Agricultural Water Management 175 (2016) 29–42

Contents lists available at ScienceDirect

Agricultural Water Management

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

Hydrological modeling and climate change impacts in an agricultural semiarid region. Case study: Guadalupe River basin, Mexico

Eugenio Molina-Navarro[a,b,*], Michelle Hallack-Alegría[b,c], Silvia Martínez-Pérez[a], Jorge Ramírez-Hernández[d], Alejandro Mungaray-Moctezuma[c], Antonio Sastre-Merlín[a]

[a] Department of Geology, Geography and Environment, Geology Unit, Faculty of Biology, Environmental Sciences and Chemistry, University of Alcalá, Ctra. Madrid-Barcelona Km. 33.6, 28871 Alcalá de Henares, Madrid, Spain

[b] Centro de Ingeniería y Tecnología, Universidad Autónoma de Baja California, Campus Tijuana, Blvd. Universitario 1000, Unidad Valle de las Palmas, Tijuana, B.C., Mexico

[c] Facultad de Ingeniería, Universidad Autónoma de Baja California, Campus Mexicali, Blvd. Benito Juarez s/n, Parcela 44, 21280 Mexicali, B.C., Mexico

[d] Instituto de Ingeniería, Universidad Autónoma de Baja California, Campus Mexicali, Av. de la Normal s/n Col. Insurgentes Este, 21280 Mexicali, B.C., Mexico

ARTICLE INFO

Article history:
Received 17 August 2015
Received in revised form 19 October 2015
Accepted 29 October 2015
Available online 14 November 2015

Keywords:
Climate change
Hydrological modeling
Mexico
Semiarid
SWAT
Water management

ABSTRACT

In northern Mexico, water resources management has become a challenging task, aggravated by the vulnerability of this region to climate change. The semiarid Guadalupe River Basin is under additional pressure due to wine production and drinking water supply. We have applied the SWAT model to the upper section of this basin to assess the impacts of several climate change scenarios on its water availability. An overall good performance was obtained (daily and monthly NSE values of 0.66 and 0.86 for calibration; 0.52 and 0.76 for validation). Water balance and flow components prediction was satisfactory. However, although peak flows were well represented, the model overestimated discharge during low flow periods. Once evaluated, high and low emissions climate change scenarios were simulated using projections based on CMIP3 for both scenarios and for short (2010–2039) and long term (2070–2099) obtained from the Baja California Climate Change Action Program. Noticeable impacts of climate change on river flow were obtained, with runoff reductions around −45% in the short term, but up to −60% in the long term. Main drives seem to be precipitation reduction, in addition to an increasing water loss- in percentage-via evapotranspiration. Aquifer recharge is expected to decrease up to −74%, with a consequent reduction of groundwater flow. We also quantified the differentiating impacts during dry, normal and wet years. The latter was the most affected (annual streamflow reduction up to −72%), especially during winter and spring. On the contrary, a slight runoff increase is expected during dry years, especially during summer. These runoff reductions were supposed to be a huge problem for a region where pressure on water resources is already very strong. Our model framework may provide water managers with an approximation of how climate change possibly can affect water availability, serving as a tool to test further scenarios.

1. Introduction

Water resources management and planning around the world have become a challenging task due to climate change uncertainties (Ficklin et al., 2013a) in addition to a global concern on its effects in regions suffering from water scarcity (Mahmoud et al., 2014). In arid and semiarid zones that face high inter-annual rainfall variability and scarcity of fresh water, which are commonly associated to extreme events such as floods and droughts, the sustainable use of this resource becomes a priority. In North America, drought conditions have been persistent extending across Mexico (Stahle et al., 2009) and the United States of America in single-regional and pan-continental scales (Cook et al., 2014). At a local scale, the study of extreme events becomes difficult since it is not easy to analyze impacts with specific constrains such as groundwater availability or crops irrigation.

* Corresponding author at: Department of Geology, Geography and Environment, Geology Unit, Faculty of Biology, Environmental Sciences and Chemistry, University of Alcalá, Ctra. Madrid-Barcelona Km. 33.6, 28871 Alcalá de Henares, Madrid, Spain.

E-mail addresses: eugenio.molinanavarro@gmail.com (E. Molina-Navarro), mhallack@uabc.edu.mx (M. Hallack-Alegría), silvia.martinez@uah.es (S. Martínez-Pérez), jorger@uabc.edu.mx (J. Ramírez-Hernández), alejandro.mungaray@uabc.edu.mx (A. Mungaray-Moctezuma), antonio.sastre@uah.es (A. Sastre-Merlín).

http://dx.doi.org/10.1016/j.agwat.2015.10.029
0378-3774/

In Mexico, water resources have recently experienced rising demands because of population growth, in addition to recurrent droughts that have lasted for 20 years starting in 1994 (Stahle et al., 2009). This situation is particularly severe in northern Mexico (CONAGUA, 2013a), a region that covers approximately 50% of the Mexican total surface area and, with a rapid economic growth. The State of Baja California, northwest Mexico, is located in a semi-arid region, which according to the Baja California Climate Change Action Program report (PEACC, 2012), is particularly vulnerable to climate change. The region is expected to diminish its annual average precipitation in a range of 10–20%, while its temperature is projected to rise from 1.5 °C to 2.5 °C in the next 50 years (PEACC, 2012). Thus, management tools accounting for multiple environmental stressors such as climate change are needed to assess the future of hydrological resources in these regions. One such tool is the Soil and Water Assessment Tool (SWAT). It is a physically based, basin-scale, continuous-time, semi-distributed hydrological model that uses spatially derived data on topography, land use, soil, and weather for hydrology and water quality modeling and operates on a daily time step (Arnold et al., 1998; Arnold and Fohrer, 2005). SWAT has been widely and successfully used throughout the world with different purposes such as planning and management of water resources, modeling sediments and nutrients exports, evaluating the effects of land use management or climate change in both hydrology and water quality or agricultural issues (e.g. Ficklin et al., 2013b; Molina-Navarro et al., 2014a; Napoli and Orlandini, 2015; Nielsen et al., 2013; Savé et al., 2012). Recently, Gebremariam et al. (2014) have evaluated different watershed models, finding SWAT as the most suitable for scenario-testing because of its ease of use and flexibility.

