Ecological Indicators 58 (2015) 55–63

Contents lists available at ScienceDirect

Ecological Indicators

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

Analyses of landuse change impacts on catchment runoff using different time indicators based on SWAT model

Bingqing Lin[a], Xingwei Chen[a,b,*], Huaxia Yao[c,d], Ying Chen[a], Meibing Liu[a], Lu Gao[a], April James[d]

[a] The Geographical Institute of Fujian Normal University, Fuzhou 350007, China
[b] Cultivation Base of State Key Laboratory of Humid Subtropical Mountain Ecology, Fuzhou, China
[c] Dorset Environmental Science Centre, Ontario Ministry of Environment and Climate Change, 1026 Bellwood Acres Road, Dorset, Ontario, Canada P0A 1E0
[d] Department of Geography, Nipissing University, 100 College Drive, Box 5002, North Bay, Ontario, Canada P1B 8L7

ARTICLE INFO

Article history:
Received 28 August 2014
Received in revised form 14 May 2015
Accepted 18 May 2015

Keywords:
Landuse change
Change in runoff
Flood indicator
Drought indicator
SWAT model
Jinjiang catchment

ABSTRACT

Previous researches mainly focused on the runoff responses to landuse change based on annual, seasonal or monthly time scales, there are few studies based on daily scale. We conducted a comprehensive investigation into runoff responses on the daily scale as well as annual and monthly time scales using SWAT, and compared the impacts of time scales with different time indicators quantitatively. Jinjiang, a coastal catchment of southeast China with a humid sub-tropical climate, was used for simulations. A calibrated SWAT model produced satisfactory reproduction of annual, monthly and daily runoff processes over a nine-year (2002–2010) period at three gauging stations. Runoff was then simulated and compared using the same meteorological input but two different landuse scenarios (1985 and 2006, with reduced forest and increased cropland and urbanized area). The results showed varying change in runoff among three time scales and three catchments. The annual runoff had the smallest increase between two scenarios, monthly runoffs had medium rates (increasing in all months except October–November), and daily runoff had the largest rates with the increase in flood peaks but decrease in drought flows, because of the variable influence on interception/evapotranspiration loss, percolation and antecedent soil water storage. Indicators of different time scales (annual runoff, monthly runoff, maximum 1-day and 5-day flood runoff, minimum 1-day and 7-day runoff) proved appropriate for analysing landuse change impacts.

1. Introduction

Water quantity and quality are critical factors affecting the ecological integrity of aquatic systems, and widespread alteration of flow regimes requires scientific knowledge of hydrological indicators for the protection of river ecosystems (Armanini et al., 2011); a Canadian Ecological Flow Index was developed based on benthic macroinvertebrate flow sensitivity index for Canadian rivers. Stream runoff plays an important role in water quality and ecology including phytoplankton, zooplankton and bacterial communities (Godlewska et al., 2003; Sokal et al., 2010; Wu et al., 2015), and hydrological indicators are included and used in ecological research and management such as watershed or stream health assessments (e.g., US EPA, 2012; Biggs et al., 2002).

Hydrological indicators, representing part of ecological parameters, are often altered by natural or artificial processes such as climate change and landuse change. As one of the important drivers leading to hydrological and ecological change, landuse change may influence canopy interception, evapotranspiration and percolation and eventually cause flood-drought disasters or ecological problems (Chang, 2007; Chen et al., 2009; Gebremicael et al., 2013; Saghafian et al., 2008). The relations of hydrological components and landuse have been researched around the world, and used to predict the impacts of future landuse change on hydrology and water resources (Maetens et al., 2012; Bewket and Sterk, 2005; Du et al., 2012). Typical methodologies used in these studies included observations from experimental catchments, time series analysis for characteristic variables (e.g., runoff, evapotranspiration), and simulation studies using hydrological models, as reviewed by Wei et al. (2013).

Hydrological models including distributed physically based models, such as SHE, TOPMODEL, HEC, VIC, IHDM, WATFLOOD and SWAT, are capable of simulating temporal-spatial variations in hydrological processes and assisting in understanding the

* Corresponding author at: The Geographical Institute of Fujian Normal University, Shangsan Street #8, Fuzhou City 350007, Fujian Province, China. Tel.: +86 13067215215.
E-mail address: cxwchen215@163.com (X. Chen).

http://dx.doi.org/10.1016/j.ecolind.2015.05.031
1470-160X/

mechanisms of influence behind landuse impacts. Many previous studies have demonstrated the ability of SWAT in detecting the impacts of landuse and climate change on hydrological components in different areas (Fan and Shibata, 2015; Nie et al., 2011; Guo et al., 2008; Zhou et al., 2013; Gassman et al., 2007). SWAT has been applied to investigate the influence on water resource by simulating annual yield for different periods which differed in landuse (Baker and Miller, 2013; Nie et al., 2011), the response of monthly runoff to urbanization at Charlie Creek, Florida (Dixon and Earls, 2012), the changes in monthly and seasonal runoff over the course of a year (increased runoff in flood season, decreased runoff in drought season) caused by damages to natural forests in Poyang Lake basin (Guo et al., 2008). SWAT has already been used to study the influence of landuse change on annual and monthly runoffs in our study catchment, the Jinjiang catchment, a result of the rapid economic growth, as seen elsewhere in the south-eastern coastal region of China (Wang and Chen, 2008). However, its applications to daily runoff changes are limited in the literature. Generally, the studies which have focused on evaluating hydrologic change in annual runoff do not sufficiently describe changes at the daily scale. Zhou et al. (2013) simulated change in runoff for all three time scales (annual, monthly, daily). However, the hydrologic changes among time scales have been rarely discussed in the literature and what kind of time indicators is applicable for the daily runoff has not been reported. Relative to the longer scale, the shorter-scale runoff has less stability and more complicated relations with landuse (Wei et al., 2005). We believe that an investigation into landuse impacts on runoff for different time scales is meaningful to illustrate the impact mechanisms on hydrological processes. Therefore, we chose the Jinjiang River catchment and SWAT to simulate changes to runoff at annual, monthly and daily time scales under two landuse scenarios, and to analyze the differences in the responses with different time indicators. Also we note and consider the role played by precipitation in the runoff responses to landuse change.

