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Effects of forest on seasonal runoff in North China

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Abstract. The relationship of forest-water is a hot and important issue in ecohydrology studies. The relations between forest and water had been widely investigated, whereas information on the impact of forest on seasonal runoff is still lacking. In this study, the statistical and graphic analyses based on the long-term hydrological data of the 20 watersheds in the rocky mountain area of North China were made to analyse the impact trend of forest on seasonal runoff. The results showed that the low flow coefficient decreases by 3.3 % with a 10 % enhancement of the forest coverage. However, the effects of forest on high flow are much more complex and no obvious changing trends can be observed. With increasing forest coverage (f), the high flow show a trend of "increasing (f<20 %)—stable (f is 20-60 %)—decreasing (f>60 %)", and there has the largest high flow when f is 20%～60%, the largest high flow coefficient is about 30%.

1. Introduction

Forest-water relationship is a hot and important issue in ecohydrology studies. Forests are considered to be the main measures for soil and water conservation because they play an active role in reducing erosion. However, compared with other land use types, forest evaporation has more rainwater, resulting in a negative impact on water budget. [1-3]. The Chinese government had implemented many large-scale reforestation programmes in the last decades, and the total investment reached ¥720 billion (114 billion dollars) [4]. Although with a large economic and ecological benefit, reforestation can potentially reduce water capacity [5-7]. Thus, further understanding into the forest-water relationship is particularly essential.

Studies on the relations between forest and water had been previously investigated during the past years (herein references). The debate was fruitless because of the complexity of hydrological processes affected by multiple factors such as climate, geography, forest type and structure. The scientific method to solve the disputes is hydrological survey in river basins. Paired basin designs were developed to study the effects of forests on water cycle [8]. It is reported that deforestation will lead to the increase of flood volume and flood peak through the experiment of partitioned watershed. It is found that forests can lead to increased flow. It was also reported that reforestation delayed the flow increase by one month because the soil needed a longer replenishment period until flow was generated. These studies have shown that forests have an impact on the flow reduction characteristics. [9, 10].

It is important to note that the annual water yield does not tell the complete story [11]. On the other hand, the effects of forest on seasonal flows are less well understood, few researchers make special studies about that. However, the impact of vegetation change on seasonal water yield plays a more important role than those of the annual water yield [12]. For example, the distribution of yearly streamflow in areas with seasonal rainfall was generally of greater importance than the total annual water yield [13]. Ide et al. (2013) showed that the seasonal effects of forest on runoff exhibited different temporal variations with the annual effects, and the seasonal variations of water yield more clearly represent the persistence of changes after clear-cutting than does the annual effects of forest. It is helpful to distinguish between the effect of forest clearing on total water yield and on the seasonal distribution of flows [14].

Seasonal rainfall and runoff characteristics in North China are particularly evident, especially in the June and September. During this period, rainfall and runoff usually accounts for more than 85% and 75% of the annual precipitation, respectively while those from October to May in next year only accounts for 25% and 35%, respectively. Thus, understanding into the effects of forest on seasonal flows in North China may have an important significance.

Paired catchment methodology was the most accurate method, although it was difficult to find the paired catchments in China. Comparison of the different catchments can provide a feasible method. However, the majority of the forest-hydrology studies are at plot scale [15], little information can be found on the watershed-scale studies [7, 16]. As is known, forest is a prominent feature of river basin flow. Describing the role of forests in the hydrological cycle in terms of rainfall distribution, evapotranspiration, infiltration and runoff generation is an important step in understanding the availability of water resources. During rainfall events, some raindrops fall directly from tree crowns to the ground, while others are intercepted by tree crowns, shrubs and grasses. Forest structure changes the process of rainwater circulation. The interaction between forest structure and rainfall is complex and unpredictable [15].

The objective of this study was thus to test a hypothesis: the effect of forest on streamflow is not the simple increase or decrease, it should be dependent on its coverage. To test this hypothesis, we discussed the relationship between high flow and low flow with forest coverage in north China at watershed-scale, respectively. The results are assessed in terms of their implications for plant water balance.

2. Materials and Methods

2.1. Study area

The study area is in the earth-rock mountainous area of North China, and the boundary is 35°4′-44°11′N to 111°41′-120°17′E. The total land area accounts for 2.7% of China's total land area. The topographic features are low mountain and hilly landforms. Elevation ranges from 1 to 2,940 meters. The area is a semi-humid continental monsoon climate, with an average annual precipitation of 460 mm, about 75% of which is distributed between June and September in the rainy season. The average annual temperature is 8.1 C. In order to eliminate human disturbance of runoff, we have arranged all large-scale water conservancy projects (such as dams) in the study area, and must ensure that no water conservancy projects are included in the basin. We finally selected 42 eligible River basins.