However, SWAT applications in Mexico are scarce in the scientific literature. The model has been used for different purposes in the south of the country (Inurreta-Aguirre et al., 2013; Salas-Martínez et al., 2014), where precipitation is higher and there is absence of water stress. Bueno-Hurtado et al. (2013) have applied SWAT with hydrological purposes in arid zones of México, but model performance results are not offered. The model has been also used in some transboundary large watersheds located in the Arizona-Mexico border (Nie et al., 2011; Niraula et al., 2012, 2015) which have more data availability than the ones inland Mexico. SWAT applications are more frequent in southwest United States, mostly in large watersheds, addressing various objectives such as modeling hydrology and water quality (Ficklin et al., 2013b), modeling pesticide load (Luo et al., 2008) or assessing climate change sensitivity (Ficklin et al., 2013c). Nevertheless, SWAT has not been extensively used in this area yet, probably because of the difficulties that this model presents when applied in arid and semiarid climate rivers due to their spatial and temporal flow variations (Niraula et al., 2012). Single-outlet calibration these rivers watersheds can be misleading and thus spatial calibration based on data at multiple

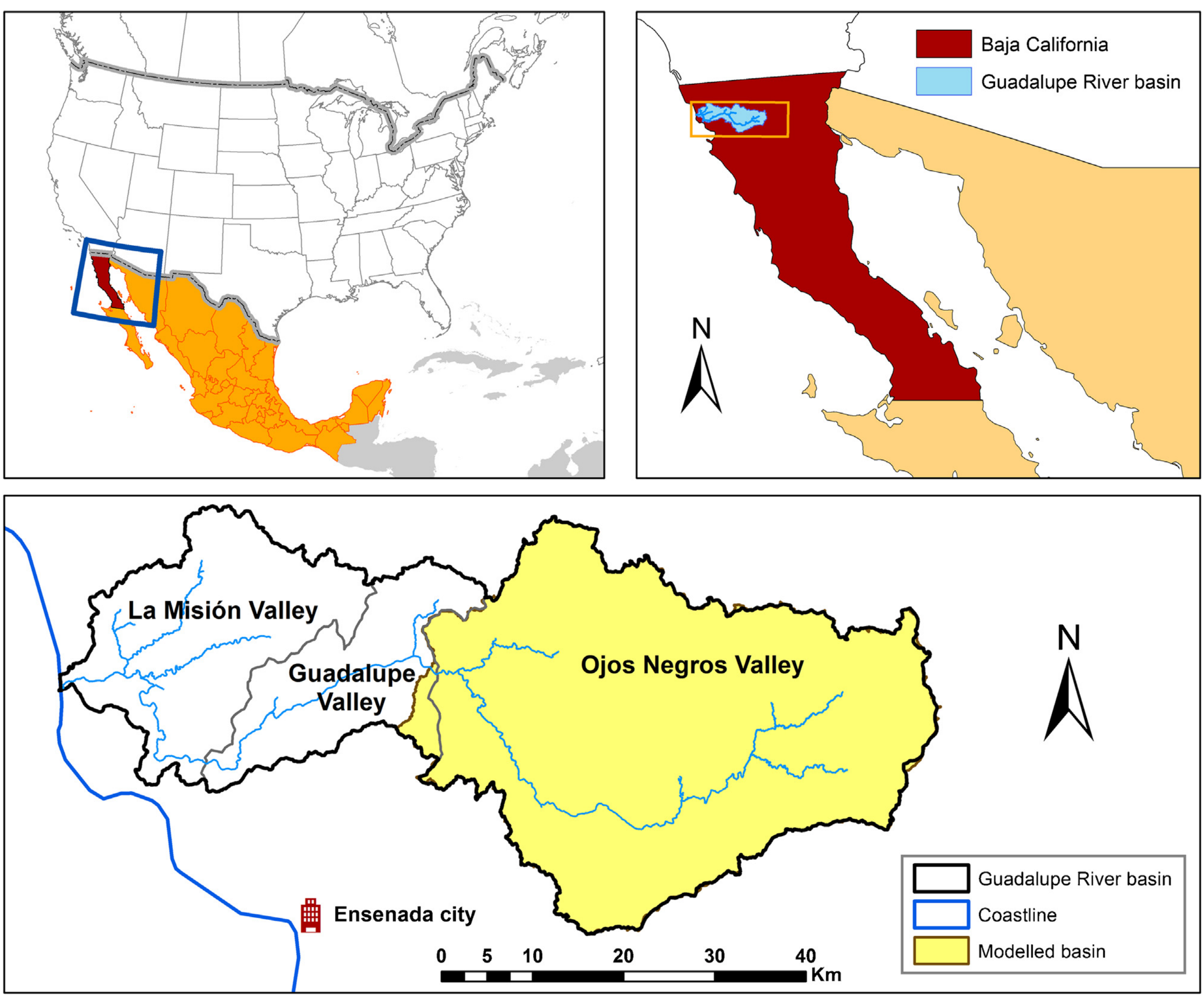

Fig. 1. Location of the Guadalupe River basin in Baja California (Mexico).