2. Study area and data

Jinjiang catchment is located predominantly in Quanzhou City, in south-eastern Fujian Province of China. It has an area of 5629 km^2 and occupies 53.8% of Quanzhou land area, and the elevation ranges from 0 to 1580 m. There are two major river branches within Jinjiang River, the east branch goes through Shanmei station and the west branch goes through Anxi station, merging 2.5 km upstream of the Shilong station. The drainage area upstream of Shilong is our study catchment (5042 km^2, Fig. 1). The study area is characterized by a sub-tropical climate, with average annual temperature and precipitation of 20° and 1686 mm, respectively. More than 80% of the annual precipitation falls in the wet season (from March to September) with both convective storms and sea-based typhoons. The dominant landuse is forest, followed by orchard (fruit trees, tea trees, etc.), cropland (e.g., rice and peanut land) and urbanized area. The catchment has experienced intensive human activities and rapid economic development over the past decades, resulting in extensive landuse change and substantial impact on river runoff.

The spatial information and data include DEM, soil type and landuse. The 30 m × 30 m resolution DEM was obtained from the International Scientific Data Platform of the Chinese Academy of Sciences (http://datamiffor.csdb.cn/admin/datademMain/jsp). The digital soil type map (1:500,000) from the Soil Fertilizer Laboratory of Fujian Province was used to identify eleven soil types for our catchment. Soil water characteristics (e.g., hydraulic conductivity, available water capacity) for each soil type were obtained by using the SPAW software developed by USDA (Saxton and Rawls, 2006).

Landuse maps are available for two separate years (1985 and 2006) and were obtained from Landsat Thematic Mapper (TM) images by supervised classification and manual interpretation

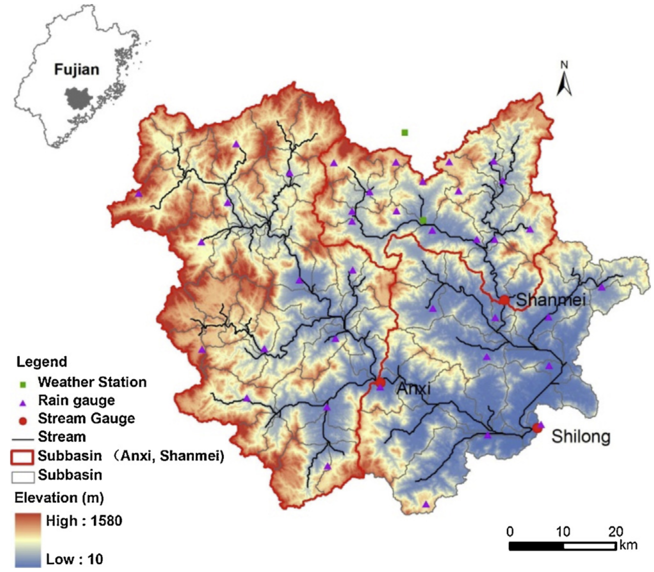

Fig. 1. Study catchment, its river system, and gauging stations (DEM source: International Scientific Data Platform of the Chinese Academy of Sciences).

after radiometric and geometric correction. The 1985 map was provided by the Nanjing Soil Institute of Chinese Academy of Sciences, and the 2006 map was produced by our team. Landuse was categorized into seven types: cropland (e.g., rice and peanut land), forest, grassland, orchard (e.g., tea and fruit land), water, urban, and bare land. Landuse area and their changes between 1985 and 2006 are listed in Table 1. From 1985 to 2006, the major changes were attributed to rapid expansions of orchard and urbanized areas, at expense of reduced cropland, forest and grassland. Over the 21-year period, the total area of landuse change was 44.9%, 48.9%, and 38.8% for Shilong, Anxi, and Shanmei catchments, respectively. During this period, the entire study catchment lost cropland, grassland and forests by 49.6%, 88.3% and 9.3%, respectively. Lost forest area was as large as 289 km^2, although only representing 9.3% of the total watershed area. In contrast, orchard and urban lands have significantly increased by 1173.2% and 227.1%, respectively. Anxi sub-catchment had undergone the most drastic landuse change, which decreased in cropland and forest by 54.3% and 19.1%, increased in orchard and urban by 1254.4% and 280.7%, respectively. The Shanmei sub-catchment had smaller changes (forest lost by only 2.4%) because it belongs to the environmental management area of the Shanmei Reservoir.

We selected 2001–2010 as the study period, because discharge data before 2001 were not available. The 2001–2010 are used to represent post landuse that coincides with the 2006 landuse map, and the 9 years of data allow examination of inter-annual variability (e.g., variation in precipitation). River discharge data (2001–2010) were provided by the Water Conservation Agency of Fujian Province for the stations at Anxi and Shilong, and by Quanzhou City for the Shanmei station. Meteorological data (daily precipitation, daily maximum temperature, daily minimum temperature, daily mean relative humidity, daily mean wind speed) for 2001–2010 were provided by the Meteorology Agency of Fujian Province, including two weather stations at Yongchun and Dehua, and 32 rain gauges in the catchment (Fig. 1).

3. Methodology

3.1. Application of SWAT

SWAT (Soil and Water Assessment Tool) is a physically based distributed hydrologic model operating on a daily time step and is designed to predict impacts of land management practices on