Science of the Total Environment xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Detecting the quantitative hydrological response to changes in climate and human activities

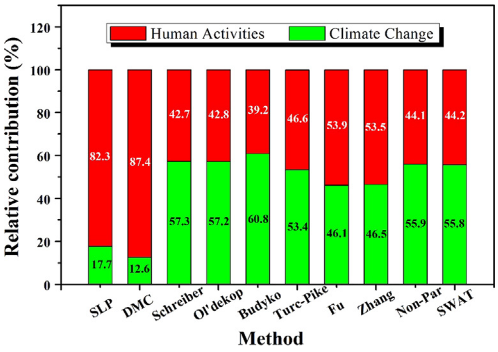
Jingwen Wu [a,b], Chiyuan Miao [a,b,*], Xiaoming Zhang [c], Tiantian Yang [d], Qingyun Duan [a,b]

[a] *State Key Laboratory of Earth Surface Processes and Resource Ecology, College of Global Change and Earth System Science, Beijing Normal University, Beijing 100875, China*
[b] *Joint Center for Global Change Studies, Beijing 100875, China*
[c] *Institute of Water Resources and Hydropower Research, Beijing 100048, China*
[d] *Department of Civil and Environmental Engineering, University of California, Irvine, CA 92697, USA*

HIGHLIGHTS

- Ten commonly used quantitative methods drawn from three main categories were reviewed.
- All ten methods were used to assess the impacts of climate change and human activities on runoff in the Yanhe River basin.
- Climate change had the larger effect on decreases in runoff, accounting for 54.1% (mean estimation).
- Three main quantitative categories were compared and the relative merits were summarized.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 17 September 2016
Received in revised form 2 February 2017
Accepted 2 February 2017
Available online xxxx

Dr. D. Barcelo

Keywords:
Climate change
Human activities
Quantitative hydrological response
Budyko
Yanhe River basin
SWAT

ABSTRACT

Understanding the relative contributions of climate change and human activities to changes in runoff is important for sustainable management of regional water resources. In this study, we systematically review ten commonly used quantitative methods drawn from three main categories—empirical statistics, elasticity-based methods, and hydrological modeling. We explain the calculation processes for the different methods and summarize their applications and characteristics. Then, using the Yanhe River basin as a case study, we employ all ten methods to separate out the effects of climate change and human activities on changes in runoff. The results show that climate change played a dominant role in the decline in runoff in the Yanhe River basin. Climate change was estimated to account for 46.1%–60.8% (mean 54.1%) of the total decrease in runoff, whereas human activities accounted for 39.1%–53.9% (mean 45.9%). Elasticity-based methods and hydrological modeling produced similar estimates, but the estimates made using empirical statistics were different. Empirical statistics were not a suitable method for the Yanhe River basin. We also discuss the factors that influence the different methods and the applicable conditions for each methodological category.

---

[*] Corresponding author at: State Key Laboratory of Earth Surface Processes and Resource Ecology, College of Global Change and Earth System Science, Beijing Normal University, Beijing 100875, China.
E-mail address: miaocy@bnu.edu.cn (C. Miao).

http://dx.doi.org/10.1016/j.scitotenv.2017.02.010
0048-9697/© 2017 Elsevier B.V. All rights reserved.

Please cite this article as: Wu, J., et al., Detecting the quantitative hydrological response to changes in climate and human activities, Sci Total Environ (2017), http://dx.doi.org/10.1016/j.scitotenv.2017.02.010

1. Introduction

Observational evidence from many regions throughout the world indicates that hydrological cycles are influenced both by climate change and by human activities (Huntington, 2006). Climate change—such as changes in precipitation, temperature, or other climatic variables—can lead directly or indirectly to changes in runoff (Dam, 1999). As an example of climate change, the average global surface temperature increased by 0.85 °C between 1880 and 2012, according to the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) (Qin et al., 2014). Human activities, such as irrigation, afforestation, urban construction, dam construction, and reservoir operation, are believed to have both direct and indirect impacts on hydrological processes, with consequent effects on the spatiotemporal distribution of water resources (Milly et al., 2005; Zhang et al., 2001). In recent years, the availability of water resources has decreased, both at the regional scale and at the global scale (Vorosmarty et al., 2000). This downward trend in water resources has been attributed to ongoing changes in climate and human activities, and is expected to continue (Vorosmarty et al., 2000). Moreover, decreases in runoff have already resulted in serious social and ecological issues throughout the world (Wang et al., 2012). Understanding the separate effects that climate change and human activities have on changes in runoff will be beneficial in many ways: (1) it may help in the development of adaptive measures in response to climate change (Wang, 2014). (2) It may reduce unnecessary losses from the water cycle (Jia et al., 2014). (3) It will help with provision of a dependable water source for food production and human consumption (Liang et al., 2015). (4) It will aid the development of sustainable water-management strategies that will enable the desired level of functionality within the local ecosystem (Gao et al., 2016). It should be noted that climate evolution in recent decades is a combination of human-induced climate change (e.g. increased greenhouse gas emissions) and naturally induced climate change caused by internal forcing. Hydrologists tend to use the terminology ‘climate change’ to reflect both human-induced climate change and naturally induced climate change, and then quantify the effects on hydrological processes.

Numerous studies have attempted to quantitatively analyze the impacts of climate change and human activities on runoff changes in recent years (Li et al., 2009; Miao et al., 2011; Zeng et al., 2015; Zhao et al., 2014). To date, the methods used fall mainly into three groups: empirical statistics, elasticity-based methods, and hydrological modeling.

