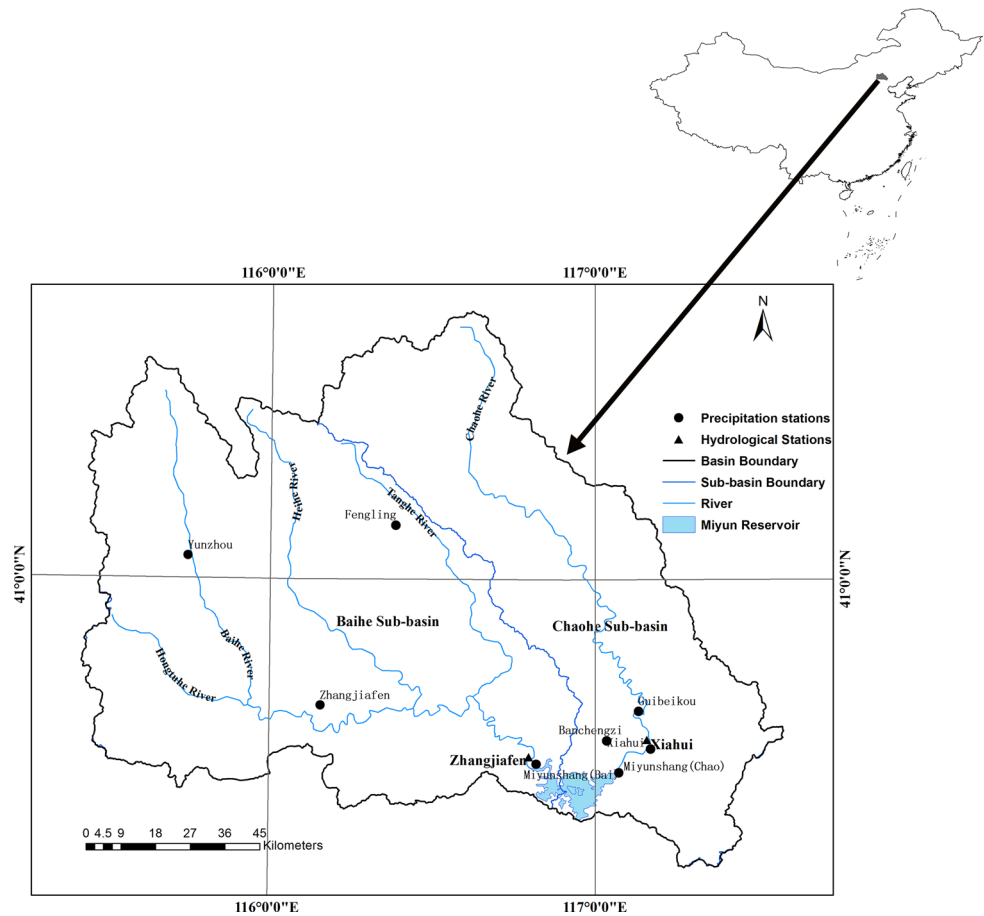


Table 1 Landsat images used in this study

Image	Path/row	Date
Landsat 5 TM	123–031	2001.10.19
	123–032	2000.10.20
	124–031	1999.10.28
	124–032	2000.10.27
Landsat 7 ETM+	123–031	2005.11.14
	123–032	2005.11.14
	124–031	2005.11.21
	124–032	2005.11.21

Table 2 Area and hydrological station of each sub-basin

Sub-basin	River	Hydrological station	Area of sub-basin (km ²)
Chaohe sub-basin	Chaohe River	Xiahui	6,229.71
Baihe sub-basin	Chaohe River	Zhangjiafen	9,550.45

Table 3 Sediment loads measurement in each hydrological station from 2002 to 2005

Hydrological station	Sediment loads (10 ³ tons)			
	2002	2003	2004	2005
Xiahui	0	5.8	5.0	27.7
Zhangjiafen	1.2	42.8	16.7	1.36

Precipitation data

The average annual precipitation data in each sub-basin from 2002 and 2005 were obtained from the following procedure. First, rainfall data from eight precipitation stations in the MRB from 2002 and 2005 were obtained from Hydrology and Water Resources Scientific Data Sharing Network (<http://www.hydrodata.gov.cn>). These data were then binned into 10-day increments to produce 3 precipitation data points per month and 36 points per year from each precipitation station. Next, using the spline

