IOP Conf. Series: Earth and Environmental Science **170** (2018) 032018 doi:10.1088/1755-1315/170/3/032018

Runoff and sediment load change and its influencing factors in the Xiaonanchuan River Basin, China

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Abstract. Based on the annual monitoring data of runoff and sediment and the Normalized Difference Vegetation Index (NDVI), the water and sediment change and the vegetation coverage dynamics in the Xiaonanchuan (XNC) River basin were analyzed. The main impacts factors of the water and sediment change were further identified by using the Multiple Linear Regression method. It is found that the runoff was increasing and the sediment was reducing in the XNC River basin during 2000 to 2013. Simultaneously, a significant upward trend was shown in NDVI. It indicates that the vegetation coverage was increasing and the natural ecological environment was improved in the basin. The quantitative analysis results show that the vegetation coverage is the dominant influencing factor of the water and sediment change in the XNC River basin. Therefore, under the condition of recent climate change, ecological restoration is one of the most effective way to prevent water and soil loss in arid area.

1. Introduction

Variation in the runoff and sediment load in rivers is mainly influenced by the climate change and land use change [1]. The climate change is the dominant factor in the characteristics of river flow and sediment transport on a long-time scale, while the effect of land use change on hydrological processes may exceed the climate change on a short-time scale [2, 3]. Since 2000, the contribution rate of climate and land use change to the change of runoff in China has reached an average of 53.5% and 46.5%, respectively [4]. Some scholars pointed out that the contribution of land cover change to runoff and sediment reduction accounts for a large proportion in the upper reaches of the Yellow River, and the impact has exceeded the climate change since 2000 [5]. The Huangshui River, the largest primary tributary of the upper reaches of the Yellow River, has a very important role in maintaining ecological balance in northwest arid area [6]. Huangshui River basin is located in the transitional zone between Qinghai-Tibet Plateau and the Loess Plateau, with low vegetation coverage and serious soil erosion [7, 8]. However, the main factors affecting the water and sediment change in this area are not clear. This study selects a typical small watershed in the central southern Huangshui River basin-Xiaonanchuan (XNC) River basin as the study area, analyses the trend of runoff and sediment transport and the spatial and temporal difference of vegetation coverage in the basin, and identifies the key factors affecting the process of water and sediment transport in the basin. This study not only provides a good reference for the related research in this field, but also provides an important scientific basis for prevention of soil and water loss in arid area and protection of water and soil resources in the basin.

2. Study area

The XNC River is the primary tributaries of the Huangshui River located in the northwest China. The river basin lies between the latitudes of 36°17′ to 36°33′ N and the longitudes of 101°38′ to 101°56′ E, and it has an area of 368.6 km^2 (Fig. 1). The basin is higher in the south than in the north, and it is located at the elevations ranging from 2160 to 4125 m, with the average elevation of 2867.3 m. The land use types mainly include grassland, arable land, and forest, totally accounting to above 95% of the area of the basin. The basin is characterized by an alpine continental climate, and it experiences four seasons each year. The solar radiation is strong and the air temperature varies widely from day to night. The precipitation is less and the evaporation is larger. The basin has an annual runoff with about 0.3×10^8 m^3 and suffers a significant condition of water resources shortage.

