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Effect of forest on sediment yield in North China

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Abstract

Forest-sediment relationship is a hot and important issue in Ecohydrology studies. China has implemented many large-scale reforestation programmes in the last decades to address the growing soil erosion and desertification. In this study, we made statistical and graphic analyses on the long-term hydrological data of the 39 watersheds in the rocky mountain area of the North China, and then we were able to analyze the effect of forest on sediment yield. Our results show that the effect is weak in the less-precipitation regions (when MAP < 500 mm). And in the more-precipitation regions (when MAP > 500 mm), the impact of forest on reducing sediment yield is different with the varied forest coverage (f), the relationship between the sediment yield and forest coverage show a quadratic polynomial.

Key Words: North China, Forest, Sediment yield, Effect

1 Introduction

In the past century, research on forest-sediment relationship has made great progress worldwide. Even today, this topic remains a hot issue in ecohydrology studies. Loss of forest is a major environmental concern worldwide. On steeper lands, loss of tree cover may allow increased soil erosion, by surface runoff, gullying and land sliding, and a consequent increase in sediment delivery to the river system and in basin sediment yield (James et al., 2007). So it would be helpful to have a research of forest effects on sediment yield.

With the worsening of the environment and the awareness of the ecological benefits of forests, many countries or regions are actively conducting reforestation effort to increase forest coverage (Scott et al., 1998; Jackson et al., 2005; Sun et al., 2006). Soil erosion is a serious environmental problem in China, to solve the growing soil erosion and desertification, China had implemented many large-scale reforestation programmes in the last decades, and the total investment reached ￥720 billion (114 billion dollars) (Yao et al., 2011). The successful of using forestation programs to solve ecological problems in China has attracted considerable worldwide attention. At the same time, it forced many researchers and officials to pay more attention to the effects of forest on sediment, especially in the semi-arid and developed North China (Bi et al., 2009).

North China has developed economy and serried cities (e. g. Beijing), and is an important region in Chinese economic development. Understanding and predicting the effects of forest on sediment yield from catchments is indispensable for the safety of the cities, and supporting policy decisions dealing with off-site effects of soil erosion such as sediment deposition within river channels and reservoirs, flooding, coastal development, and contamination of floodplains and water bodies with agrochemicals and other pollutants associated with the eroded sediments (Clark, 1985; Owens et al., 2005; Ramos and Martinez-Casasnovas, 2004; Stenngen et al., 2001; Syvitski and Milliman, 2007; Verstraeten and Poesen, 1999; Woodward, 1995).

So far, many studies on sediment yield have been conducted in small-scale catchments of less than 100 km^2 (Gao et al., 2007; Lefrancois et al., 2007; Estrany et al., 2009; Deasy et al., 2009). And some studies have attempted to explain the global pattern of sediment yield in terms of vegetation (Douglas, 1967; Jansen and painter,

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1974; Zheng, 2006; Chen and Cai, 2006) and land use (Trimble, 1975; Dunne, 1979; Verstraeten and Poesen, 2001). Many recent investigations have sought to explain sediment yield on the basis of the combined effect of the morphometric, climatic and hydrologic variables of drainage basins (Lu and Higgitt, 1999; Phippen and Wohl, 2003; Verstraeten et al., 2003; Tamene et al., 2006; Restrepo et al., 2006; Molina et al., 2008; Ali and Boer, 2008). However, less attention has been paid to the effects of forest on sediment yield in larger catchments, where have many difficulties such as spatiotemporal variability in climatic conditions, land use and soil texture (Chantha et al., 2010). The main purpose of this paper is to detect the effect trend of forest on sediment yield in the catchments which is < 1000 km^2. A further objective is to introduce a better understanding of forest-sediment relationship, and provide a basis for future forestry development.

