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Watershed modelling using generated rainfall by Arc-SWAT

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ABSTRACT

In this study, the Soil and Water Assessment Tool (SWAT), integrated with ArcGIS as ArcSWAT, was employed to model runoff and sediment yield using generated rainfall data from a small agricultural watershed in eastern India. The model's ability to generate daily and monthly rainfall was assessed over a six-year period (2007 to 2012). Geographic Information System (GIS) techniques were utilized to delineate watershed and sub-watershed boundaries, drainage networks, and to create slope and soil texture maps. Land use and land cover were classified using supervised classification of cloud-free satellite imagery from IRS-P6 (LISS III), captured on October 8, 2012.ArcSWAT predicts surface runoff using the Soil Conservation Service (SCS) Curve Number (CN) method, while sediment yield is estimated with the Modified Universal Soil Loss Equation (MUSLE). Rainfall generation in the model is based on a first-order Markov chain model. Simulated daily and monthly rainfall, runoff, and sediment yield data for the six-year period were compared with observed values. The results indicated that the model's predictions of monthly rainfall closely matched observed data. Additionally, the simulated monthly runoff and sediment yield, based on the generated rainfall, aligned well with observed values during the monsoon seasons from 2007 to 2012. These findings suggest that the ArcSWAT model can satisfactorily generate rainfall and accurately predict monthly surface runoff and sediment yield, making it a valuable tool for developing management strategies for erosion-prone areas in small agricultural watersheds

Keywords: Watershed, Hydrological Modelling, ArcSWAT model, Generated Rainfall, Runoff and Sediment Yield

INTRODUCTION

The effective control of land and water resource degradation can be achieved through the watershed approach, which considers a watershed as a geographically distinct area contributing runoff to a common outlet. As a fundamental unit for planning and management, a watershed's hydrological behavior must be accurately understood for effective management. Given the dynamic nature of watersheds, their behavior varies spatially and temporally, necessitating intensive studies of individual watersheds to develop tailored management plans. Such studies also facilitate the transfer of findings to other watersheds with similar characteristics. Estimating runoff and sediment yield is crucial for designing soil conservation structures and identifying critical areas within a watershed for targeted management interventions, especially when resources are limited. Numerous hydrologic and water quality models are currently available to evaluate the complex hydrological and environmental processes involved.

Several hydrological models ranging from empirical to physically based distributed parameter have been developed to predict runoff, erosion, sediment and nutrient transport from agricultural watersheds under various management regimes. Among these models, Soil and Water Assessment Tool (SWAT) model is the most recent one used successfully for simulating runoff, sediment yield and water quality of small, medium and large watersheds. Recently SWAT model was interfaced with ArcGIS and known as ArcSWAT (Winchell *et al.*, 2010). The SWAT is a distributed parameter continuous time model developed by the USDA-ARS (Arnold *et al.*, 1996 & 1998). Major components of the model include surface hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, ground water and lateral flow.

The compilation and input of hydrologic data that are required by the ArcSWAT model are often cumbersome. The tediousness and time-consuming nature of extraction of watershed parameters can be eliminated by means of Remote Sensing Technology (RST) and Geographic Information System (GIS) in addition to obtaining high accuracy (McVicar and Jupp, 1998; Launen and Dupuis, 1996; Rochester *et al.*, 1996). The Digital Elevation Models (DEMs) can be used successfully to extract several watershed parameters. These techniques can provide more precise and reproducible measurements than the traditional manual techniques applied to topographic maps. Remote sensing technique is suitable to study the most recent pattern of land use/cover. Input data for the ArcSWAT model can be extracted with the use of GIS mainly from the map layers including land use/cover, DEM, soil texture, slope, drainage and watershed boundary.

