Agricultural Water Management 104 (2012) 113–120

Contents lists available at SciVerse ScienceDirect

Agricultural Water Management

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

Comparison of soil and water assessment tool (SWAT) and multilayer perceptron (MLP) artificial neural network for predicting sediment yield in the Nagwa agricultural watershed in Jharkhand, India

A. Singh[a,*], M. Imtiyaz[b], R.K. Isaac[c], D.M. Denis[c]

[a] Regional Research Station (Old Alluvial Zone), Uttar Banga Krishi Viswavidyalaya, Majhian, Patiram, Dakshin Dinajpur, West Bengal, India
[b] College of Technology, Sam Higginbottom Institute of Agriculture, Technology and Sciences, Allahabad, Uttar Pradesh, India
[c] Department of Soil Water Land Engineering and Management., Sam Higginbottom Institute of Agriculture, Technology and Sciences, Allahabad, Uttar Pradesh, India

ARTICLE INFO

Article history:
Received 10 June 2011
Accepted 2 December 2011
Available online 23 December 2011

Keywords:
Hydrologic model
Water resources
Watershed hydrology
Measured sediment yield
Model calibration
Model validation

ABSTRACT

The present study was conducted in the Nagwa watershed in Jharkhand state, India. The watershed has been identified as a sensitive area for sediment and non-point source pollution. Damodar Valley Corporation (DVC), Hazaribagh, India has taken initiatives to implement several soil and water conservation measures. A calibrated and validated model to simulate hydrological processes will be a great help to the concerned watershed managers. The objectives of this study were to compare the monthly sediment yield simulation results from the soil and water assessment tool (SWAT) and the multilayer perceptron (MLP) artificial neural network model during the calibration (1993–2004) and validation periods (2005–2007), and determine the most appropriate model for the watershed. The annual average measured sediment yield was 3.7 t/ha. The annual average simulated sediment yield was 3.1 and 5.0 t/ha for MLP and SWAT model, respectively. Both models generally provided good correlation and model efficiency for simulating monthly sediment yield during calibration and validation. For the SWAT model the coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (*NSE*) values were 0.78 and 0.76 during calibration and 0.68 and 0.66 during validation, respectively. The MLP model performed better than SWAT with R^2 and *NSE* values of 0.84 and 0.76 during training and 0.77 and 0.74 during validation periods, respectively.

In the present study, the MLP artificial neural network model was a better model than SWAT for simulating sediment yield from the single outlet of this watershed based on calibration and validation results. The water resource managers and different stakeholders can use this validated model for planning and implementing appropriate soil and water conservation measures.

1. Introduction

Water quantity and quality problems are of great concern everywhere in the world and especially in watersheds located in sub-humid and subtropical climate regions of India that are dominated by monsoon climate conditions. Most of the rainfall occurs in 18–38 events of high magnitude which generate significant surface runoff during the monsoon period from June to October (Thapliyal, 1997). These heavy rains cause floods and severe erosion of the top soil layer which ultimately leads to degradation of soil resources and pollution of surface water bodies that are used for irrigation, power generation, sanitation, recreation and other purposes. Extensive soil erosion and its associated problems have already deteriorated land and water resources of India. Sheet and rill erosion exist almost throughout the whole country. If the present rate of erosion is allowed to continue, it may pose severe problems for agriculture. Dhruva Narayan and Ram Babu (1983) have stated that around 10% of the total annual soil loss of 5334 Mt in India is deposited in reservoirs and reduces their storage capacity to a large extent. As the eroded soil carries huge amounts of nutrients, nutrient loss is also an associated problem. In this situation a concerted effort is needed to formulate plans and implement appropriate soil and water conservation measures. Before taking up any effective measures to check sediment loss, proper understanding of the watershed and the hydrological processes is essential and requires the application of various models. This saves time and helps planners to plan appropriately. Numerous researchers have studied hydrological models and data driven models throughout the world. Vaidyanathan (1991) has reviewed the programs on soil and water conservation measures and pointed out several drawbacks. He remarked that there is a need to develop scientific information and databases on natural resources at watershed level. In India, few watersheds are being monitored such as the watershed under investigation. Hydrological models have

* Corresponding author. Tel.: +91 3522 253898; fax: +91 3522 253637.
E-mail address: ajai_jpo@yahoo.com (A. Singh).

0378-3774/$ – see front matter
doi:10.1016/j.agwat.2011.12.005

now become indispensable to understand the natural hydrological process occurring at watershed scale. As these processes are further modified by human activities, the application of integrated watershed modeling becomes more important to study the change in land–water–atmosphere interactions. The integrated effect of practices such as agricultural management and withdrawals from surface water and groundwater can be better examined through a modeling approach.