2 Materials and methods

2.1 *Study area*

The study area is the rocky mountain area in North China, bounded by 35°4′–40°11′N and 111°41′–120°17′ E. As the water source area of Beijing and many other cities, it has important study significance. The total area is 264, 832. 7km^2 and accounts for 2. 7% of the entire land area of China. The topography of the region is characterized by low mountain and hill landscapes. The elevation varies from 1 to 2, 940 m. The soil texture is dominated by cinnamon soil. Different from other regions, the soil layer is very thin (< 1 m). The forest coverage in this region is low (about 20% – 30%), main variety is broadleaved deciduous forest.

This region has a semi-humid continental monsoon climate with a mean annual temperature of 12℃. Rainfall in this area is highly variable, both spatially and temporally. The mean annual rainfall generally ranges from 350 mm to 800 mm. More than 85% of the rain falls between June and October.

Xin et al. (2010) summarized 15 factors that affected the watershed sediment yield. Our study area is not too large, the differences of the factors such as climate, topography, geography and vegetation in this area is not very obvious. In North China, there are four main factors which affect the watershed sediment yield: precipitation, forest, slope, watershed area. In order to weaken the interference of the slope, we chose watersheds with similar slope; many researches indicate that 1, 000 km^2 may be the threshold to analysis the forest effects (Murray et al., 2010; Oudin et al., 2008; Donohue et al., 2007). Therefore, in this study, we only select the watersheds of $< 1, 000$ km^2. Ultimately, we had selected the 39 eligible watersheds. Their information is shown in Table 1.

Table 1 Collected data sets from the selected watersheds

ID	Watershed	MAP (mm)	Forest coverage (%)	Sediment yield (t/km^2)	Time period	Mean slope (°)
1	Fengzhen	399. 28	2. 46	806. 09	1960 – 1991	1. 6
2	Huili	482. 93	14. 97	120. 06	1971 – 1991	4. 6
3	Lengkou	705. 84	27. 96	369. 58	1960 – 1984	3. 6
4	Liujiaping	562. 76	6. 16	158. 02	1971 – 1991	4. 8
5	Beizhangdian	562. 92	31. 39	1, 300. 22	1965 – 1991	2. 2
6	Nantuling	393. 58	15. 70	315. 03	1964 – 1991	4. 6
7	Koutou	701. 99	37. 55	911. 16	1960 – 1979	3. 9
8	Tangshan	615. 96	6. 60	20. 54	1962 – 1991	0. 8
9	Weichang	435. 27	27. 89	1, 242. 31	1960 – 1991	3. 7
10	Dahekou	390. 51	0. 53	11. 59	1960 – 1991	1. 3
11	Daqinggou	366. 86	13. 92	334. 20	1960 – 1970	3. 8
12	Fuguizhuang	665. 72	11. 57	95. 03	1961 – 1991	1. 3
13	Siping	501. 98	16. 88	121. 51	1980 – 1991	4. 4
14	Yuhekou	675. 67	85. 98	54. 50	1960 – 1991	4. 2
15	Yumenkou	706. 41	59. 41	199. 92	1962 – 1991	4. 7

