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Getting water right: A case study in water yield modelling based on precipitation data

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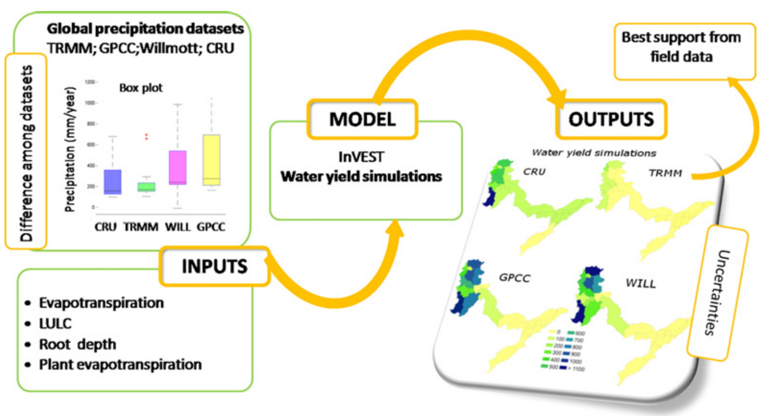
HIGHLIGHTS

- Differences in precipitation over the Andes in Central Patagonia are striking.
- The sensitivity of water yield modelling to precipitation inputs is large.
- Small differences among datasets translate into large differences in water yield.
- It is essential to evaluate the uncertainty related to input when modelling ES.
- Using the best precipitation data is fundamental for modelling hydrological ES.

GRAPHICAL ABSTRACT



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ABSTRACT

Water yield is a key ecosystem service in river basins and especially in dry regions around the World. In this study we carry out a modelling analysis of water yields in the Chubut River basin, located in one of the driest districts of Patagonia, Argentina. We focus on the uncertainty around precipitation data, a driver of paramount importance for water yield. The objectives of this study are to: i) explore the spatial and numeric differences among six widely used global precipitation datasets for this region, ii) test them against data from independent ground stations, and iii) explore the effects of precipitation data uncertainty on simulations of water yield. The simulations were performed using the ecosystem services model InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) with each of the six different precipitation datasets as input. Our results show marked differences among datasets for the Chubut watershed region, both in the magnitude of precipitations and their spatial arrangement. Five of the precipitation databases overestimate the precipitation over the basin by 50% or more, particularly over the more humid western range. Meanwhile, the remaining dataset (Tropical Rainfall Measuring Mission — TRMM), based on satellite measurements, adjusts well to the observed rainfall in different stations throughout the watershed and provides a better representation of the precipitation gradient characteristic of

Abbreviations: InVEST, Integrated Valuation of Ecosystem Services and Tradeoffs; ES, ecosystem services; CHB, Chubut River Basin; UCH, Upper Chubut River Basin; MCH, Middle Chubut River Basin; LCH, Lower Chubut River Basin; CRU, Climate Research Unit; TRMM, Tropical Rainfall Measuring Mission; GPCC, Global Precipitation Climatology Centre; TRMMv6, Tropical Rainfall Measuring Mission version 6; TRMMv7, Tropical Rainfall Measuring Mission version 7; INTA, Agriculture Technology National Institute; LULC, land use/land cover; FAO, Food and Agriculture Organization of the United Nations.

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the rain shadow of the Andes. The observed differences among datasets in the representation of the rainfall gradient translate into large differences in water yield simulations. Errors in precipitation of +30% (−30%) amplify to water yield errors ranging from 50 to 150% (−45 to −60%) in some sub-basins. These results highlight the importance of assessing uncertainties in main input data when quantifying and mapping ecosystem services with biophysical models and cautions about the undisputed use of global environmental datasets.

1. Introduction

Freshwater flows are essential for ecosystems, agriculture, industry, human consumption, hydropower, fisheries, and recreation. Not surprisingly then, recent developments in ecosystem services modelling for resource management have focused on water yield as a key ecosystem input.

Patagonia is rich in water resources, though population growth, and urban and industrial development are taking a toll on the capacity of watersheds to deliver water related benefits to people. Besides that, climate change scenarios predict a decrease in annual precipitations and an increase in temperature for most of the region (Nuñez et al., 2008; Garreaud and Falvey, 2009), making the situation worse. For instance, freshwater is becoming a limited resource for different urban areas in the region, especially along the arid Atlantic coast where most people live.