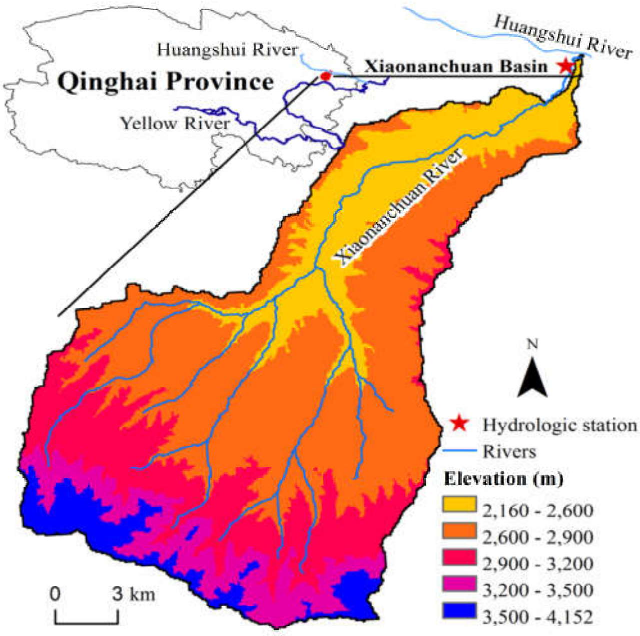

Figure 1. Location and terrain of the XNC River basin.

3. Date and Method

The annual monitoring runoff and sediment data from 2000 to 2013 by the Wangjiazhuang Hydrological station were used to analyze the water and sediment change. The station is located at the estuary of the XNC River (Fig. 1). In addition, the MOD13Q1 Normalized Difference Vegetation Index (NDVI) product was collected to extract the characteristics of the vegetation coverage variation. The NDVI product is a 16-day combination dataset that is available at a resolution of 250 m.

The multiple linear regression method was utilized to determine the main impact factors of the runoff and sediment load change in the XNC River basin. Due to the different magnitudes among the climatic, hydrological, and land use variables, a standardization disposal for the variables is necessary before regression calculation. The treatment is shown as:

$$k = xi / xavg \quad (1)$$

$$Cv = (\Sigma (xi - xavg)2 / (n - 1))1/2 / xavg \quad (2)$$

$$x0 = (k - 1) / Cv \tag{3}$$

Where x_0 is the normalized value of the variable, x_{avg} is the average annual value of the variable, and n is the length of the data series.

The multiple linear regression equation is constructed by using the normalized variable value.

$$yi = b0 + bixi + \ldots +bmxmi + ei \qquad i=1, 2, \ldots, n \tag{4}$$

Where y_i is the estimation for the observed value of dependent variable, $x_{1i}\ldots x_{mi}$ are the normalized values of the independent variables, $b_0\ldots b_m$ are the regression coefficients which are calculated by the least square method, e_i is the residual.

4. Results and Discussions

4.1. Runoff and sediment load change

From 2000 to 2013, the average annual runoff (R) was about 26.5×10^6 m^3 in the XNC River basin. The runoff showed a significantly upward trend at a confidence level of 95%, with an average increase rate of 1.9×10^6 m^3/a. The maximum annual runoff was 58.0×10^6 m^3 which was found in 2012, and the minimum annual runoff was 10.7×10^6 m^3 that was found in 2000 (Fig. 2). Inversely, the average annual sediment load (SL) was about 76.7×10^6 kg and showed a non-significantly downward trend in the XNC River basin. The average reduce rate of the sediment load was approximate 5.0×10^6 kg/a. The amounts of sediment load in subsequent years were lower than that in 2000 or 2001, except the maximum of 218.4×10^6 kg which was found in 2007. The minimum annual sediment load was 20.2×10^6 kg that was shown in 2010 (Fig. 3). Impacted by the runoff and sediment load, the average sediment concentration (SC) was about 3.46 kg/m^3 in the XNC River basin. It also showed a significantly decrease trend at the confidence level of 95%, with an average change rate of -0.55 kg/m^3a (Fig. 4). The maximum and minimum of the average sediment concentration were 13.20 kg/m^3 and 0.72 kg/m^3 which were found in 2000 and 2005, respectively.