Continue

ID	Watershed	MAP (mm)	Forest coverage (%)	Sediment yield (t/km^2)	Time period	Mean slope (°)
16	Yakou	725.18	8.16	190.08	1964 – 1991	2
17	Pingquan	533.60	2.23	578.88	1960 – 1991	3.3
18	Lijiaxuan	663.51	10.94	205.38	1960 – 1976	1.3
19	Liying	632.92	20.89	438.08	1960 – 1991	4.1
20	Yangjiaying	657.40	7.34	270.22	1960 – 1991	1.6
21	Zhenzizhen	641.16	8.92	80.88	1960 – 1991	1.4
22	Shuipingkou	750.39	21.53	157.65	1960 – 1991	2.5
23	Nihe	750.18	19.95	228.83	1960 – 1973	3.7
24	Manshuihe	648.52	45.80	54.56	1960 – 1991	4.9
25	Wangjiahui	465.81	16.47	412.26	1960 – 1991	4.9
26	Wangan	597.44	13.50	43.92	1976 – 1991	4.5
27	Shifokou	656.77	16.67	101.18	1963 – 1991	1.4
28	Shizhandao	569.71	12.96	996.27	1960 – 1991	2.4
29	Shimen	544.25	6.42	563.58	1960 – 1991	3.6
30	Luozhuangzi	769.23	66.79	83.47	1974 – 1991	4.6
31	Luzhuang	457.62	16.12	1,945.59	1971 – 1991	4.6
32	Lanqiying	767.80	46.03	149.61	1960 – 1991	4
33	Caijiazhuang	560.95	21.23	695.68	1960 – 1991	2.3
34	Douluoqiao	456.09	6.42	1,159.89	1960 – 1991	3.5
35	Zhaojiagang	627.15	0.33	1.82	1980 – 1991	0
36	Bianqiangshan	441.91	20.22	2,454.62	1963 – 1991	3.1
37	Yangquan	525.11	5.73	1,965.33	1971 – 1991	2.7
38	Qingbaikou	424.19	72.06	15.46	1963 – 1991	4.7
39	Macun	505.69	0.37	44.96	1971 – 1991	1.2

2.2 *Data*

All the annual precipitation and sediment data were obtained from Hydrological Yearbook of PR China, although the data have not been published, they have already been printed and issued for internal use. In order to ensure the quality of data sets, we also make reference to the relevant data from China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/). The digital elevation model (DEM) of this region was used to delineate the catchment boundaries of all catchments, and has a resolution of 90 m × 90 m. The DEM and forest cover data are both derived from Data Sharing Infrastructure of Earth System Science (http://www.geodata.cn/).

2.3 *Methods*

In this paper, we used statistical and graphic analyses to make the whole study.

3 Results

3.1 *The division of studied basins by precipitation and forest coverage*

Precipitation is the source of runoff, and it's also the main impact factor of the forest cover. An analysis in sub-regions or basin groups with different MAP may be helpful in further improving our understanding of forest effects (Wang et al., 2011). Therefore, the study basins are divided into two parts in the following study, which are the less-precipitation basin group and the more-precipitation basin group.

All basins were selected to show the linear relationship between the MAP and mean annual sediment yield (Fig. 1). The results indicate that, the data sets could be apparently divided into two parts.

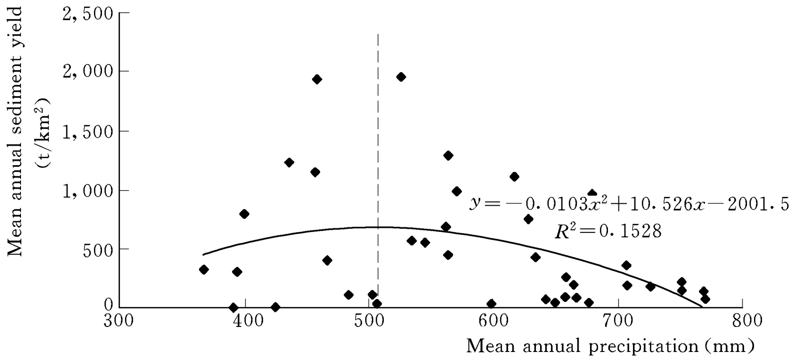

Fig. 1 Relationship between sediment yield and precipitation

Generally, more forests usually with higher annual precipitation. Similar to the results of Wang et al. (2011), by plotting the forest coverage and mean elevation of all basins, there is no significant relation between them (R^2 = 0.0022, not shown here). This indicates that the forest coverage in the rocky mountain area of the north China is less controlled by temperature, instead, it seems to be mostly determined by the annual precipitation (Fig. 2). When the MAP is < 500 mm, the forest coverage is generally within 0 – 20% and increases slowly with MAP, probably because the forests can only grow on limited wet sites such as riparian zones and the adjoining lowest segment of slopes associated with valley bottoms. On the other hand, when the MAP is > 500 mm, the forest coverage is higher and increases quickly.