Many researchers applied SWAT model in different countries including India under various management regimes of the watersheds and reported promising results (Srinivasan *et al.*, 1993; Srinivasan and Arnold, 1994; Rosenthal *et al.*, 1995; Cho *et al.*, 1995; Bingner, 1996; Bingner *et al.*, 1997; Srinivasan *et al.*, 1998; Peterson and Hamlett, 1998; Tripathi *et al.* 2003, 2005; Kamble *et al.,* 2006; Gassman et al. 2007; Mishra *et al.*, 2007; Agrawal *et al.* 2009; Tripathi 2012). Tripathi *et al.* (2004) evaluated the performance of SWAT model for generating rainfall for eight years in eastern India. In these studies, the model was tested using observed rainfall for simulating the surface runoff. However, the model has not been tested widely used for simulating the sediment yield. Also, prediction of surface runoff and sediment yield using generated rainfall has not been reported much in the literature.

In India very, little efforts have been made on the use of hydrologic and water quality models to develop management plan for small agricultural watersheds using systematic modelling approach. For developing the long-term management plan of a watershed requires rainfall data for several years. The ArcSWAT has capability to generate rainfall and thereafter, surface runoff, sediment yield and nutrient losses on daily, monthly and annual basis. Adequate procedure to calibrate and validate these models is an important research issue. A Model should be adequately tested before using it for effective watershed management specifically if generated rainfall is the basic input.

Physically based hydrological models including ANSWERS, AGNPS, SHE, SWRRB and SWAT developed in advanced countries have been tested and applied in those countries. These models are site specific and require considerable computation time. Objective models requiring minimum amount of data and computational time are to be tested and applied under Indian conditions. The SWAT model recently interface with ArcGIS and named as ArcSWAT, which can be applied to a large ungauged rural watershed with more than 100 numbers of small sub-watersheds. The ArcSWAT is a physically based continuous model capable of simulating surface runoff, sediment yield and nutrient losses from small, medium and large watersheds. It is important to test the model on daily as well as monthly basis under Indian condition using generated rainfall so that it can be applied for management purpose.

The ArcSWAT requires weather data as input. In addressing hydrologic response to weather inputs, it is seldom sufficient to examine only the response to observed weather events. Use of observed sequences gives a solution based on only one realization of the weather process. What would be the result if another series with the same properties as the observed series were used? What is the range of results that may be obtained with other equally likely weather sequences? To answer these questions, it is desirable to generate synthetic sequences of weather data based on the stochastic structure of the meteorological process.

The weather variables needed for most of the hydrologic and water quality models include precipitation, maximum and minimum temperatures, solar radiation, or some related variable (Knisel, 1980). These variables are usually recorded daily, and most deterministic models require daily values. Rainfall prediction plays an important role in management of a watershed. For hydrologic applications, predicted rainfall on daily basis has unique importance in designing the water harvesting structures, erosion control measures and for developing the management plan for the critical erosion prone areas of a watershed. Several research workers across the world have developed rainfall prediction models to solve the aforesaid problems (Buishand, 1978; Chin, 1977; Gabriel and Neumann, 1962; Georgakakos and Bras, 1984; Richardson, 1981).

Since precipitation was chosen as the primary variable and daily precipitation amounts were determined independently of the other variables, any precipitation model that produces daily precipitation values (subject to some criterion of goodness) could be used for precipitation component. In ArcSWAT a first-order Markov chain model (Bailey, 1964) is used to describe the occurrence of wet or dry days. The Markov chain model for daily precipitation occurrence has been studied extensively by several investigators (Gabriel and Neumann, 1962; Caskey, 1963; Weiss, 1964; Hopkins and Robillard, 1964; Haan *et al.*, 1976; Smith and Schreiber, 1973. Tripathi *et al.* 2004).

