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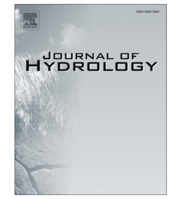

Review papers

Separating the impacts of climate change and human activities on streamflow: A review of methodologies and critical assumptions

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A R T I C L E   I N F O

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A B S T R A C T

Climate change and human activity are two major drivers that alter hydrological cycle processes and cause change in spatio-temporal distribution of water availability. Streamflow, the most important component of hydrological cycle undergoes variation which is expected to be influenced by climate change as well as human activities. Since these two affecting conditions are time dependent, having unequal influence, identification of the change point in natural flow regime is of utmost important to separate the individual impact of climate change and human activities on streamflow variability. Subsequently, it is important as well for framing adaptation strategies and policies for regional water resources planning and management. In this paper, a comprehensive review of different approaches used by research community to isolate the impacts of climate change and human activities on streamflow are presented. The important issues pertaining to different approaches, to make rational use of methodology, are discussed so that researcher and policymaker can understand the importance of individual methodology and its use in water resources management. A new approach has also been suggested to select a representative change point under different scenarios of human activities with incorporation of climate variability/change.

Contents

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1. Introduction

Climate change is considered to be one of the major drivers behind diminishing water resources availability and changing spatial distribution over the globe (Kundzewicz et al., 2008). Global warming, acting as a catalyst in the process of climate change, accelerates variability of different atmospheric variables (Arnell, 1999). Apart from climatic variability, human activities such as modification of land use/land cover (LULC), industrialization, and urbanization also alter hydrological processes and have exerted global-scale impacts on environment with significant implications on water resources. Among different components of hydrological cycle in a watershed, streamflow is considered as the most important resultant for water resources management and its variability affects the water use pattern significantly in different sectors like agriculture, domestic, industry, hydropower generation and navigation.

Recently researchers have used long term streamflow data to quantify its variability and attributed the total streamflow change, at different time scales, as a function of climate change and human activities. Climate change causes alteration in precipitation, evaporation, soil moisture availability (Gleick, 1986; Dooge, 1992), and time of flow routing (Prowse et al., 2006). Whereas, human activity influences streamflow variability and subsequent complications because of induced land use changes (Li et al., 2009), urbanization (Rose and Peters, 2001), construction of dams and water retention structures (Ye et al., 2013). Land use changes alter soil properties, interception of precipitation, surface roughness (Wang et al., 2013b), and flood frequency (Brath et al., 2006) while urbanization causes higher surface runoff generation, and reduced lag time between precipitation and runoff leading to increase in peak flow.

The rapid increase of population along with increase in water demand for various sectors poses severe challenges to water resources. Thus, decision and policy makers are drawn towards managing the consequences of hydrological impacts of climate change and human activities for optimal water resources management (Sun et al., 2005). The individual impacts of climate change and human activities are, therefore, necessary to frame different adaptation measures due to climate change in watersheds and to realize the future water use pattern for different human activities. Researchers have adopted methodologies like hydrological modeling (Ma et al., 2009; Li et al., 2009; Liu et al., 2013b), climate elasticity (Zheng et al., 2009; Yang and Yang, 2011), Budyko coupled elasticity (Liang et al., 2013; Zhang et al., 2013) and decomposition method (Wang and Hejazi, 2011; Sun et al., 2014), hydrological sensitivity method (Zuo et al., 2014; Guo et al., 2014), Tomer Schilling framework (Tomer and Schilling, 2009;Ye et al., 2013), time trend method (Zhang et al., 2012), and paired catchment method (Huang et al., 2003; Liu et al., 2004) to investigate the impact of climate change and human activities on changes in streamflow.

There are many assumptions which need to be taken care of during the implementation of different approaches to address the problem. This further decides the framing of policies for development and management of regional water resources and implementation of different adaptation measures to mitigate changes in water availability and its spatial distribution. Given the growing importance of this specific research field, the objectives of this study are- a) to understand the theory of different approaches used for separating the individual impacts of climate variability and human activities on streamflow, and b) to discuss and interpret critical assumptions and issues for the use of different methods in this aspect study. Overall, the research perspective is necessary to frame climate change adaptation measures and to develop guidelines for human activities for sustainable availability of water resources.

2. Methodologies used for separating the impact of climate variability/change and human activities on streamflow

Numerous methods have been utilized for separating the individual impact of climate variability and human activities on streamflow. These methods can be categorized as experimental approaches, hydrological modeling, conceptual approaches, and analytical approaches. The experimental approaches include time trend and paired catchment observations and analysis whereas hydrological modeling is used to simulate streamflow under natural and impact conditions. The conceptual approaches include applications of Budyko hypothesis (decomposition and sensitivity method) and Tomer-Schilling framework, analytical approach includes climate elasticity and hydrological sensitivity methods. The following sections deal with theory and assumptions of each of these approaches.

2.1. Hydrological modeling approaches

Hydrological modeling is being used for analyzing the impacts of climate variability and human impacts on runoff by simulating runoff processes using representative hydro-meteorological data for study area. Selection of hydrological model should be done in such a way that it must be able to address specific research question within the available information resources such as data availability on different variables/process, number of stations for accounting spatial changes across a watershed, complexity of model structure.

The climate variability and human impacts separation approach can be formulated mathematically as-

$$W_T = W_N - W_L \quad (1)$$

$$W_C = W_M - W_N \quad (2)$$

$$W_H = W_T - W_C \quad (3)$$

$$Q_C = \frac{W_C}{W_T} \times 100\% \quad (4)$$

$$Q_H = \frac{W_H}{W_T} \times 100\% \quad (5)$$

where W_T = Difference between average streamflow in natural period (W_N) and average streamflow in impacted period (W_L), T refers to the total change in the streamflow during change period with respect to the natural period and L refers to flow during the impacted period; W_M = simulated natural streamflow under impacted period, M refers to the model simulated flow under impacted period; W_C = streamflow variation attributed to climate change, W_H = streamflow variation attributed to human activities; Q_C and Q_H are streamflow variation attributed to climate variability and human activities respectively. The aspect of human impact on streamflow, in most of the studies, has been considered to study either effect of land use/land cover (LULC) change or urbanization on streamflow variability.

Researchers used hydrological modeling for separating the impacts of land use/land cover change from climate change and their individual effects on mean annual streamflow. In this approach, models have been used to simulate hydrological processes first for a reference period which is considered to be natural flow period and then two separate periods logically affected due to LULC change and climate change. The difference in streamflow in later two periods is taken as approximate simulated impact by the model for two concerned conditions. As an example, the Soil Water Assessment Tool (SWAT) model was used by Ma et al. (2009), Li et al. (2009), Fan et al. (2010) to simulate first the natural