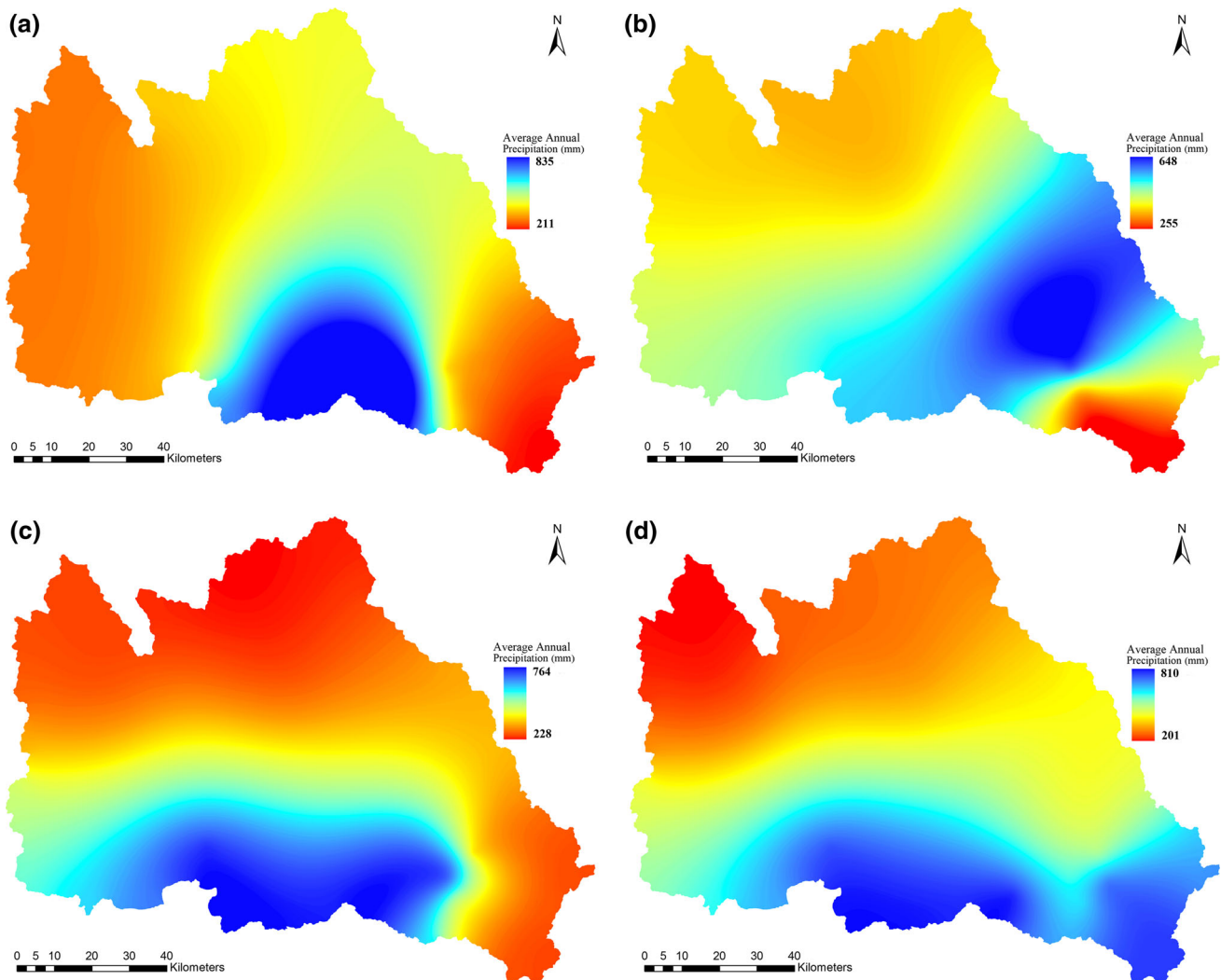


Fig. 2 **a** Spatial distribution map of average annual precipitation in 2002. **b** Spatial distribution map of average annual precipitation in 2003. **c** Spatial distribution map of average annual precipitation in 2004. **d** Spatial distribution map of average annual precipitation in 2005