2.2. Data

Annual precipitation and runoff data are all taken from the "Hydrological Yearbook of the People's Republic of China", although not published, but issued for internal use. Obtain meteorological data from China Meteorological Data Sharing Service System. Using the digital elevation model of the region, the watershed boundary is divided at a resolution of 90 m *90 M. The digital elevation model is derived from the Earth System Science Data Sharing Infrastructure (http://www.geodata.cn/). This subject is based on the Forestry Standard of the People's Republic of China (LY/T 1952-2011), "Long-term Research and Observation Method of Forest Ecosystem". All the boundaries of catchments in this study were delineated by ArcGIS software based on the DEM, using the “Hydrology” module in “Spatial Analyst Tools”.

3. Materials and Methods

3.1. Effects of forest on low flow

Low flow is often referred to as basic flow, loosely defined as the flow of groundwater from a region and then into the region over a period of time with little precipitation. Most studies have shown that the effect of afforestation on annual flow is mainly on low flow, which is an important component of annual flow in most forest basins. However, compared with the annual discharge and peak discharge, the research focus on the relationship between forest low discharge is much less[15]. In North China, the dry season usually last for up to 8 months due to the properties of seasonal rainfall. Therefore, studies on low flow are important for understanding the effects of forest on runoff.

There is a wide scattering of data points when comparing the low runoff with the forest coverage of basins (Figure 1). The negative relation suggests a decrease in low flow with increasing forest coverage, as presented by the regression equation (y=-0.3316x+0.3847), although their linear relationship is not obvious (R^2=0.1334). The results show that as the forest coverage each increases by 10%, the low flow coefficient decreases by 3.3%.

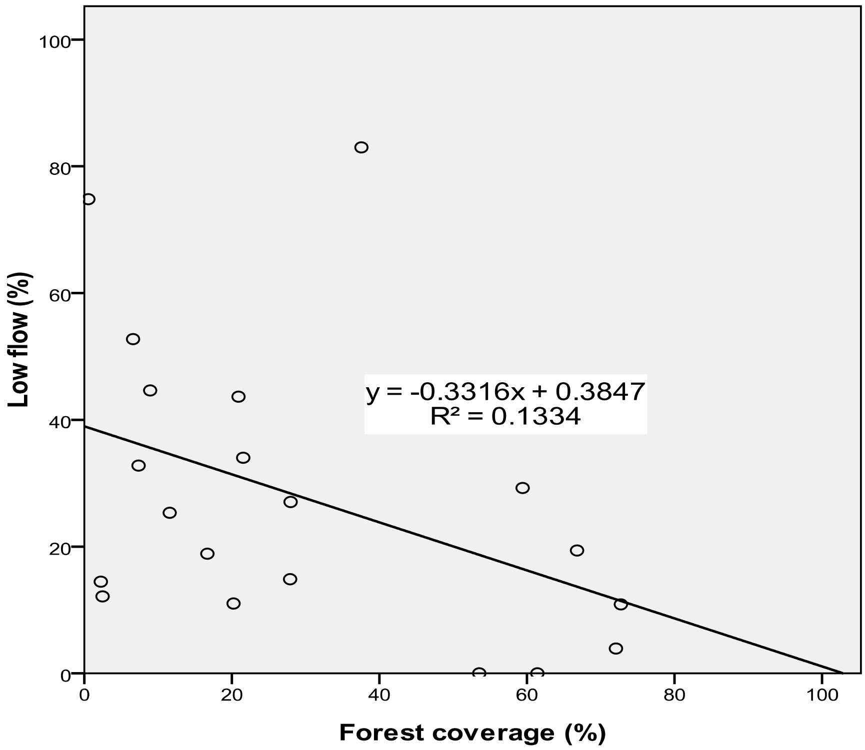

Figure 1. Changing trend of mean low flow (%) with increasing forest coverage

This results obtained herein was similar to those in most studies. Although the magnitude of effects is different, almost all paired watershed studies showed that forest harvesting increased low flows, while replanting or planting trees decreased low flows. For example, Andreassian [19] definitely showed that forestation generally decreased low flow based on the studies of the United Kingdom and United States [20, 21] and South Africa [10].

3.2. Effects of forest on high flow

Previous studies about seasonal runoff are more concentrated in the low flow, but little is known for the high flow. Although lasted only 4 months, the high flow in North China accounted for 75% of the annual runoff. Therefore, the high flow in this region has a very important significance.

The relationship between high flow and forest coverage showed that the effects of forest on high flow were much more complex than on low flow (Figure 2). Due to the small sample size, it was only roughly shown the change trend of high flow with increasing forest coverage.

