Impact of Vegetation Change and Climate Variability on Runoff in the Jingchuan Watershed in the Loess Plateau of China

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Keywords: Runoff, vegetation change, climate variability, the Loess Plateau

Abstract: Vegetation change and climate variability are often two main drivers for runoff variation. However, other factors such as human activities (e.g., road construction, agriculture, dams, urbanization) may also yield significant impact on runoff in populated watersheds. In this study, we selected the Jingchuan watershed, a sub-watershed of the Jing River Basin in the Loess Plateau as an example, to quantify runoff variation attributed to vegetation change, climate variability and other factors on runoff based on a single watershed approach. Firstly, we applied modified double mass curve (MDMC) and Autoregressive Integrated Moving Average (ARIMA) intervention to identify the impact of climate variability attributed to runoff variation. A significant breakpoint was detected in 1998. Then, multivariate Autoregressive Integrated Moving Average (ARIMAX) was used to differentiate the impact of vegetation change and other factors from non-climatic factors. The results showed that the average annual runoff attributed to vegetation change, climate variability and other factors were -16.61mm, 8.91mm and -1.33mm, respectively, resulting in a 9.03mm reduction in annual runoff over the period of 1998-2003 comparing with the runoff without impacts. These findings are beneficial to water supply and vegetation management in semi-arid areas such as Loess Plateau of China.

1 INTRODUCTION

The impact of vegetation change on runoff has been studied for over 100 years (Stednick, 1996; Andréassian, 2004; Brown et al., 2005). Conclusions from small watersheds (less than 100 km^2) show that vegetation change can significantly influence annual runoff by altering evapotranspiration (Bosch and Hewlett, 1982; Jones and Post, 2004). However, the impact of vegetation change on hydrology in large watersheds (more than 1000 km^2) has some inconsistent results, which shows both positive and negative effect on runoff (Costa et al., 2003; Siriwardena et al., 2006; Lin and Wei, 2008; Zhang et al., 2012). The lack of an efficient, commonly-accepted methodology can constrain forest hydrological studies in large watersheds.

The Jingchuan watershed is located in the Loess Plateau, with severe soil erosion and water scarcity. Our objective of this study is to quantify runoff variation attributed to climate variability, vegetation change and other factors by use of a single watershed approach, which can help us understand the effect of vegetation recovery on runoff, and control soil erosion in the Loess Plateau and eventually support water resource management in dry regions.

2 MATERIALS AND METHODS

2.1 Study Watershed and Data

The Jingchuan watershed, a sub-watershed of the Jing River Basin, is located in Loess Plateau (Figure 1). It covers an area of 3155.12 km^2 and belongs to temperate continental climate. The average annual temperature is 9 °C, annual precipitation reaches to 525.5 mm, and majority of which falls in wet season (May-October). The Jingchuan watershed is dominantly covered by farmland and grassland, which are 42.3% and 36.5% of total watershed area. The Jing River Basin experienced afforestation since late 1990s to prevent severe soil erosion.

Zhao, R., Zhang, M. and Hou, Y.
Impact of Vegetation Change and Climate Variability on Runoff in the Jingchuan Watershed in the Loess Plateau of China.
In *Proceedings of the International Workshop on Environment and Geoscience (IWEG 2018)*, pages 529-532
ISBN: 978-989-758-342-1

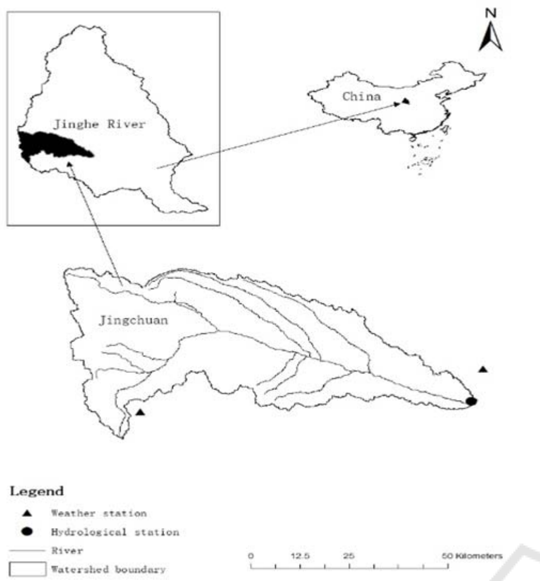

Figure 1: The location of the Jingchuan watershed.