There are many process based hydrological models available currently. Among these, soil and water assessment tool (SWAT) (Arnold et al., 1998) has been the most widely used model, which was developed to simulate runoff, sediment yield and non-point source pollutants losses from agricultural watersheds. Previous applications of SWAT for water flow and pollutant loading have shown favorable comparisons with the measured counterparts in various parts of the United States (Rosenthal et al., 1995; Arnold and Allen, 1996, 1999; Srinivasan et al., 1998). The robustness of SWAT in predicting sediment loads at different watershed scales has been shown in several studies. Srinivasan et al. (1998) concluded that SWAT sediment accumulation predictions were satisfactory for the 279 km^2 Mill Creek watershed located in north central Texas. Arnold and Allen (1999) used SWAT to simulate average annual sediment loads for five major Texas river basins and concluded that the SWAT predicted sediment yields compared reasonably well with estimated sediment yields obtained from rating curves. Saleh et al. (2000) applied the SWAT model in two phases to assess the effect of dairy production on water quality within the Upper North Bosque River Watershed (UNBRW) of north central Texas. The SWAT model also adequately predicted monthly trends in average daily flow, sediment, and nutrient loading over the validation period with Nash-Sutcliffe coefficients ranging from 0.54 to 0.94 except for NO_3–N which had a value of 0.27. They also concluded that the total-N and total-P loads in the UNBRW could be reduced by about 33 and 79%, respectively, if the dairy waste application fields were replaced by grassland. Santhi et al. (2001) found that SWAT simulated sediment loads matched well with measured sediment loads for two Bosque River (4277 km^2) sub-watersheds, except in March. Tripathi et al. (2003) found that SWAT sediment predictions agreed closely with observed daily sediment yield for the watershed in Damodar–Barakar catchment. Kaur et al. (2004) concluded that SWAT predicted annual sediment yields reasonably well for a test watershed in Damodar–Barakar, India. Mishra et al. (2007) found that SWAT accurately simulated the effects of three check dams on sediment transport within the Banha watershed in northeast India.

Usually the evaluation of the hydrological processes is done by using the conceptual models which present good results. However, conceptual models are difficult to develop and the calibration of the model parameters is subjective. Alternatives are empirical models which connect inputs and output by means of a mathematical function without an explicit relationship with the catchment characteristics. An artificial neural network (ANN) is an example of an empirical model. ANN is a computing method which mimics the human brain and nervous system. It is a mathematical structure, which is capable of approximating arbitrarily complex nonlinear processes that relate the inputs and output of any system. ANN models have been used successfully for modeling complex nonlinear input/output time series relationships, classification, pattern recognition and other problems in a wide variety of fields. The high degrees of empiricism and approximation in the analysis of hydrologic systems are highly suitable for the application of ANN (Hsu et al., 1995). Artificial neural networks are used for estimating the values of variables in hydrologic and mechanical modeling like daily and monthly flow, flow rate, temperature, snow melting and suspended materials. Some of these studies are: estimation of maximum flood (Bodri and Cermak, 2000), estimation of flow rate (Dibike and Solomatine, 2001), modeling of precipitation and runoff modeling (Luk et al., 2001; Nagy et al., 2002), reservoir operation (Chang et al., 2005), hydrologic time series modeling and sediment transport prediction (Firat and Gungor, 2004; Agarwal et al., 2006), and rainfall-runoff modeling (Sajikumar and Thandaveswara, 1999; Kumar et al., 2005; Antar et al., 2006). Raghuwanshi et al. (2006) developed ANN models to predict both runoff and sediment yield on a daily and weekly basis, for a small agricultural watershed and reported that these ANN models based on simple input could be used for estimation of runoff and sediment yield, missing data, and testing the accuracy of other models. Agarwal et al. (2009) compared the runoff and sediment yield from an Indian watershed using the back-propagation artificial neural network modeling technique and single and multi-input linear transfer function models. They reported that the single input linear transfer function runoff and sediment yield forecasting models were more efficacious than the multi-input linear transfer function and ANN models. Yenigun et al. (2010) found that the ANN technique could be applied with a little error for missing sediment data in reservoirs.

Limited research has been carried out on the comparison of ANN and SWAT models for predicting monthly sediment yields. Recently, the performances of SWAT as a process-based model and of ANN as a data-driven model in simulating sediment load have been assessed (Srivastava et al., 2006; Demirel et al., 2009; Talebizadeh et al., 2009). Srivastava et al. (2006) compared the ANN and SWAT model and concluded that the ANN model performed better than the SWAT model. Morid et al. (2002) reported that the ANN model performed better than the SWAT model during low flow periods and conversely SWAT yielded better results during high flow periods. They also stated that this may be due to the scarcity of large observed data in the training set. ANNs have different models with different training algorithms. The SWAT model has been applied in few watersheds under the Damodar Valley Corporation (DVC) command area, but a comparison study of SWAT and ANN has not been carried out for any watershed in Damodar Barakar catchment in India. It is important to test the ANN and SWAT models and to compare their performances to select a suitable model for taking up appropriate conservation measures. The objectives of this research were to (i) compare multilayer perceptron (MLP) artificial neural network and SWAT model simulation results for sediment yield, and (ii) determine the most appropriate model for the Nagwa watershed based on calibration and validation results so that the model can also be used in ungauged watershed with similar topography and agro-climatic conditions for prediction of sediment yield.

2. Materials and methods

2.1. Study area and input data set

The Nagwa watershed is located in the eastern part of India. The watershed is approximately 9246 ha of which about 30–40% is under shrubs and forest, and the remaining under cultivation. The average elevation of the command is 540 m above mean sea level. It is bounded by 23°59′08″ to 24°05′41″N latitudes and 85°16′35″ to 85°23′45″E longitudes. The topography of the watershed is undulating with flat land in major parts. The slope of the watershed ranges from 1 to 16% with an average of 1.8%. The average annual rainfall of the area is 1200 mm of which more than 80% occurs during the monsoon months from June to October and the rest in the winter months (December and January). The daily temperature ranges from a maximum of 42.5 °C (1st May, 1999) to a minimum of 2.5 °C (18th January, 1999). The daily mean relative humidity varies from a minimum of 21.7% in the month of April to a maximum of