Table 4 Average annual precipitation of each sub-basin from 2002 to 2005

Sub-basin	Average annual precipitation (mm)			
	2002	2003	2004	2005
Chaohe sub-basin	358	498	427	432
Baihe sub-basin	403	492	589	506

interpolation method, 36 precipitation data layers were obtained for the whole basin over 1 year. Finally, the spatial distribution maps of average annual precipitation from 2002 to 2005 were obtained using the zonal statistics method in ArcGIS software (Fig. 2a–d).

By dividing the MRB into two sub-basins, the average annual precipitation of each sub-basin is shown in Table 4.

FVC data

A BP neural network was used to calculate the FVC in 2002 and 2005 (Chen et al. 2011), and the FVC map in each year is shown in Figs. 3 and 4.

Results and discussion

Annual precipitation during 2002 and 2005

From the annual precipitation distribution maps (Fig. 2), it was shown that the spatial distribution of annual precipitation is very different between 2002 and 2005. Additionally, the variation in precipitation at each station also changes. From the average annual precipitation data of each sub-basin (Fig. 5), it is clear that the

Fig. 3 FVC map of the study area in 2002

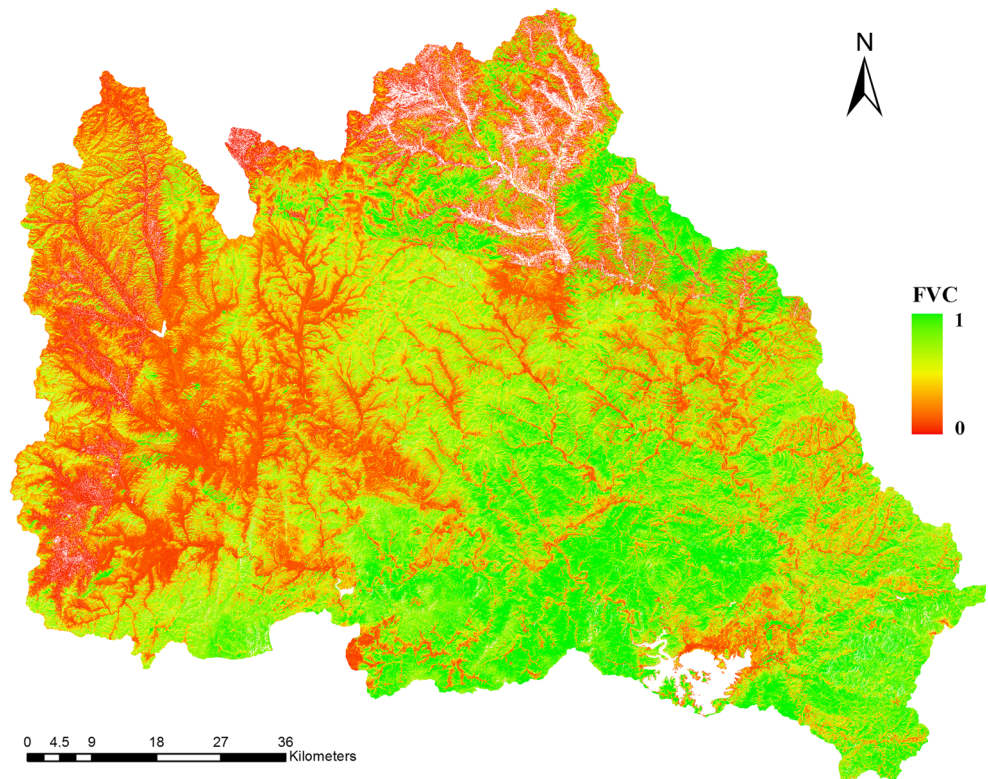
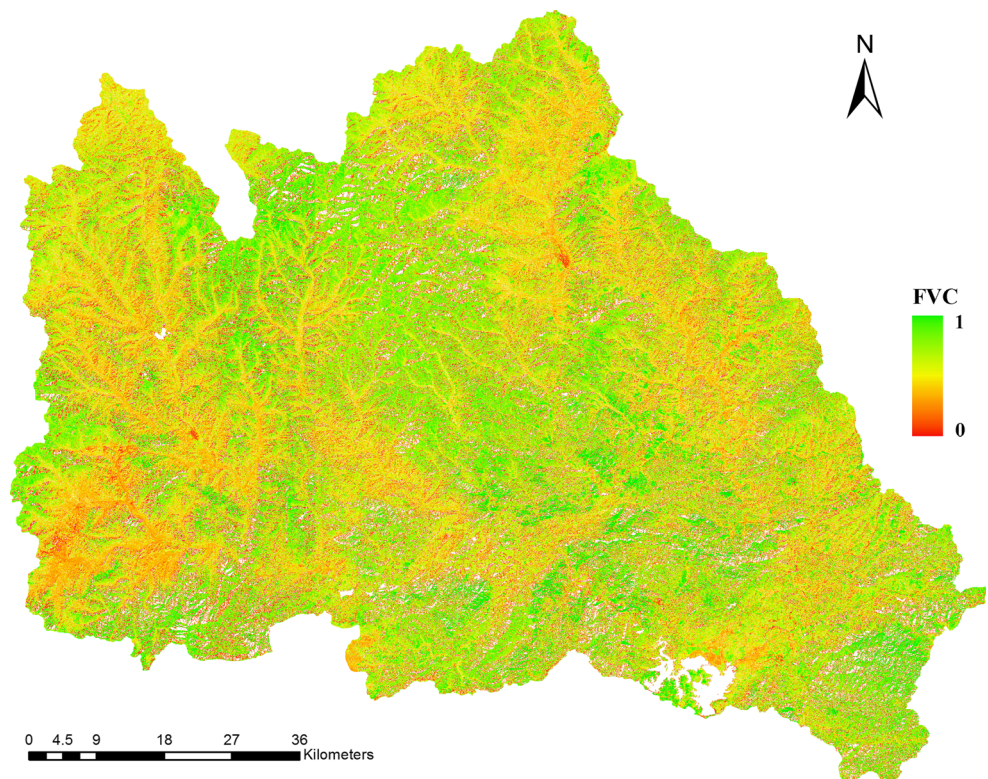