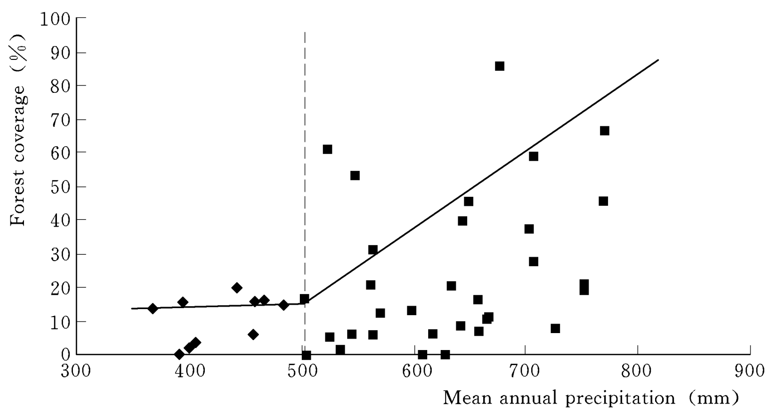

Fig. 2 Relationship between the forest coverage and MAP

All above imply that the MAP of 500 mm can be used as the threshold for dividing the basins into two separate groups in following analysis: the less-precipitation basin group and the more-precipitation basin group, associated with the climatic precipitation gradient.

3.2 *The impact of forest on suspended sediment yield in the less-precipitation basins*

When the precipitation is less than 500 mm, the watershed sediment load is scattered, without apparent regularity. The correlation between forest cover and mean annual suspended sediment yield is poor, and with increasing forest cover, namely annual suspended sediment yield has a weak linear increase in the trend, but the R^2 is as small as 0.1654 (Fig. 3). It may mean that at this stage, the sediment reduction led by forest is small, and this reduction is less than the increase brought by precipitation. Therefore, at this stage, the impact of forest on the sediment may be very weak, while the precipitation is the main factor.

Bosch and Hewlett (1982) undertook a review of paired catchments and concluded that water yield changes are greatest in highest rainfall areas. Travis E. Huxman et al. (2005) also believe that forests influence ET to a greater extent in more mesic climates and less so in arid climates. All these previous studies showed that, forest had little effect on water yield in the low-precipitation area. Runoff is the main carrier of sediment transport in North China, so the effect of forest may also be weak when the MAP is less than 500 mm.

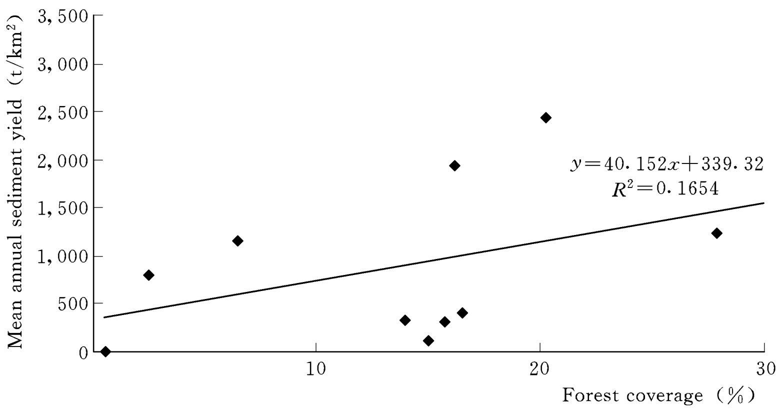

Fig. 3　Relationship between sediment yield and forest coverage in the less-precipitation basins (MAP < 500 mm)

3.3　*The impact of forest on sediment in the more-precipitation basins*

When MAP is more than 500 mm, Fig. 1 shows that with increasing precipitation, sediment yield is a decreasing trend. This is not consistent with our common sense, which leads us to think about the impact of the forest. With the increase of precipitation, the forest coverage also increases rapidly.

