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Review

Advances in separating effects of climate variability and human activity on stream discharge: An overview

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ABSTRACT

Separating effects of climate change (ΔQ^c) and human activity (ΔQ^h) on stream discharge at the watershed scale is needed for developing adaptive measures to climate change. However, information is scarce in existing literature regarding whether such separating is feasible and whether reliable results can be produced. The objectives of this overview were to: (1) compare currently-used methods; (2) assess assumptions and issues of the methods; and (3) present a generic framework that overcomes possible issues. Based on the overview of fifteen recent representative studies, two methods can be used to estimate absolute magnitudes of ΔQ^c and ΔQ^h, while another method can be used to distinguish relative magnitudes of ΔQ^c versus ΔQ^h only. Because the methods' fundamental assumptions about baseline versus altered period, water storage change and deep groundwater loss, precipitation-runoff relationship, hysteresis influence of human activity, and record of time series can seldom be satisfied for many watersheds, it is more realistic and practical to distinguish relative effects than to estimate absolute magnitudes of ΔQ^c and ΔQ^h. Moreover, a generic framework was presented for gauged watersheds with negligible groundwater loss, aiming to avoid misuse of the methods in practice.

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1. Introduction

In recent years, a number of studies have been conducted to use long-term historical data [14,61] to separate effects of climate variability and human activity on stream discharge. The rationale behind those studies is that a watershed's stream discharge and the variation in that discharge is a function of climate and human activity [5,52]. As representatives in existing literature, fifteen studies (Table 1), including Huo et al. [20], Ficklin et al. [12], Li et al. [25], Tomer and Schilling [51], Zhao et al. [71], Ma et al. [26], Wang and Hejazi [53], Dong et al. [10], Hu et al. [19], Wang et al. [54], Peng et al. [37], Wang et al. [55], Ye et al. [65], Zeng et al. [67], and Zhan et al. [68], were selected for overview because these studies used one or two of the three methods (Table 2), namely climate elastic model, modeling-based approach, and conceptual model, that have recently been utilized to understand how climate and human activity contribute to long-term average change in stream discharge. The climate elastic model estimates discharge change induced by climate as a weighted average of changes of precipitation and evaporative demand, whereas the conceptual model only distinguishes relative (i.e., does not quantitatively estimate) contributions of climate and human activity to discharge change. The modeling-based approach uses a hydrologic mathematical model to quantitatively predict discharge changes induced by climate change and/or human activity.

These fifteen studies share four common features. First, they are representatives of such studies published in recent years and thus can represent the latest development of the methods that have been used to separate effects of climate change and human activity on stream discharge. Second, they were conducted in various geographic areas with different climate conditions: twelve of them across China and the other three across the United States (USA). Third, they have been published on prestigious peer-reviewed journals with an emphasis of either basic research or practical application: five on *Journal of Hydrology*, two on *Hydrological Processes*, one on *Water Resources Research*, and seven on regional or localized periodicals. Fourth, only one (Peng S) of the primary authors is a coauthor of another study conducted by Wang et al. [54], indicating that these studies can reflect diverse views of independent researcher groups.

Given that separating effects of climate variability and human activity on stream discharge is needed for developing adaptive measures to climate change at watershed scale, it is crucial to better document the applicability, assumptions, and technical issues of currently-used methods. The objectives of this overview were to: (1) compare currently-used methods; (2) assess assumptions and issues of the methods; and (3) present a generic framework that overcomes possible issues of the methods for assessing effects of climate variability and human activity on stream discharge. The overview is based on recent fifteen representative studies (Tables 1 and 2).

2. Currently-used methods

Following a description of the common rationale for the aforementioned three methods (Table 2), this section presents the formulization of each of the methods.

2.1. Common rationale

For a gauged watershed of interest, its historic time series on precipitation, air temperature and stream discharge are split into subseries from a year before which human activity is negligible. The record years prior to this break year are defined as baseline (or near-pristine) period (designated "*bp*" for description purpose), while the record years after this break year are defined as altered (or changed) period (designated "*ap*" for description purpose). All currently-used methods are based on the rationale that the difference between the mean annual stream discharge during altered period ($\overline{Q}_{ap}$) and the mean annual stream discharge during baseline period ($\overline{Q}_{bp}$) can represent the total change of stream discharge (ΔQ) between *ap* and *bp*, and that ΔQ is combination of climate change and human activity. Based on this rationale, if interactions between climate change and human activity at watershed scale are neglected, which is usually reasonable [51,70], ΔQ can be estimated as:

$$\Delta Q = \overline{Q}_{ap} - \overline{Q}_{bp} = \Delta Q^c + \Delta Q^h \tag{1}$$

$$\Delta Q^c = \overline{Q}^c_{ap} - \overline{Q}_{bp} \tag{2}$$

$$\Delta Q^h = \overline{Q}^h_{bp} - \overline{Q}_{bp} \tag{3}$$

where ΔQ^c is the change of stream discharge induced by climate change only; ΔQ^h is the change of stream discharge caused by human activity only; $\overline{Q}^c_{ap}$ is the mean annual stream discharge under the climate during altered period while any human activity is neglected; and $\overline{Q}^h_{bp}$ is the mean annual stream discharge under the climate during baseline period while the human activity during altered period is considered.

In practice, this common rationale can be realized in different ways. For example, the fifteen studies, except for Wang et al. [54], used observed data on stream discharge to compute ΔQ, and either an empirical or a physically-based model to estimate ΔQ^c (or ΔQ^h) but not both. If ΔQ^c is estimated, $\Delta Q^h = \Delta Q - \Delta Q^c$, whereas, if ΔQ^h is estimated, $\Delta Q^c = \Delta Q - \Delta Q^h$. In contrast, Wang et al. [54] estimated both ΔQ^c and ΔQ^h, and computed the total change of stream discharge as $\Delta\tilde{Q} = \Delta Q^h + \Delta Q^c$. The discrepancy between $\Delta\tilde{Q}$ and ΔQ (computed using the observed data on stream discharge) was attributed to "other factors" that those authors did not specify.

2.2. Climate elasticity model for ΔQ^c

Some studies estimated ΔQ^c in terms of the climate elasticity model [23,30] expressed as:

$$\Delta Q^c = \frac{\partial Q}{\partial P}(\Delta P) + \frac{\partial Q}{\partial E_p}(\Delta E_p) = \varepsilon_P(\Delta P) + \varepsilon_{Ep}(\Delta E_p) \tag{4}$$

where P is precipitation; ΔP is the change of precipitation between altered and baseline period; E_p is potential evapotranspiration or PET [5,52]; ΔE_p is the change of PET between altered and baseline period; $\varepsilon_P = \frac{\partial Q}{\partial P}$ is the change rate of stream discharge with precipitation; and $\varepsilon_{Ep} = \frac{\partial Q}{\partial E_p}$ is the change rate of stream discharge with PET.

In their study, Ma et al. [26] defined the two change rates as:

$$\varepsilon_P = \varepsilon_1 \frac{\overline{Q}}{\overline{P}} \tag{5}$$

$$\varepsilon_{Ep} = \varepsilon_2 \frac{\overline{Q}}{\overline{T}} \frac{\Delta E_p}{\Delta T} \tag{6}$$

where ε_1 and ε_2 are two coefficients; $\overline{Q}$, $\overline{P}$, and $\overline{T}$, respectively, are the mean annual stream discharge, precipitation, and air temperature for entire record period; and ΔT is the change of air temperature between altered and baseline period.