Fig. 4 FVC map of the study area in 2005



annual precipitation in 2005 is higher than that in 2002 and the precipitation in the Baihe sub-basin is higher than in the Chaohe sub-basin. This latter relationship

fits the meteorological pattern of the overall basin, wherein precipitation decreases from southeast to northwest.

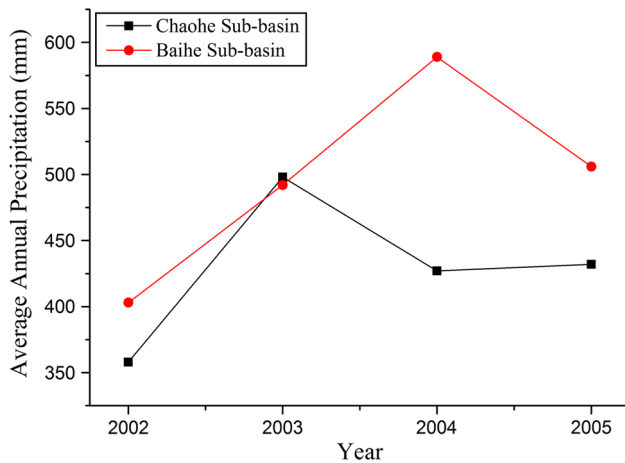


Fig. 5 Average annual precipitation in each sub-basin from 2002 to 2005

Table 5 Average FVC and FVCC of each sub-basin in 2002 and 2005

Sub-basin	Average FVC in 2002	Average FVC in 2005	FVCC
Chaohe sub-basin	0.451	0.544	0.093
Baihe sub-basin	0.424	0.553	0.129

FVC and FVCC of each sub-basin in 2002 and 2005

From Figs. 3 and 4, it is easily found that FVC values within the MRB are higher in the southeast than the northwest and highest in the middle northern, middle southern, and southeastern portions of the basin. By dividing the basin into two sub-basins, the average FVC of each sub-basin and FVCC in 2002 and 2005 were calculated (Table 5).

