Estimation of Annual Maximum and Minimum Flow Trends in a Data-Scarce Basin. Case Study of the Allipén River Watershed, Chile

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Abstract: Data on historical extreme events provides information not only for water resources planning and management but also for the design of disaster-prevention measures. However, most basins around the globe lack long-term hydro-meteorological information to derive the trend of hydrological extremes. This study aims to investigate a method to estimate maximum and minimum flow trends in basins with limited streamflow records. To carry out this study, data from the Allipén River watershed (Chile), the Hydrologiska Byråns Vattenbalansavdelning (HBV) hydrological model at a daily time step, and an uncertainty analysis were used. Through a calibration using only five years of records, 21-year mean daily flow series were generated and the extreme values derived. To analyze the effect of the length of data availability, 2, 5, and 10 years of flows were eliminated from the analyses. The results show that in the case of 11 years of simulated flows, the annual maximum and minimum flow trends present greater uncertainty than in the cases of 16 and 19 years of simulated flows. Simulating 16 years, however, proved to properly simulate the observed long-term trends. Therefore, in data-scarce areas, the use of a hydrological model to simulate extreme mean daily flows and estimate long-term trends with at least 16 years of meteorological data could be a valid option.

Keywords: long-term flow trends; data scarce; hydrological modeling

1. Introduction

Water availability changes each year due to local, global, natural, and anthropogenic phenomena. These changes and the constant increase in demand, be it for human consumption, irrigation, hydropower, or industrial use, require increasingly efficient water resources planning and management [1]. Moreover, the frequency and magnitude of extreme meteorological events, such as floods and droughts are currently changing [2,3]. Despite scientific and technological progress, the population remains exposed to these events [4]; therefore, trend analysis of hydroclimatic variables has become the study focus for many researchers around the world [3,5,6].

Several studies have shown that changes in flow time series are due to climatic [7–10] and/or anthropogenic factors [11–13]. To analyze the hydrological behavior in a watershed it is important to determine maximum and minimum flow trends; however, ascertaining the history of a basin can be a difficult task when the available hydrometeorological information is limited [14]. Most drainage basins around the globe are ungauged or data-scarce, either because a required variable has not been sampled at the required resolution or because it has not been observed during a period of interest [15]. To address this limitation, different approaches have been developed to estimate stream flows in ungauged areas [16], for example, multiple linear regression (MLR), variations of autoregressive...
moving-average (ARMA) models, artificial neural networks (ANNs) [17,18], and the widely used conceptual or physically-based hydrological models.

Currently, hydrological models are important components in planning and management of water resources, since they allow the simulation of streamflow series through a simplified representation of hydrological processes. There are various hydrological models, which vary in complexity and utility [19]. Most hydrological models can be classified as conceptual models, with parameters, or at least some parameters, that cannot be directly physically interpreted or measured, making it necessary to estimate them through a calibration process [20,21]. These models can be lumped, semi-distributed, or distributed. Depending on the aim of the study and information availability, lumped models may be preferred, since they provide acceptable results in terms of accuracy [22] and are simpler to interpret and implement than distributed models, especially in scarce-data cases.

In recent years, several studies have reported a decrease in precipitation and in snow and glacier coverage [23–29] and increasing temperature trends [30,31] in south-central Chile. These changes might affect the way in which water is managed on a regional scale, as well as how extreme events, such as floods and droughts, are faced.

Several countries around the globe currently need to face the lack of hydrological data for water-related management and planning. In Chile, streamflow records have a relatively short length of 30 years on average [32], and gauging stations are unevenly distributed throughout the country [33], limiting basin-and regional-scale analysis of flow trends and making it difficult to study runoff changes [34,35].

Time series reconstruction using a dendroclimatological approach [36–41] has been one of the most used methods to conduct hydrological long-term trends analyses. Tree-ring records provide continuous series of past environmental changes for the last several centuries and in some cases, millennia [36]. However, there is still a lack of specific studies related to the analysis of extreme flow trends and, more importantly, such trends in basins with limited hydrological information. Several studies used extensive databases [42–45] and performed a data quality control considering criteria such as no gaps and a length of time-series of at least 40–50 years. Thus, the objective of this article is to investigate a method to estimate such hydrological extreme trends, with a controlled and known uncertainty, in a basin with limited data availability. With this aim, a combined approach of hydrological modeling with a calibration using 5-years of data, a short simulation window (up to 21 years), and uncertainty analysis of flow trends is used.

2. Study Area and Data

2.1. Study Area

The Allipén River watershed was chosen as a case study location. The Allipén River watershed until the Río Allipén en Los Laureles stream-gauge station (1652 km²) is located in southern Chile and monitored by the Chilean General Water Directorate (DGA; Figure 1). The Allipén River rises in the Andes Mountains. Its climate varies between warm, temperate and rainy in the middle and lower parts of the watershed to cold, temperate and rainy with Mediterranean influence in its upper part (the Andean area). Annual precipitation can reach 3000 mm and mean monthly temperatures oscillate between −3 and 18 °C. The watershed receives mostly pluvial precipitation, with slight snow influence in the upper part, presenting a mixed hydrological regime (pluvio-nival). In the upper watershed volcano-sedimentary rock formations of the Tertiary and Quaternary periods are prominent, while in the Central Valley there are unconsolidated deposits of glacial origin and highly permeable alluvial material [46].

2.2. Data

To implement the hydrological model of the watershed, mean daily precipitation, temperature, and monthly evapotranspiration series representative of the watershed are required. The Los Laureles,