ARTICLE IN PRESS

Catena xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Catena

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

Simulation of stream flow and hydrological response to land-cover changes in a tropical river basin

Vicente de Paulo Rodrigues da Silva[a,*], Madson Tavares Silva[a], Vijay P. Singh[b,d], Enio Pereira de Souza[a], Célia Campos Braga[a], Romildo Morant de Holanda[c], Rafaela Silveira R. Almeida[a], Francisco de Assis Salviano de Sousa[a], Armando César Rodrigues Braga[a]

[a] *Federal University of Campina Grande, Campina Grande, PB, Brazil*
[b] *Department of Biological and Agricultural Engineering, Texas A&M Univ., TX, USA*
[c] *Federal Rural University of Pernambuco, UFRPE, Recife, PE, Brazil*
[d] *Department of Civil & Environmental Engineering, Texas A&M Univ., TX, USA*

A R T I C L E I N F O

Keywords:
Land cover
SWAT model
Stream flow
Sediment yield
Surface runoff

A B S T R A C T

Land cover of river basins has undergone multiple modifications and conversions as a result of various pressures on ecosystems. This study calibrates and validates the Soil and Water Assessment Tool (SWAT) model for determining the hydrological response to land-cover changes in the Lower-Middle São Francisco River sub-basin (LMSFR), Brazil. The SWAT model was calibrated with 1993–1994 data from hydrological station at Juazeiro, while data from the 1995–2004 period were used for validation. We analyzed three scenarios of land cover which were compared to current landscape (pasture land): scenario I (pasture land is replaced by natural vegetation), scenario II (pasture land is replaced by maize crop cultivation), and scenario III (pasture land is replaced by bare soil). Calibration of the SWAT model in the LMSFR produced good results, as all evaluation indices reached satisfactory values in both calibration and validation periods for Juazeiro and validation period at Floresta. However, the calibrated model, when applied to Abreus, did not accurately simulate monthly stream flow (where $r^2 = 0.51$ and $NE = 0.26$). Scenario III had the greatest impact and influence on the sediment yield, which corresponded to an increase of 93.7% in comparison to the current land cover. This study identified regions where reforestation should be urgently carried out in the north part and extreme south of the sub-basin due to the overall level of land degradation.

1. Introduction

The land cover affects sediment yield, potential evapotranspiration, and surface runoff of the basin and hence influences the water balance. Hydrologic models are essential for studying hydrologic processes and their responses to both natural and anthropogenic factors (Lironga and Jianyuna, 2012) and play a central role in the development of water management strategies. The models can be applied for planning dam construction in the future and for flood disaster risk management and they are therefore useful for the sustainable development of a country (Vilaysane et al., 2015). Land cover of river basins have undergone multiple modifications and conversions as a consequence of natural causes as well as anthropogenic actions. Land cover policy can play an important role for agricultural and urban landscapes in many regions of the world. In addition, climate change associated with land cover changes causes a strong impact on the water balance of a river basin (Defries and Eshleman, 2004). The causes of land cover change are complex and change over time and from region to region (Qasim et al., 2013).

Potential evapotranspiration exceeds precipitation during most of the year in tropical climates. The recharge in these regions generally occur in short periods of time, when seasonal rainfall and its potential effect on surface runoff can produce the best condition to generate recharge (Nimmo et al., 2005). Tropical river catchments face water resource challenges as population grows exponentially. In tropical areas deforestation of upstream watersheds and urbanization pressure generally lead to an intensification of extreme flow events and evapotranspiration is also affected leading to a broader impact on the water balance. The land use and land cover change have important environmental consequences on a wide variety of environmental issues, such as

* Corresponding author.
E-mail address: vicente.paulo@ufcg.edu.br (V. de Paulo Rodrigues da Silva).

https://doi.org/10.1016/j.catena.2017.11.024
Received 16 May 2017; Received in revised form 17 October 2017; Accepted 27 November 2017

greenhouse gases and climate change, water quality, loss of biodiversity, and loss of soil resources and impacts (Schneider and Gil Pontius, 2001). Land cover refers to natural structures such as vegetation and water surfaces, as well as manufactured structures that cover a certain region, whereas human activities that are related to the soil are called land use. When evaluating land cover and land use changes in Rift Valley, Kenya, using the SWAT model, Baker and Miller (2013) showed that land use changes resulted in the corresponding increase in surface runoff and decrease in groundwater recharge. Phomcha et al. (2012) utilized the SWAT model for recommending effective soil conservation treatments to minimize sediment yield. They demonstrated that the combination of reforestation and mulching was the most effective treatment in reducing sediment yield in the study watershed. Recent studies conducted in different regions of the world have mostly focused on the environmental consequences produced by climate change (Silva et al., 2010a; Parajuli et al., 2009; Setegn et al., 2009; Oeurng et al., 2011). Using the SWAT model, some studies have been carried out for water resources management, with focus on flood control (Durães et al., 2011; Fukunaga et al., 2015; Cibin et al., 2010; Pereira et al., 2016; Wahab et al., 2009; Hundecha et al., 2008).