From Table 4, it is shown that the average FVC is higher in the Chaohe sub-basin than in the Baihe sub-basin in 2002, but lower in 2005. The FVCC of the two sub-basins is 0.093 and 0.129, respectively. These data imply that the growth rate of vegetation in the Chaohe sub-basin is slower than that in the Baihe sub-basin.

Fractional vegetation cover change can be affected by two main factors: natural conditions and social and economic development. In the short term, social and economic development can affect FVCC more than natural conditions (Han et al. 2004). With the development of a social economy, farmland is progressively converted to schools, roads, hospitals, and other buildings, while at the same time, a growing population demands more food. To balance these competing forces, farmers must clear forests and fill lakes to maintain the necessary quantity of cultivated land. All of these factors cause changes in land use and

FVC. In 1995, the population of Miyun Basin was 878,000 and the level of urbanization was 8.3 %. By 2002 and 2005, the urbanization level had risen to 11.4 and 21.3 %, respectively. Although the level of urbanization increased rapidly between 2002 and 2005, it was still far below the same years' national average urbanization levels of 36.1 and 43 %, respectively (Ye et al. 2003).

Annual sediment loads analysis in MRB

Sediment transport is a very important process. Subject to direct or indirect factors, it can cause FVCC through water loss, soil erosion, sediment deposition, and other hydraulic effects. Water flow and sediment discharge tend to vary with basin topography, rainfall, vegetation coverage changes, soil erosion, and landform characteristics.

In the MRB, there are distinct dry and wet seasons. The dry season is characterized by continuous low sediment discharge and the wet season by continuous high sediment loads and a fivefold increase in suspended sediment flux. These data suggest that if land use is held constant, the spatial distribution of rainfall and sediment load should also be constant in the basin. Therefore, regardless of precipitation factors, the FVCC can be considered another important effect of the change in sediment loads.

The measured sediment loads at each hydrological station reflects the degree of regional water loss and soil erosion of each sub-basin. The area of each sub-basin is different (Table 1); the area of the Baihe sub-basin (9,550.45 km²) is 1.5 times larger than that of the Chaohe sub-basin (6,229.71 km²). The main contribution of sediment loads in the MRB is from the Baihe sub-basin and, overall, has increased with time (Fig. 6). The Baihe sub-basin's peak sediment load of 42,800 tons appeared in 2003, while the sediment load data for the other 3 years

