Science of the Total Environment 636 (2018) 737–750

Contents lists available at ScienceDirect

Science of the Total Environment

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

Simulating the hydrological response of a small tropical forest watershed (Mata Atlantica, Brazil) by the AnnAGNPS model

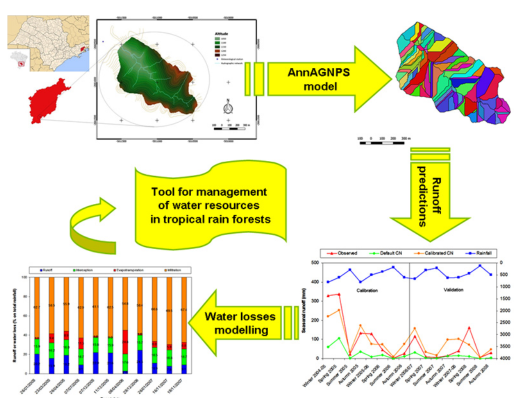
Demetrio Antonio Zema [a], Manuel Esteban Lucas-Borja [b,*], Bruno Gianmarco Carrà [a], Pietro Denisi [a], Valdemir Antonio Rodrigues [c], Mauricio Ranzini [d], Francisco Carlos Soriano Arcova [d], Valdir de Cicco [d], Santo Marcello Zimbone [a]

[a] Department "Agraria", University "Mediterranea" of Reggio Calabria, Località Feo di Vito, I-89122 Reggio Calabria, (Italy)
[b] Departamento de Ciencia y Tecnología Agroforestal y Genética, Universidad de Castilla La Mancha, Campus Universitario s/n, C.P. 02071 Albacete, (Spain)
[c] Departamento de Ciência Florestal da Faculdade de Ciências Agronômicas, Universidade Estadual Paulista, FCA – UNESP, Botucatu, São Paulo, (Brazil)
[d] Instituto Florestal, Governo do Estado de São Paulo, São Paulo, (Brazil)

HIGHLIGHTS

- The runoff prediction capability of AnnAGNPS became satisfactory at annual, seasonal and monthly scales.
- The availability of water can be attributed mainly to groundwater reserves.
- The evapo-transpiration of forest trees plays an important role in the hydrological balance
- The study has demonstrated the basic hydrological role of vegetation in water balance of tropical forest.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 23 February 2018
Received in revised form 23 April 2018
Accepted 24 April 2018
Available online xxxx

Editor: D. Barcelo

Keywords:
Hydrological cycle
Water balance
Model calibration
Evapo-transpiration
Canopy interception
Tropical forest

ABSTRACT

Given the intrinsic hydrological cycle made of large input of water vapour and intense precipitation producing large volumes of water and sediment, modelling runoff and water losses in humid tropical watersheds is important for forest and water resources management. For instance, reliable simulations of the water cycle in such environments are a prerequisite for predictions of water quality, soil erosion and the climate change effects on water resources. The distributed parameter, physically based, continuous simulation, daily time step AnnAGNPS model, was implemented in almost completely forested (98% of its area, 0.56 km^2) Cunha watershed (Brazil) to assess its capability to simulate hydrological processes under tropical conditions. The simulated surface runoff was compared to 4-year observations with statistical indices on several time scales. The model, running with default CN of forest, showed poor predictions of runoff. After increasing CN from 63 to 72 by calibration, the runoff prediction capability of AnnAGNPS was satisfactory on annual, seasonal and monthly scales, while daily runoff predictions were less accurate. Modelling water losses at event scale showed that the effect of forest vegetation on water retention during a single precipitation was more limited than for longer periods (months, seasons and years), since evapo-transpiration and interception account for small shares (>20%) of total precipitation.

* Corresponding author.
E-mail address: manuelesteban.luca@uclm.es (M.E. Lucas-Borja).

https://doi.org/10.1016/j.scitotenv.2018.04.339
0048-9697/

This study demonstrated that the AnnAGNPS model has reliable runoff prediction capacity in tropical forest watersheds at the annual and seasonal scales (E > 0.73), whereas daily runoff simulations are less accurate (E = 0.44). The use of this model may prove an important tool for water resource and territory management in tropical rainforests.

1. Introduction

Tropical forests are the richest terrestrial ecosystems in biodiversity and structural complexity terms, and perform important ecological functions, such as climatic regulation, water and nutrient cycling, maintenance of biodiversity and reducing of greenhouse gas emissions, among others (Whitmore, 1990). Tropical forests are essential for maintaining the ecological integrity of rivers and their associated watersheds (Ataroff and Rada, 2000; Neill et al., 2001). In these environments the Atlantic Forest is the most threatened biome in Brazil (SOS Atlantic Forest and INPE, 2013). As Silvano et al. (2005) stated, land use practices that reduce riparian forest cover have several impacts on streams, such as the increased sediment load and nutrient enrichment due to runoff. Therefore for tropical forests, and especially for Brazilian Atlantic forests where data on climate and runoff is scarce (especially for Mata Atlantica, Fujieda et al., 1997; Rodrigues et al., 2017; Marmontel et al., 2018), water balance evaluations are a prerequisite to understand key hydrologic cycle processes. The watersheds of humid tropical zones are characterised by large energy inputs in the form of fluxes of water vapour from mid latitudes, intense and constant precipitation, rapid weathering of inorganic and organic matter, and the rapid introduction of large volumes of water and sediment (Wohl et al., 2012). One of the main characteristics of tropical ecosystems is the intra-annual variability of precipitation and this, in conjunction with land use, can strongly affect a basin's hydrological regime (Liu et al. 2014; Shi et al. 2013; Viola et al., 2014).