The SWAT model can be utilized to determine streamflow response to variations of land cover conditions, agricultural tillage operation, and natural rainfall. This model has been used to quantify impacts of climatic change on watershed response in different regions. It has been calibrated and validated for several purposes in several parts of the world, such as climate change (Ficklin et al., 2009; Lironga and Jianyuna, 2012; Awan and Ismaeel, 2014); prediction of streamflow in river basins (Vilaysane et al., 2015); agricultural hydrologic yield (Zhang et al., 2016); water quality analysis (Cho et al., 2016); and estimation of water availability and flood flows (Pereira et al., 2016). In summary, SWAT is a watershed scale model which has been widely used to investigate the effects of natural and anthropogenic disturbances on water and nutrient cycles (Yang and Zhang, 2016). Hydrologic models, including SWAT, have much potential that remains yet to be fully exploited for tropical regions. The human impact on climate during centuries has played an important role in landscape changes, including those arising from land cover and hydrographical variables. However, an assessment of land cover and the impact of its changes over time in Brazil has been less studied. The basic hypothesis of this study is that the overall level of land degradation can be identified by the SWAT model. Additionally, this research can produce results which can be used for sustainable planning and management of the sub-basin. Most researches have mainly focused on streamflow using the SWAT model for temperate zones, while less attention has been given to tropical climate zones, mainly in northeastern region of Brazil where São Francisco River sub-basin is located. This issue is particularly important for regions where there is an entire range of complexity that arises from natural variability and human influences. To meet such demands, the present study aims to calibrate and validate the SWAT model to simulate streamflow and hydrological response to a set of future land cover change scenarios in Lower-Middle São Francisco River sub-basin, Brazil.

2. Materials and methods

2.1. Study area

Lower-Middle São Francisco River (LMSFR), an important sub-basin of São Francisco River basin (SFRB), is located in the northeast region of Brazil between 7°S and 11°S and between 42.5W and 37W (Fig. 1). The total area of the sub-basin is around 110.446 km^2. Since LMSFR is located in a semiarid region it is a water scarce sub-basin with limited rainfall. The average annual rainfall is 500 mm and the mean air temperature is 26 °C (Silva et al., 2010b). The locations of the weather station and stream gauge stations throughout the sub-basin are shown in Fig. 2. LMSFR elevation ranges from 173 m to 1280 m with an average elevation of 506 m. The topographic range varies from the cross-border area of sub-basin high point to the central part low, where the SFRB is located (Fig. 3A). Topography is flat through the river bed. The fruits are cultivated in this area, while *caatinga* and degraded land with low-intensity agriculture are dominant in the high part of the sub-basin. The main soils at LMSFR are Chromic Luvisol, Red-Yellow Podzolic soil and Quartzipsamment, which represent 24%, 12%, and 11.1, respectively.

2.2. Model description

The Soil and Water Assessment Tool (SWAT) was selected for hydrological modeling in this study to quantify the response of streamflow, sediment yield, surface runoff and potential evapotranspiration to land-cover changes in Lower-Middle São Francisco River sub-basin (LMSFR). Although a detailed description of model is given in Neitsch et al. (2002) and Arnold et al. (1998), a brief description is given here. The SWAT model requires daily data of rainfall, maximum and minimum temperature, solar radiation, relative humidity, and wind speed as an input. According to Neitsch et al. (2005) the major components of SWAT are climate, hydrology, erosion, land cover and plant growth, nutrients, pesticides, and land management.

The basic variables used in this study are topography, soil type, land-use, and climatic data that are described as follows: (a) the dominant soil types of Brazil, at the 1:5,000,000 scale; produced by the Brazilian Institute of Geography and Statistics (IBGE, in Portuguese); (b) the soil and land-use-maps, with a resolution of 30 × 30 m, taken from the sensor Landsat TM 5 using the maximum likelihood supervised classification method; (c) a digital elevation model (DEM), with a resolution of 90 × 90 m, produced by remote sensor images; (d) a digital stream network, with a resolution of 90 × 90 m, produced by the DEM processing; (d) SWAT weather input data including solar radiation, maximum and minimum temperature, wind speed and relative humidity taken from the National Meteorology Institute (INMET, in Portuguese) for the period from 1970 to 2010; (e) rainfall and streamflow data taken from the National Water Agency (ANA, in Portuguese) online database. Potential evapotranspiration (PET) was computed using the Penman-Monteith method (Monteith, 1964). The surface runoff volume was estimated using the U.S. Soil Conservation Service curve number procedure (USDA-Soil Conservation Service, 1972). Both digital elevation map and Brazilian classification soil mapping through LMSFR are shown in Fig. 3. The Brazilian soil classification was provided by the Brazilian Agricultural Research Corporation (EMBRAPA, 2006).

We selected three hydrological stations according to stream flow categories (magnitude, frequency and duration) as follows: high (Juazeiro), mean (Floresta) and low (Abreus). The hydrological station at Juazeiro was selected for calibration and validation while the hydrological stations at Abreus and Floresta were selected for validation. Calibration of the SWAT model was performed with the 1993–1994 data, while the 1995–2004 data were used for validation at Juazeiro. The validation periods for Abreus and Floresta were, respectively, 1993–2000 and for 2005–2006. Those stations are located in the sub-basin areas that have a complete daily streamflow dataset for model calibration and validation. Rainfall, temperature, solar radiation, wind speed and humidity data were collected from distributed gauging stations within LMSFR during the period from 1993 to 2004.

The model estimates relevant hydrologic components, such as surface runoff, baseflow, evapotranspiration (ET), and soil moisture change (Lironga and Jianyuna, 2012). For the SWAT model the hydrologic cycle is based on the water balance equation given by:

$$SW_t = SW_o + \sum_{i=1}^{t} (R - S_n - ET - W_a - R_f) \tag{1}$$

where SW_t is the final soil water content on day *t*; SW_o is the initial soil