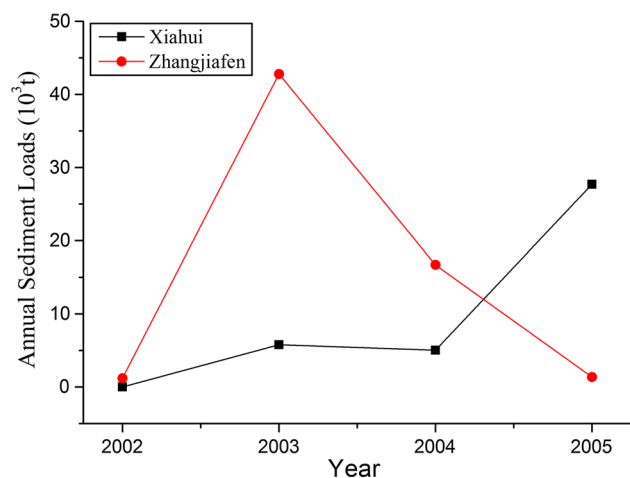


Fig. 6 Annual sediment loads in each sub-basin from 2002 to 2005

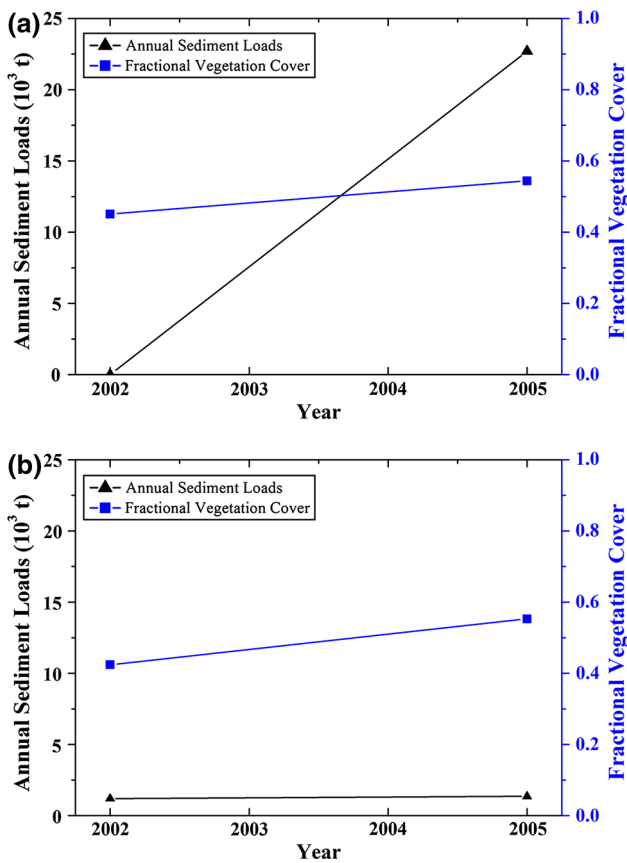


Fig. 7 **a** Relationship between annual sediment loads and FVC in Chaohe sub-basin in 2002 and 2005. **b** Relationship between annual sediment loads and FVC in Baihe sub-basin in 2002 and 2005

never exceeded 20,000 tons. The trend in sediment loads appears to first increase and then decrease, while following an overall decreasing trend. However, in the Chaohe sub-basin, sediment loads increase with time. Therefore, it is shown that in the MRB, the main contributor of annual sediment loads varies with time. From 2002 to 2004, the primary contributor of sediment is the Baihe sub-basin, while in 2005 it is the Chaohe sub-basin. This shift suggests that artificial factors dominated in the Baihe sub-basin prior to 2004, but shifted to the Chaohe sub-basin in 2005.

Relationship between FVCC and sediment loads

The data show that both FVC and annual sediment loads in both sub-basins increase between 2002 and 2005 (Fig. 7). This relationship is unexpected, as it would be expected that increased FVC would decrease soil erosion and therefore decrease sediment load. Moreover, the sediment loads increased faster than the FVC. It is concluded that the FVCC in the mountainous area is not the primary factor affecting the annual sediment loads in the MRB. This

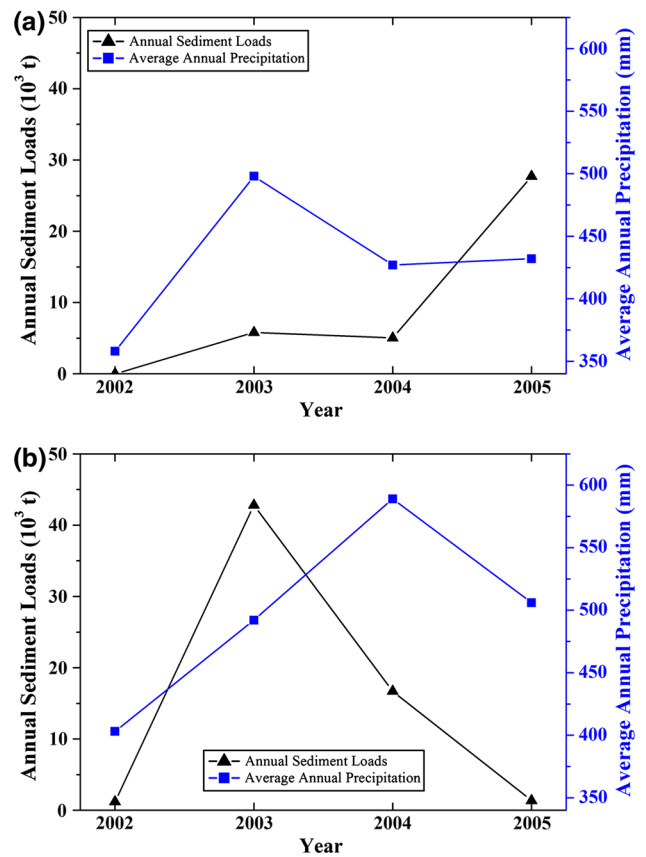


Fig. 8 **a** Relationship between annual sediment loads and average annual precipitation in Chaohe sub-basin from 2002 to 2005. **b** Relationship between annual sediment loads and average annual precipitation in Baihe sub-basin from 2002 to 2005

conclusion agrees with the findings of Restrepo and Syvitski (2006).