Empirical statistics establishes a relationship between runoff and a climate variable of interest (usually precipitation) and thus usually requires long-term historical hydrometeorology data (Wang, 2014). Such methods mainly include regression analyses (Zhao et al., 2014), time-trend analyses (Zhang et al., 2011a, b), and the double-mass curve method (Gao et al., 2011). Zhao et al. (2015) used simple linear regression in their analysis of runoff and sediment load in the Yangtze River between 1953 and 2010, and attributed 72% of the reduction in runoff and 14% of the reduction in sediment load to the effects of climate change. Kong et al. (2016) used residual analysis based on double-mass curves to indicate that 91.7% of the change in net runoff in the Yellow River between 1960 and 2012 was due to human activities. Zhang et al. (2016) used multiple linear regression to evaluate the impacts of climate change and human activities on runoff changes in the Poyang River between 1955 and 2009. They estimated that climate change was the main driver (77%) of changes in runoff.

Elasticity-based methods primarily utilize the estimated elasticities in precipitation and potential evapotranspiration to evaluate the effects of climate change. The most widely used elasticity-based methods include the nonparametric method and an analytical method based on the Budyko framework (Budyko, 1974; Dooge, 1992; Sankarasubramanian et al., 2001). Ye et al. (2013) used the Budyko-Zhang method to distinguish the relative influence of climate change and human activities on changes in streamflow in Poyang Lake between 1960 and 2007. They estimated that climate change induced changes of 105%–212.1% in runoff relative to the 1960s. Gao et al. (2016) used the Budyko framework to determine the hydrological responses to climate change and human activities in the Jing River basin during the period 1961–2009. They showed that climate change was the main driver of streamflow reduction, accounting for about 63.9% of the reduction. Mwangi et al. (2016) used the Budyko framework to separate out the relative contributions of climate change and land-use change to increases in discharge in the upper Mara River in Kenya, and found that changes in land use were the main driver, accounting for 97.5% of the increase, versus 2.5% from climate change.

Hydrological modeling employs complex models to simulate the hydrological cycle. By comparing simulations driven by different climate-variable values (whilst keeping the other variables constant), the impact of climate change on runoff variation can be assessed. Zuo et al. (2014) employed a simple hydrological model to identify the impacts of climate change and human activities on changes in runoff in the Jing River basin, and showed that 51% of the runoff decline was due to human activities. Zeng et al. (2015) used the SIMHYD model to separate out the effects of climate change and human activities on surface runoff changes in the Luan River basin and showed that 46.8% of the runoff changes were due to climate change and 53.2% were due to human activities. Ahn and Merwade (2014) used four hydrological models to jointly quantify influences on streamflow; human-induced streamflow decreases accounted for 74%, 55.5%, 71.4%, and 85.7% of the total decreases in Indiana, New York, Arizona, and Georgia, respectively.

Most studies on the impacts of climate change and human activities on changes in runoff use just one method of assessment. Gao et al. (2016) and Zuo et al. (2014) used different methods to examine runoff decline in the same catchment and obtained contradictory results: Gao et al. (2016) reported that climate change was the main driver of runoff decline but Zuo et al. (2014) reported that human activities were the main driver. Similarly, Zhang et al. (2016) and Ye et al. (2013) used different methods in the same catchment and reported different findings. Therefore, it can be seen that, in general, there is often a large degree of uncertainty in the results obtained via different methods for the same study area. In recent years, to reduce uncertainty and increase confidence in the results, some studies have assessed the impacts of climate change and human activities on changes in runoff using multiple methods (Zhao et al., 2014; Liang et al., 2015; Zhang et al., 2016). Zhang et al. (2016) employed three methods to assess the impacts of climate change and human activities on changes in runoff in the Poyang River basin, with broad agreement between the results for the entire catchment. Zhao et al. (2014) used simple linear regression and a Budyko-based method to assess the impact of climate variability and human activities on runoff changes in the middle Yellow River basin, but the results were not consistent in most catchments, especially the Yanhe River basin. The inconsistency in the results reported above suggests that distinguishing the impacts of climate change and human activities on changes in runoff is difficult because of their complex effects on runoff (Fu et al., 2007) and because of variable geographical conditions (Niraula et al., 2015). Isolating and integrating the effects of human activities and climate change on runoff requires an in-depth understanding of all factors (Chawla and Mujumdar, 2015).

To better understand the impacts of climate change and human activities on changes in runoff, we reviewed all commonly used methods—ten methods rather than just one or two methods as in preexisting studies—and then applied all methods to a single catchment (the Yanhe River basin). This approach enables us to discuss the merits and demerits of all the methods reviewed and evaluate the applicability of the different methods. The Loess Plateau is famous for its serious water erosion of the soil and enormous sediment discharge. The Yanhe River basin is a gully area typical of the Loess Plateau, featuring heavy water and soil erosion, and to some extent represents the characteristics of the Loess Plateau in general (Cheng et al., 2016). Moreover, the serious soil erosion in the Yanhe River basin has led to unsustainable land-use management (e.g. erodible soils, low vegetation cover) and if

Please cite this article as: Wu, J., et al., Detecting the quantitative hydrological response to changes in climate and human activities, Sci Total Environ (2017), http://dx.doi.org/10.1016/j.scitotenv.2017.02.010