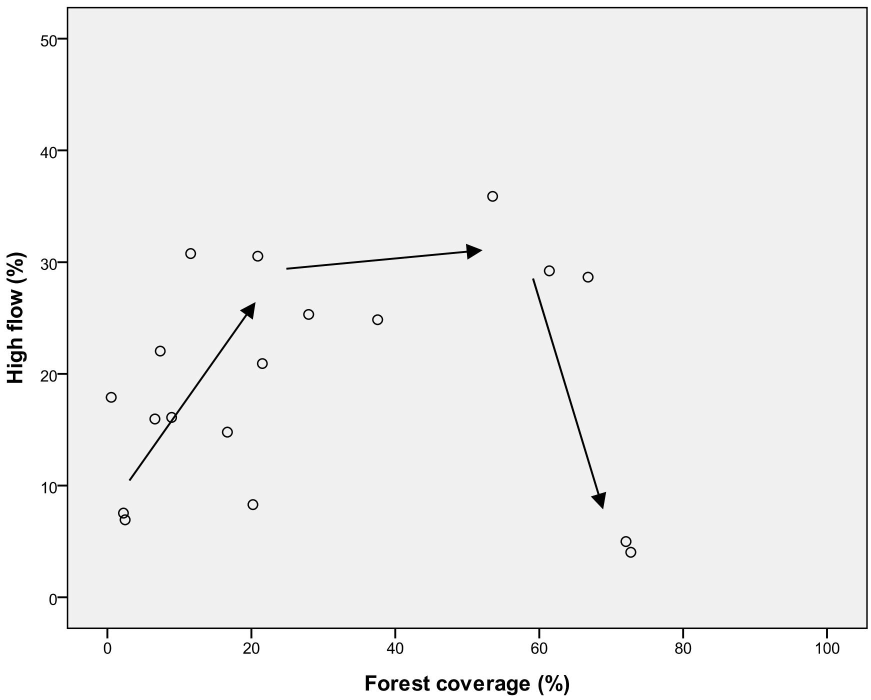

Figure 2. Changing trend of mean high flow (%) with increasing forest coverage

Seeing from the change trend of high flow, data sets can be observably divided into three parts: when the forest coverage (f) is <20%, 20%～60%, and >60%, the change trend of high flow is respectively increasing, stable, and decreasing, respectively. This may suggest that, when f is <20%, forest can increase high flow; when f is 20%～60%, the effect is much weaker; and when f is >60%, forest decreases high flow. In addition, the largest high flow was observed when f is 20%～60%, under which the largest high flow coefficient is about 30%.

4. Discussion

he key to predicting and understanding forest impacts is to know which water balance components are the "winners" affecting water volume [22]. It is well known that forest transpiration can reduce runoff with increasing coverage. Although transpiration is traditionally considered to be an important component of forest transpiration, interception from the canopy and subsequent evaporation will also increase significantly, especially for conifers [23, 24]. The evaporation of intercepted precipitation accounts for 10-20% of broadleaf precipitation and 20-40% of conifer precipitation. Generally speaking, as evapotranspiration increases, afforestation practices lead to a reduction in annual water production [15]. On the other hand, forest shade and litter can reduce soil evaporation; forest roots can also enhance soil permeability, leading to greater infiltration of groundwater, which may lead to low-flow emissions, both of which will increase water production. Therefore, the impact of forests on runoff may depend on the combined effects of these positive and negative impacts[13].

It is well known that the relationship between forest harvesting or reforestation and low flow is not only related to vegetation changes, but also to changes in soil conditions [15]. On the seasonal scale, the characteristics of other catchment areas such as soil depth and type play a much greater role in response than the annual average. A report by the Tennessee Valley Authority found no significant changes in annual water yield and low flow during forest restoration and reforestation over the next 22 years. It is concluded that the additional water required to restore and grow additional trees is balanced by improving osmosis [16]. Bruijnzeel [13] and Scott et al. [5] also showed that the potential for increasing low or basic flow was limited by afforestation because increased osmotic potential balanced increased water loss through evapotranspiration.

In this study, due to the interference of soil infiltration, the distribution of low flow is dispersed with forest coverage. However , we can still find the trend of the deforestation of low flow with increasing forest coverage, which may be attributed to the thin soil (30～50cm) in North China. Naturally, when soils are intrinsically shallow for geological reasons, the storage opportunities of soil water are decreased accordingly [14]. Therefore, the degree of the interference in this region is small, while the role of evapotranspiration may be greater.

It must be emphasized that there are still many uncertainties in the statistical analysis of the impact of forests on seasonal runoff. In addition to precipitation and forests, other meteorological factors (such as temperature) and topographic factors (such as slope) may also affect water yield. The study area is located in the same climate zone, mostly in Rocky Mountains. The meteorological and topographic properties have little change, but eventually lead to the deviation of the research results. Due to the lack of paired catchment areas, it is difficult to eliminate these additional factors. On the other hand, in order to ensure adequate data sets, only 20 watersheds with data cycles of more than 10 years are selected in this paper, which may not represent the whole research area. This may be the reason for the low coefficient of determination (0.1334) between low runoff and forest cover, which needs further study.

5. Conclusion

Using statistical and graphic analyses on the long-term hydrological data of the 20 watersheds in North China, e the impact trend of forest on the seasonal runoff were analyzed. We concluded that the forest could decrease low flow, and the low flow coefficient decreases by 3.3% with the forest coverage each increasing by 10%. The effects of forest on high flow are much more complex, and cannot simply say increase or decrease. With increasing forest coverage (f), the high flow show a trend of "increasing (f<20%)—stable (f is 20%～60%)—decreasing(f>60%)", and there has the largest high flow when f is 20%～60%, the largest high flow coefficient is about 30%. Those results have some implications for reforestation programs, although they are just a first step towards a better understanding of forest-water relationship.

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