Relationship between precipitation and sediment loads

There is an interesting relationship between average annual precipitation and the annual sediment loads at the two hydrological stations (Fig. 8). Both factors present similar fluctuations over time (Fig. 8a), which can be interpreted as the influence of climate change on sediment loads. However, the annual sediment loads in the Chaohe sub-basin suddenly increased fourfold from 5 thousand tons in 2004 to 27.7 thousand tons in 2005. Simultaneously, average annual precipitation actually decreased from 2004 to 2005. The economy of Hebei Province, however, maintained a rapid growth rate of 67.76 %, jumping from 601.83 billion Yuan in 2002 to 1.01 trillion Yuan in 2005. It is concluded that the sudden increase in annual sediment loads in the Chaohe sub-basin can be considered a result of economy growth and human activities. In the Baihe sub-basin (Fig. 8b), annual sediment loads and average annual precipitation fluctuate differently over time. For instance,

Table 6 Average annual precipitation, FVC and annual sediment loads in each sub-basin in 2002 and 2005

Sub-basin	Hydrological station	Average annual precipitation (mm)			FVC			Annual sediment loads (10 ³ tons)		
		2002	2005	Change	2002	2005	Change	2002	2005	Change
Chaohe Sub-basin	Xiahui	304	664	360	0.451	0.544	0.093	0	27.7	27.7
Baihe Sub-basin	Zhangjiafen	374	685	311	0.424	0.553	0.129	1.2	1.36	0.16

in 2003, a large increase in annual sediment loads occurs without a corresponding increase in average annual precipitation. The phenomenon may have been caused by a 2003 rainstorm that occurred in the Baihe sub-basin. In 2004, annual sediment loads markedly decreased, while average annual precipitation increased; in 2005, annual sediment loads dropped sharply, from 16,700 to 1,360 tons. This sharp decline was most likely caused by decreased precipitation and is expected from the increase in FVC (Table 5).

In Table 6, we detail the average annual precipitation, FVC and annual sediment loads in each sub-basin in 2002 and 2005. It is shown that increased average annual precipitation and FVC produced different levels of increased annual sediment loads in the two sub-basins: a sharp increase in the Chaohe sub-basin, but only a slight increase in the Baihe sub-basin. Because production of sediment in the basin is such a complex process, we cannot give a satisfactory explanation for all phenomena, but it is certain that FVCC is the main factor responsible for soil erosion.

Conclusion

More quantitative information is needed at the watershed scale to help governing bodies make appropriate decisions. It is difficult to distinguish the effects of FVCC in an area with a warm, temperate, semi-humid, continental monsoon climate, such as the MRB, which has suffered from sandstorm and extremely severe soil erosion in recent years. In this paper, the relationship between FVCC and annual sediment loads is discussed. RS, GIS and statistical analysis method is used to study FVCC, sediment loads and the driving force between them.

The results show that the sediment loads in two sub-basins in the MRB are a reflection of precipitation and anthropogenic FVCC. With RS technology, FVC can be calculated in different years in the MRB. Societal issues (population growth, economic development and urbanization) have also been identified as primary driving factors of FVCC in the MRB.

From our results, it can be concluded that vegetation can significantly reduce the sediment concentration in rivers in mountainous areas with more vegetation and lower

urbanization levels. This finding strongly supports the implementation of Grain for Green Program in China. Because the level of urbanization in the MRB during the study period was far lower than the national average, we cannot know how higher levels of urbanization affects sediment loads. Additionally, a more reliable method needs to be developed to calculate FVC; this will make the calculation of FVCC more robust. Lastly, it is found that sediment loads can be used to quantitatively separate the biophysical and anthropogenic influences and to identify critical thresholds that may lead to dramatic changes in the watershed ecosystem. These findings should be quite useful for sensible watershed development and management planning.

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