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The Impact of El Niño/Southern Oscillation on Hydrology and Rice Productivity in the Cauvery Basin, India: Application of the Soil and Water Assessment Tool

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ABSTRACT

This study was performed to further understanding of the variations in hydrology and rice crop productivity during different El Niño/Southern Oscillation (ENSO) events in the Cauvery River Basin of Tamil Nadu, India using the Soil and Water Assessment Tool (SWAT). The entire Cauvery Basin was divided into 301 sub-basins and further subdivided into 3,601 Hydrological Response Units (HRU). Based on the National Oceanic and Atmospheric Administration (NOAA) official website, information on El Niño (1972, 1982, 1987, 1991, 1997, 2002 and 2004) and La Niña (1970, 1971, 1973, 1974, 1975, 1988, 1998, 1999 and 2000) years were obtained. The SWAT model was continuously run from 1970 to 2008, and a composite for El Niño, La Niña and normal years was constructed to understand their influence on hydrology and rice crop productivity in the study area. From the analysis, it was clear that an El Niño episode is correlated with rainfall, hydrology and rice productivity in the Cauvery river basin. The validation of the SWAT model indicated the capability of SWAT to accurately predict stream flow and rice productivity. It was evident from the investigation that the quantum of rainfall was more during El Niño years with high inter-annual rainfall variability (809.3 mm to 2,366 mm) compared with La Niña and normal years. As a result, the soil water recharge, including percolation and soil water availability in the surface layers, was increased in the El Niño years. Simulated rice productivity over 39 years in the Cauvery Basin ranged between 1,137 and 7,865 kg ha^{-1} with a mean productivity of 3,955 kg ha^{-1}. The coefficient of variation in rice productivity was higher during La Niña (21.4%) years compared with El Niño (14.7%) and normal years (14.6%). The mean rice productivity was increased in both El Niño and normal years, indicating the possibility of higher yields than those in La Niña years. An analysis of the hydrological data and rice productivity showed that the risk of failure was low during El Niño years compared with normal or La Niña years. This behavior could be utilized for forecasting rice crop productivity under different ENSO conditions and can provide information for policy makers when deciding on water allocation and import / export policies.

1. Introduction

Short-term climate variations exert large influences on hydrology and crop productivity. It is well recognized that El Niño/Southern Oscillation (ENSO) is the dominant mode of short-term climate variability, and its impacts are felt worldwide. The direct impacts of ENSO on the tropics are severe, particularly for countries that are affected by monsoons, such as Australia, India, Indonesia and Africa (Quinn 1987; Sikka 1980; Shukla 1987; Krishna Kumar et al. 1999). The 1997–98 El Niño, which is regarded as the "El Niño of the 20th Century", caused widespread droughts in the tropics leading to forest fires, with an estimated economic loss exceeding $20 billion USD in Southeast Asian countries (Stone et al., 1996). Due to its widespread global impact, understanding and modeling the processes and predicting ENSO have dominated climate research over the last two decades (Wallace and Thompson, 2002; Wang et al. 2004). The Indian Meteorological Department incorporates ENSO information into the statistical model used for forecasting monsoon rainfall (Rajeevan et al. 2006).

From observations, McBride and Nicholls (1983) and Nicholls (1988) found a useful predictive relationship between the ENSO index of a particular season and the regional rainfall over Australia and Indonesia in subsequent seasons. Similar relationships are also noticeable over the Indian monsoon region (Shukla and Mooley, 1987). For instance, Geethalakshmi et al. (2005) studied the linkage

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between ENSO and rainfall over Tamil Nadu, India during both the southwest (June through September) and northeast (October through December) monsoon seasons. The authors noted that during the summer monsoon, the relationship is negative, i.e., rainfall is less than normal during El Niño years, and the opposite is observed during La Niña years. In contrast, the relationship during the northeast monsoon is positive, i.e., rainfall is more than normal during El Niño years and less than normal during La Niña years (Geethalakshmi et al. 2009). Because rainfall variations have direct impacts on local agriculture, efforts have been made to utilize the ENSO-rainfall linkage for agricultural planning (Nicholls, 1988; Hansen et al., 1998; Mjelde and Keplinger, 1998; Hill et al., 1999).

A study conducted by Annamalai et al. (2007) revealed the uncertainty of the ENSO-monsoon relationship in future warming scenarios. This indicates that understanding and modeling the effects of ENSO, including changes in rainfall, on local hydrology and agricultural productivity are important both in current and future climates. Hence, this paper focuses on understanding the categorical ENSO influence on hydrology and rice productivity in the Cauvery River Basin, India.

The Cauvery River Basin is an important river basin in India in terms of agriculture and food security. The basin spans two southern Indian states, Karnataka and Tamil Nadu. The Tamil Nadu Cauvery Basin contributes 40% of the food grain production of Tamil Nadu. Rice is the major crop and is primarily irrigated using water from the Cauvery River. During the season of kharif (June-September), the beginning of crop activity depends upon the release of water from the Mettur Reservoir. Although the traditional Mettur Dam water release date has been June 12th since its construction in 1934, the water has only been released on the scheduled date fourteen times. In the other years, the release date has been delayed by the Chief Engineers of the Cauvery Basin, Public Works Department authorities and the District Collectors based on the amount of water in the reservoir. Due to large variations in rainfall in the catchment as well as in the delta area of the basin, water availability during paddy cultivation is becoming highly uncertain. Additionally, the possible anthropogenic effect of induced warming on increasing the variability of precipitation cannot be excluded. Hence, cultivating paddies in the kharif season is a challenging issue in the Cauvery Basin. In this context, a study was conducted with the goal of testing the impact of ENSO events on water availability in the Cauvery River Basin and its subsequent influence on rice production.