Here we conduct a modelling analysis of water yields for the Chubut River basin in Patagonia, Argentina. The Chubut River is ideal for such an analysis because it is a relatively small river basin, and is yet important to as many as 50% of the population in the Chubut Province. This river, as most of the rivers that flow across the arid Patagonia, is fundamental for agricultural irrigation and water supply for human consumption. This basin is also an important case study in terms of ecosystem services (ES) due to the existence of a number of regional projects aimed at creating hydroelectric dams which will provide irrigation water for new agricultural areas (Plan Director, 2013).

All ecosystem services models involving freshwater derive in part from precipitation data as a critical input. Precipitation is a key driver of the hydrological cycle, as well as one of the most difficult variables to measure because of its high spatial heterogeneity and temporal variability (Junzhi et al., 2012). Accurate measurements of precipitation are important to environmental scientists, as well as to a wide range of decision makers related to faming, industry, emergency management, urban areas, and natural areas (Ebert et al., 2007). However, estimating precipitation is difficult in many parts of the world due to the logistic complexity and high costs of establishing and maintaining the required infrastructure (Yilmaz et al., 2005). Patagonia is not an exception and the spatial characterization of precipitation based on actual field data is sparse at best, due to nonexistent ground-based radars and a poor network of rain gauges. When precipitation data at the scale of a watershed are required the only alternative is to use global precipitation datasets. Such data sets, available in different resolutions, are based on ground observations, satellite estimation, a combinations of both, or outputs from general circulation models. Whereas many studies have found that global precipitation datasets provide a good representation of temporal trends and global-scale spatial distribution, they often exhibit marked differences among themselves at the regional scale (Getirana et al., 2011). Getirana et al. (2011) compared six daily and sub-daily precipitation datasets and their impacts on the water balance of the Negro River Basin (Amazonas). They found that gauge-based data are the most accurate; however some satellite and model-based datasets can reproduce the water cycle at the basin scale and monthly time step fairly well. In addition to this, Hamel and Guswa (2015) found that the uncertainties introduced by errors in climate input data are significant and spatially heterogeneous, affecting the spatial distribution within the Cape Fear watershed of areas with high and low water yields.

Whereas the above studies suggest that precipitation data can be highly uncertain, systematic studies of the consequences of this uncertainty for resource management priorities are rare. In Patagonia, the consequences of this lack of analysis might be worse due to data scarcity and the vastness of the region.

In this context, the aim of this study was to analyze the agreement among different global precipitation datasets and with data from available independent ground stations and to explore the effect of precipitation data uncertainty on simulations of water yield over a Patagonian pilot watershed, the Chubut River Basin (CHB). Because so much interest in water yield stems from assessments of ES, we used the model InVEST to generate spatially explicit estimates of water yield in different sub-basins of the CHB.

The paper is organized as follows: Section 2 describes i) the InVEST model used for simulating water yield, ii) the precipitation datasets available for the CHB, and iii) the characteristics of the CHB. In Section 3, we present a comparison of the precipitation datasets and the sensitivity of water yield in the Chubut watershed to the uncertainties in precipitation data using the InVEST model. We also present a calibration of the model to the ecohydrological parameter Z. Finally, Section 4 includes discussion and conclusions.

2. Methodology

2.1. The Chubut River Basin as a case study

The Chubut River originates in the western extra Andean region of Patagonia (Rio Negro province) and flows for about 800 km, first south and then east across the Chubut province and into the Atlantic Ocean (Fig. 1). The basin reaches an altitude of 2300 m in its source, Nacimiento, at an altitude of 950 m, is the higher and westernmost flow gauge station used for this study. The Chubut River's hydrograph is characterized by two peak discharges, one in spring from snowmelt and the other in the fall from rainfall.

The CHB basin has a total area of 57,400 km^2 and is divided in 3 major sub-basins, upper (UCH), middle (MCH) and lower (LCH), themselves divided in a total of 24 sub-basins (Fig. 1). The lower basin is the most populated, concentrating more than 50% of the Chubut province population. The Chubut River is the only water supply for over 200,000 people (Commendatore and Esteves, 2004).

One multipurpose dam, Florentino Ameghino, with a capacity of 1500 hm^3, was built in 1968 for energy production and to regulate flow of the lower basin for flood control, irrigation, and water provision (Plan Director, 2013).

2.2. Precipitation data

A number of global or quasi-global precipitation datasets, with different spatial and temporal resolutions, and generated using different methodologies are available. For the purpose of this study and considering the dimensions of the basin, only datasets with the higher spatial resolution were selected. In total, six mean annual precipitation datasets were analyzed (Table 1): the Climate Research Unit (CRU); the Willmott from the University of Delawere; the Global Precipitation Climatology Centre (GPCC), and three different versions of the precipitation datasets produced by the Tropical Rainfall Measuring Mission (TRMM), which is