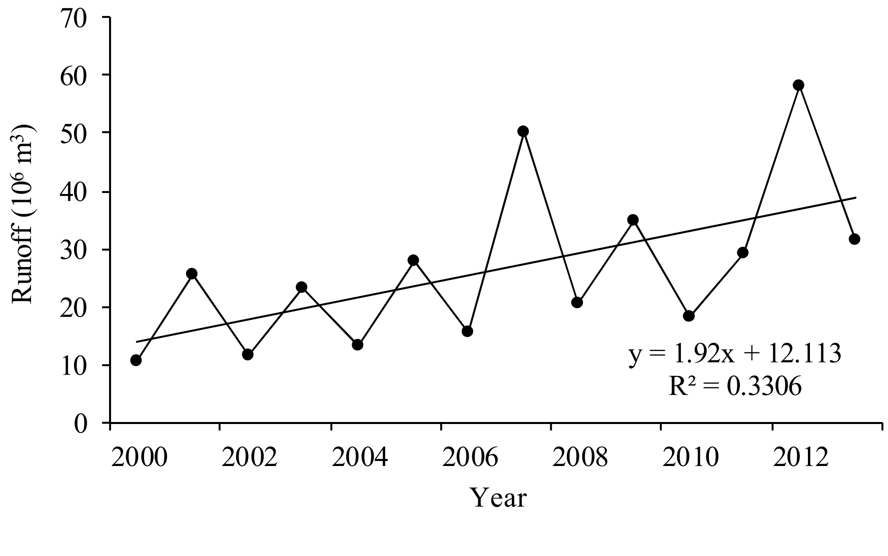

Figure 2. Annual runoff change in the XNC River basin from 2000 to 2013.

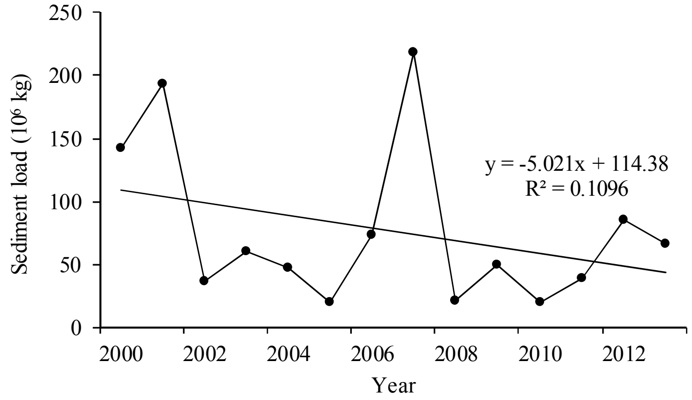

Figure 3. Annual sediment load change in the XNC River basin from 2000 to 2013.

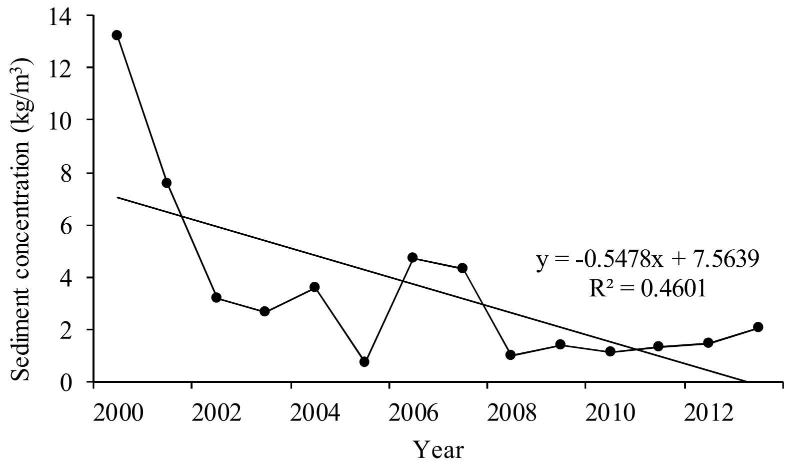

Figure 4. Annual average sediment concentration change in the XNC River basin.