The hydrologic cycle is used to model the storage and movement of water between different layers of the Earth, such as biosphere, atmosphere, lithosphere and hydrosphere. Rapidly changing climate and land use management may place the water-related functions of forests at risk. In this context, simulation tools able to accurately predict the hydrological behaviour of tropical forests are necessary. If these tools are available and their use is reliable, the future management of tropical forests and water resources may be more easily targeted to their conservation and valorisation.

An integrated approach is vital for successful watershed ecosystems management (Verstraeten et al., 2003). Computer-based hydrologic models are essential tools for water resource planning, development and management because they enable long-term simulations of the effects of watershed processes and management activities (Singh and Woolhiser, 2002). The evaluation of best management practices has also been facilitated by watershed hydrologic models (Arabi et al., 2006; Douglas-Mankin et al., 2010). A number of watershed-scale models with components able to simulate water runoff, soil erosion and sediment and pollutant transport have been developed that vary in complexity and data input requirement terms (Borah and Bera, 2004). However, when hydrological and geomorphological data are scarce, which is the case of Brazilian watersheds, it is unfeasible to apply a complex hydrologic model that is driven by large amounts of data (Beskow et al., 2011).

Among the available hydrological models on the watershed scale, AnnAGNPS and SWAT use the SCS-TR 55 method for runoff calculations (SCS, 1986), which is a suitable approach in poor-data environments. The basic principles of AnnAGNPS are similar to those of SWAT, but best management practices simulations appear to be the strength of AnnAGNPS (Srivastava et al., 2002). Thus this latter model is more advisable for the future planning of watersheds. The AnnAGNPS model combines the advantages of GIS (Geographic Information Systems) data processing with the physical characterisation of watersheds by offering modelling opportunities for ungauged areas that have limited data and prohibit using models that rely on calibration to obtain input variables (Shamshad et al., 2008). The model has been successfully used in many areas of the world in recent years, including Spain (Chahor et al., 2014; Taguas et al., 2009; Zema et al., 2016), Nepal (Shrestha et al., 2006), Italy (Licciardello et al., 2007), Belgium (Zema et al., 2012), Czech Republic (Kliment et al., 2008), India (Sarangi et al., 2007), Australia (Baginska et al., 2003), Malaysia (Shamshad et al., 2008), Canada (Das et al., 2006), USA (Polyakov et al., 2007; Parajuli et al., 2009; Yuan et al., 2008; Pease et al., 2010) and China (Liu et al., 2008; Hua et al., 2012). These studies evaluated the ability of the AnnAGNPS model to predict runoff, sediment and pollutant loadings under different climate and land use conditions in various watersheds with areas ranging from 0.1 to 2500 km^2. Conversely, and as far as the authors know, no AnnAGNPS applications in watersheds of tropical forests, such as Brazilian Atlantic biomes, are used to model runoff generation and other hydrological processes. Very few works conducted under tropical conditions exemplify the difficulty in obtaining the appropriate number of parameters needed in the calibration of this model, especially in Brazil, where these data types are scarce (De Mello et al., 2016; Marmontel et al., 2018). Moreover in Brazil, these studies have taken into account large basins (Viola et al., 2014), and have thus neglected smaller watersheds, where instead research has provided some of the most important insights into hydrological functions in forest ecosystems (Neill et al., 2006). In many watersheds in Brazil, streamflow data are less commonly available than rainfall records. Quantitative assessments of streamflow by rainfall-runoff models have not been made, and have left serious problems with land-use change and its effects on water resource management to one side (Beskow et al., 2011).

In a small watershed (Cunha, Brazil), taken as a case study, this paper aims to evaluate: (i) the accuracy of the AnnAGNPS model in simulating the hydrological response of Brazilian Atlantic tropical forests by default input parameters using a 4-year database of observations; (ii) the possibility to improve the model's runoff prediction capacity through calibration; (iii) propose the resulting value of calibrated Curve Numbers for tropical forests; (iv) if the model proves reliable under the experimental conditions, the amounts of different water losses (e.g., infiltration, evapo-transpiration, interception) in tropical forests, as predicted by AnnAGNPS on the daily scale.

If the applicability and reliability of this model are verified by the calibration/validation activity of this study on the different time scales (annual, seasonal, monthly and daily), AnnAGNPS may help land managers to adopt strategic choices to manage water resources and predict the hydrological effects of climate change on tropical forest watersheds in Brazil.

2. Materials and methods

2.1. Study area

The Cunha watershed (Fig. 1a) is located in the Parque Estadual da Serra do Mar (Cunha Municipality, Sao Paulo State, Brazil). The study area consists of a mountain plateau of 1000–1200 m altitude, and the headwater area of the Paraiba Valley (East Atlantic region). The region is covered with the Mata Atlantica (rainforest of the Serra do Mar mountain chain). This latter is one of the most typical areas of Atlantic forest.