Hydrological, climate and LAI data used in this study dated back to 1983. The hydrological records were obtained from the Jingchuan hydrological station, and monthly runoff and precipitation data were collected to calculate annual and seasonal data series. According to historical records, the average annual runoff only 39.5mm, and the hydrological year can be divided into dry season (November-April) and wet season (May-October). Meanwhile, two active climate stations are available in the study watershed, Kongtong station is located in the upstream and Xifeng in the downstream. Monthly mean/min/max temperature records in the two stations were obtained from Climatic Data Center, China Meteorological Administration (CMA). In this study, LAI data from GLASS (Global Land Surface Satellite Products) products were used to indicate the vegetation variation characteristics.

2.2 Method

Climate variability, vegetation change and other factors such as human activities are main factors for runoff variation. Firstly, modified double mass curve (MDMC) was used to separate climate variability and non-climate factors (Wei and Zhang, 2010). In modified double mass curve (MDMC), the y-axis is *Qa* which represents cumulative runoff and the x-axis is *Pae* which represents cumulative effective precipitation (the difference between precipitation and actual evapotranspiration). Seasonal data series were applied in this study. If non-climatic factors have no significant effect on runoff, the MDMC should be a straight line while a significant breakpoint can be found if non-climate factors made significant effect on runoff. Moreover, we employed the Autoregressive Integrate Moving Average (ARIMA) Intervention model to examine the significance of the breakpoint. Then, predicted line can be established using linear regression with the data before the breakpoint. The difference between observed line and predicted line refers to runoff variation caused by non-climate factors (ΔQ_{anc}). Finally, the multivariate time series analysis (ARIMAX) is used to separate the vegetation change and other factors from non-climate factors (Hou et al., 2018). By taking the cumulative LAI changes and ΔQ_{anc} as input, we can get the predict ΔQ_{anc0} . The difference between ΔQ_{anc} and ΔQ_{anc0} expresses the influence of others (other factors and statistical errors). The 95% confident interval (CI) is adopted to remove the statistical errors. In this way, runoff variation attributed to other factors (ΔQ_o) and the vegetation change (ΔQ_f) can be quantified.

3 RESULTS

A breakpoint was found in the year 1998 (Figure 2). Additional, ARIMA Intervention model (Table 1) confirmed the significance of the breakpoint. Using linear regression, predicted line was calculated. According to the calculation, seasonal runoff variation caused by non-climate factors varied from -79.25mm to 10.88mm, while, the climate variability effect on seasonal runoff ranging from -22.33mm to 90.97mm.

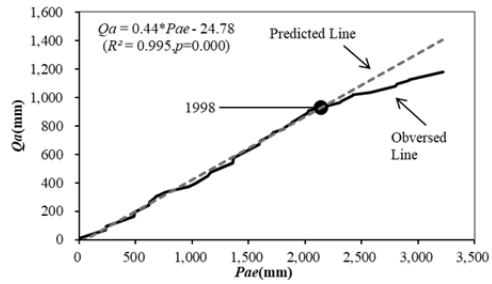

Figure 2: Modified double mass curve (MDMC) in the Jingchuan watershed. In which, Qa is cumulative runoff, Pae cumulative effective precipitation.

Table 1: ARIMA Intervention model.

Model Input	Model structure	Parameter estimation		
		$p(1)$[a]	$\Omega(1)$[b]	$\Delta(1)$[b]
Slope of MDMC	ARIMA Intervention: ln(x), (1,0,0), intervention at Year 1998	**-0.33 (*p*=0.035)**	**-1.74 (*p*=0.000)**	**-1.00 (*p*=0.000)**
[a] The autoregressive parameter; [b] Parameters for intervention.				