4.2. Vegetation coverage change

The average annual value of NDVI was 0.31 in the XNC River basin between 2000 and 2013. The NDVI in forest was highest with the annual value of 0.37. The NDVI in arable land and grassland were close, with the annual value of 0.29 and 0.30, respectively. The NDVI in unused land was lowest in the basin with the annual value of 0.24. The NDVI has shown an increase trend in the whole basin and the dominant land use types since 2000, but this trend was not significant at the confidence level of 95% (Fig. 5). It indicates that the vegetation coverage was increasing gradually, and the ecological environment was improved in the XNC basin. The upward trend of the NDVI was relatively stronger in arable land which was followed by grassland. Comparably, the trend was weaker in forest. The average growth rates of NDVI in arable land, grassland, and forest were 0.0039, 0.0038 and 0.0019 per year, respectively. Consequently, the NDVI in the whole basin has increased by 0.0036 per year from 2000 to 2013.

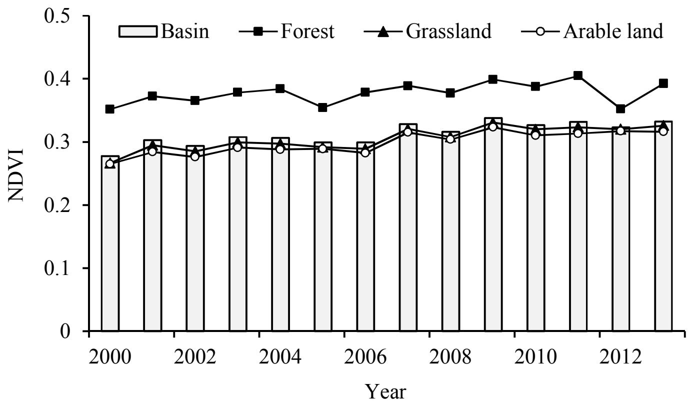

Figure 5. Change of annual NDVI in the XNC River basin and main land use types.

4.3. Main influencing factors of the water and sediment change

The correlation analysis between hydrological factors with precipitation (P), air temperature (T), and NDVI was conducted to identify the main impact factors of the water and sediment change in the XNC River basin. The results show that the runoff has a significantly positive correlation with precipitation and NDVI at a confidence level of 95%, with the correlation coefficient of 0.54 and 0.62, respectively. This indicates that the change of vegetation coverage is the dominant control factor of the runoff change in this area, followed by the precipitation. The positive correlation between sediment load and runoff is significant at the confidence level of 95%, with a correlation coefficient of 0.53. It implies that there is a certain cooperative relationship between sediment transport and runoff. In addition, the average sediment concentration in river is negatively correlated with the NDVI significantly at a confidence level of 95%. It indicates that the vegetation coverage plays an important role in the controlling of sediment yield in the basin. The projects such as afforestation and ecological restoration are the most effective way to control the water and soil loss in this area.

Using R, SL, and SC as the dependent variables, and P, T and NDVI as independent variables, the regression equation was established. The results show that NDVI plays a decisive role in the change of runoff and sediment load in the XNC River basin, and the absolute values of regression coefficient can exceed 0.5 (Table 1). Therefore, the increase and reduce trend, respectively, shown in the runoff and sediment load may be the results from the enhanced vegetation coverage in the area.

Table 1. Regression coefficients of runoff and sediment load in the XNC River basin.

	NDVI	T	P	R
R	0.54	-0.39	0.32	-
SC	-0.62	0.08	-0.17	-
SL	-0.81	0.50	-0.14	1.10

5. Conclusion

In this study, the water and sediment change and its major influencing factors in the XNC River basin were determined based on the runoff and sediment monitoring data and the NDVI products from 2000 to 2013. The results show that the runoff increased significantly, with a change rate of 1.9×10^6 m^3/a in the basin. In contrast, the sediment load showed a non-significant reduce trend with a change rate of -5.0×10^6 kg/a. Simultaneously, land use conditions are improving in the basin. The quantitative analysis indicates that the enhanced vegetation coverage is the dominant impact factor of the water and sediment change, and it has the effect of promoting and inhibiting on the runoff and sediment yield, respectively. With the current climate condition, the ecological restoration is one of the most effective way to prevent water and soil loss in the arid area.

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Acknowledgments
This work was financially supported by the Yellow River Institute of Hydraulic Research fund.

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