In the more-precipitation basins, the effect of forest on sediment is more complex than that in drier areas, the relationship between the sediment yield and forest coverage (f) show a quadratic polynomial ($y = -0.2326x^2 + 17.057x + 138.55$, $R^2 = 0.1335$, $n = 36$) (Fig. 4), and the forest coverage of 36% could be a threshold. When f is < 36%, the sediment yield increased with the increasing forest coverage; and when f is > 36%, the sediment yield showed a decreasing trend.

Precipitation is the main source of water yield, and should not be ignored in the analysis of the effect of forest. We should always remember the increase of forest coverage means that the MAP is also increased (Fig. 2).

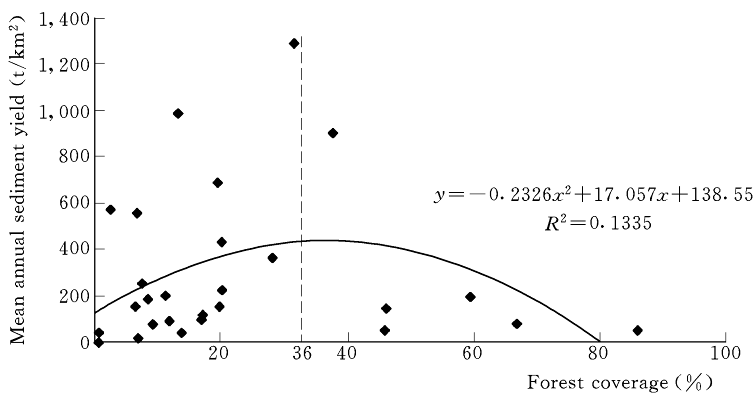

Fig. 4　Relationship between sediment yield and forest coverage in the more-precipitation basins (MAP > 500 mm)

4　Discussion and conclusions

The key to predict and understand the forest impact is to identify which factor is "the winner" in affecting sediment, like researches about the effects of forest on water yield (Wang et al., 2011). Precipitation is the most important source of sediment, the increase in precipitation will inevitably bring about increased sediment. Forest reduces the kinetic energy of raindrops and the hydrodynamic power of flowing water (Morgan, 2005), protects the ground's surface from the impact of raindrops, controls the rate of infiltration and reduces surface runoff (Xin et al., 2010). The final impact of forest on sediment depends on the synthetic effect of these positively or negatively influencing processes. It can be seen that, with increasing forest coverage, sediment change is largely a fight between the positive impact of increasing precipitation and the negative impact of forest.

Using statistical and graphic analyses on the long-term hydrological data of the 39 watersheds in North China, we were able to analyze the impact trend of forest on water yield. Our results show that there is a non-linear relationship between sediment yield, precipitation and forest, with two critical thresholds of MAP = 500 mm and f = 36%. Using these two thresholds, the effects of forest on sediment can be divided into three stages:

(1) MAP < 500 mm: When precipitation is low, the forest coverage is also very low (f < 30%), the sparse forest do not provide effective protection from soil erosion. When the mean annual precipitation increased, the sediment yield showed a significant increase driven by an increase in erosion due to rainfall. At this stage, the protective effect of the forest cover is not significant. Thus, precipitation plays a dominant role in effecting sediment yield.

(2) MAP > 500 mm and f < 36%: At this stage, with increasing forest coverage, the sediment yield also shows an increasing trend. But that do not mean that forest could increase sediment, for the increasing forest coverage also means the increasing precipitation, and the increasing trend of sediment may caused by the precipitation.

(3) MAP > 500 mm and f > 36%: At this stage, the sediment yield showed a significantly decrease with increasing forest coverage, because the forest cover provided greater protection, even while the annual precipitation increased. Forest cover plays a more important role than precipitation at this stage. When the annual precipitation increased further, the sediment yields did not increase for the forest provided adequate protection to prevent soil erosion and sediment yield. And the protection of this stage is larger than f < 36%.

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