2. Materials and methods

2.1. Description of the study area

The Cauvery River Basin (Fig. 1) is located in southern India and covers an area of 81,155 km^2. Of this area, 44,016 km^2 lies in the state of Tamil Nadu in India from 10.00 to 11.30 °N and 78.15 to 79.45 °E; the rest is located in the state of Karnataka.

The Tamil Nadu Cauvery Basin receives an annual average rainfall of 956 mm, and over 4.4 million people are employed in the agricultural sector in this basin. Major rivers in the Cauvery watershed are Cauvery, Vennaru, Kudamuruti, Paminiar, Arasalar and Kollidam. Most of the upstream and catchment areas of the Cauvery River Basin receive rainfall during the southwest monsoon season, filling up the Mettur Reservoir on the Cauvery River, which supplies water to the Tamil Nadu Cauvery Basin. However, the Cauvery delta area of Tamil Nadu receives most of its rainfall during the northeast monsoon season. Because this river basin receives rainfall from both the monsoons, rice is cultivated in both the kharif (southwest monsoon) and rabi (northeast monsoon) seasons.

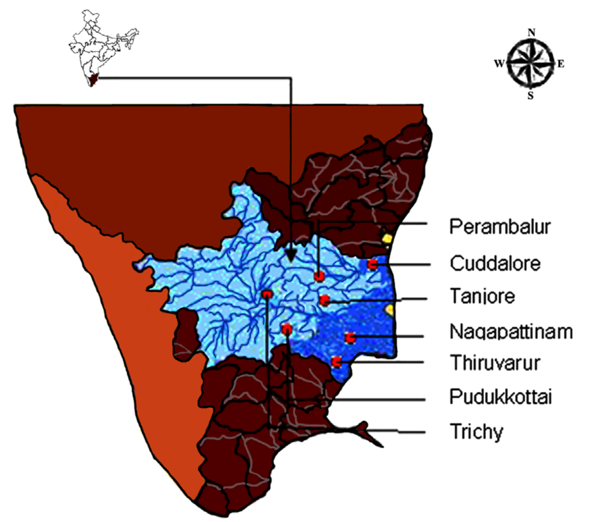

Fig. 1. Location of Cauvery river basin in India.

2.2. SWAT model description and model setup

The Soil and Water Assessment Tool (SWAT) is a GIS (Geographic Information System)-based decision support tool that has been successfully applied in many watersheds around the world including the United States, the United Kingdom and Africa (Arnold et al., 1993, 1998). In the current study, SWAT was used to understand the variations in hydrology and rice crop productivity of the Cauvery River Basin during different observed ENSO events. The SWAT model can be used for assessing the impact of strategic decisions such as changing the crop pattern, identifying new crop areas, selecting the best sowing time, improving irrigation water management, developing optimum fertilizer schedules for better economic results.

For running the SWAT model, a Digital Elevation Map of the study region was derived from the STRM 90 m elevation dataset. The elevation in the Cauvery Basin varies from zero to 2,674 m above MSL. Automatic delineation of the watersheds was performed to explain the spatial variability of various input parameters. In this study, the basin between the Mettur reservoir of Tamil Nadu and Coloroon was modeled. Information on soil was based on the soil map at 1: 50,000 scale obtained from the Remote Sensing Unit of Tamil Nadu Agricultural University. Although the Cauvery Basin has a variety of soils, the majority of the study area has sandy clay loam and sandy loam soils. A sizable area also possesses sandy clay and clay soils. The land use data were obtained from the Indian Space Research Organisation (ISRO), Bangalore. In the Cauvery Basin, 77.8% of the area is covered by rice crop, 9% by rice fallow pulses and 8.5% by forest cover. A marginal area is occupied by corn, cotton, grain sorghum and other crops (Fig. 2). Most of the rice crop is grown on a slope between 0 and 3%, and forest occupies most of the high, steep areas. Because the rice crop occupies most of the cultivable area, we focused our study on the rice crop.

The entire Cauvery Basin was divided into 301 sub-basins for spatial aggregation, and each sub-basin was further divided into hydrological response units (HRUs), which have unique combinations of soil, slope, land use and weather. For each land use in every HRU, management practices, including time of sowing, harvest, intercultural operations and different inputs, were specified. In total, there were 3,601 HRUs in the study area.

Observed daily rainfall (Fig. 3) and temperature data from 1970 to 2008 were obtained from the research stations of Tamil Nadu Agricultural University and the India Meteorological Department. For rice yield simulation, the SWAT Model uses maximum and minimum temperature, solar radiation, rainfall, wind speed and relative humidity prevails during the crop growing period.