While seasonal runoff variation attributed to climate variability were quantified by MDMC, we used the ARIMAX model to separate the effect of vegetation change and other factors from non-climate factors. Table 2 shows the parameters of the selected ARIMAX model. Figure 3 demonstrates the differences between observed (ΔQ_{anc}) and predicted accumulated seasonal runoff variation for the non-climatic factors (ΔQ_{anc0}), which is modelled by ARIMAX model.

Moreover, we use 95% CI to eliminate statistical errors. There were 3 data series within the 95%CI (1999-wet, 2001-wet and 2002-dry), which suggested that runoff deviation attributed to other factors in these seasons can be ignored. After that, runoff variation attributed to vegetation change and other factors can be quantified.

Table 3 illustrates the quantification results from 1998 to 2003 in the Jingchuan watershed. Annual, dry season and wet season runoff variation caused by climate variability are 8.91mm, -16.40mm and 34.22mm, respectively, indicating that vegetation change can significantly decrease annual and wet season runoff (16.61mm and 37.22mm) and increase dry seasonal runoff (4.01mm).

Table 2: ARIMAX model of seasonal runoff variation attributed to non-climate factors.

Model Input	Parameter Estimation	
	$p(1)$[a]	$\Delta LAIa$[b]
$\Delta Qanc$: In ARIMA(1,0,0) + $\Delta LAIa$	**0.832 (*p*=0.0004)**	**-168.059 (*p*<0.0001)**
[a] The autoregressive parameter; [b] The accumulated LAI changes.		

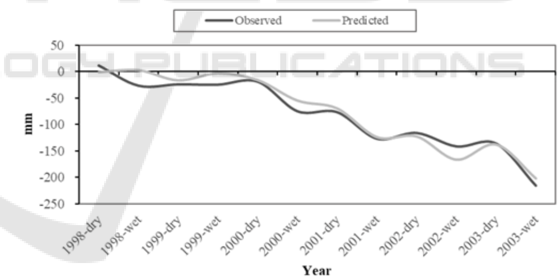

Figure 3: Observed and predicted cumulative runoff variation for the non-climatic factors.

Table 3: The quantification of different factors attributing to runoff variation.

Season	ΔQ_o(mm)[a]	ΔQ_f(mm)[b]	ΔQ_c(mm)[c]	ΔQ(mm)[d]	LAI	Reference LAI
DRY	1.55	4.01	-16.40	-10.83	0.26	0.26
WET	-4.22	-37.22	34.22	-7.22	0.98	0.92
ANNUA L	-1.33	-16.61	8.91	-9.03	0.62	0.59
[a] Runoff variation attributed to other factors; [b] Runoff variation attributed to vegetation change; [c] Runoff variation attributed to climate variability; [d] The total runoff variation.						

4 DISCUSSION

Vegetation recovery by Grain for Green program in the Jingchuan watershed yielded a negative effect on annual runoff, a 5% increment in LAI averagely resulted in about 42% reduction in annual runoff. A similar study in the Loess Plateau also showed that land use/cover change (reforestation) produced over 50% of the reduction in annual runoff (Zhang et al., 2008). Actually, transpiration of planted trees and grass in the Loess Plateau are relative high, leading to the reduction of annual runoff (Li et al., 2016; Jian et al., 2015; Duan L et al., 2016). Therefore, in the process of ecological restoration in Loess Plateau, we should choose vegetation type with low transpiration and less water consumption to reduce the negative impact on water supply.

5 CONCLUSIONS

Annual and seasonal runoff in the Jingchuan watershed are sensitive to vegetation change, a slight increase in LAI due to forest and grass planting leading to high transpiration. Meanwhile, climate variability and vegetation change yield offsetting effects suggesting a relative stable water supply in the study area. Our results also demonstrate a great implication for water resource management and ecological restoration in the Loess Plateau.

ACKNOWLEDGMENT

This research was supported by National Key Research and Development Program of China (No. 2017YFC0505006) and China National Science Foundation (No. 31770759).

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