Very few watersheds are gauging rainfall in the developing countries. In India most of the watersheds selected for development and management purpose under various projects have only one rain gauge for the entire watershed and sometimes are not at all gauged. It is almost impossible to gauge each and every sub-watershed of all the watersheds of the country. The generated rainfall for prediction of surface runoff and sediment yield and thereafter developing the management plane is therefore, essential. Keeping the above-mentioned importance of the generated rainfall in estimation of runoff and sediment yield in mind, this study was undertaken to estimate runoff and sediment yield of a watershed located in the eastern India using generated rainfall by the ArcSWAT model.

Results of this study revealed that SWAT model can generate daily rainfall satisfactorily and thereby it could produce daily and monthly surface runoff and sediment yield closer to the observed values. They concluded that SWAT model can be used for generating the daily rainfall and can be used for developing multiple year management plans for the critical erosion prone areas of a small watershed.

MATERIALS AND METHODS

Study Area

The Dhangaon watershed was selected for the present study. This watershed is located in upper Hump River of Shivnath subbasin, Bemetra district of Chhattisgarh, India (Fig. 1). The watershed has 65.38 km^2 area, lies between 81°27′30″ E to 81°35′0″ E longitude and 21°46′15″ N to 21°51′15″ N latitude with elevation ranging from 270 m to 290 m above MSL. The slope of the watershed ranges from 1 to 3.5%. Dhangaon watershed is a 5th order watershed comprising of 15 villages. The predominant soil of watershed silty loam is clay (kanhar) and soil depth ranges from 0 to 155 cm. The watershed receives an average annual rainfall of 1000 mm (1998 to 2012). The daily mean temperature ranges from 40.0°C to 3.0°C. The daily mean relative humidity varies from a minimum of 40% in the month of April to a

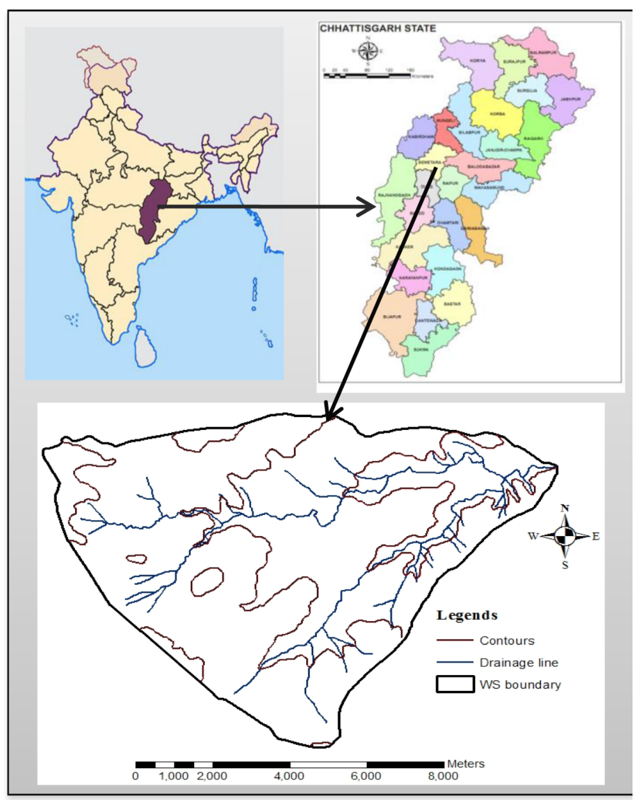

Fig. 1. Location map of Dhangaon watershed in Chhattisgarh

maximum of 85% in the month of July. The overall climate of the area can be classified as sub-tropical. Major crops grown in the area are paddy, maize and minor millet in kharif season.

Data Acquisition and Analysis

The cloud free geocoded digital data in CD of the study area was obtained from NRSA, Hyderabad, India. The path 102, row 057, scenes of IRS-P6 (LISS III) satellite with date of pass 8th October, 2012 was used for the study. Survey of India topographic map with 1:50,000 scale was used. Meteorological data such as rainfall and temperature (25 years) and hydrological data such as runoff and sediment yield (5 years) of the watershed were collected, respectively from Centre Water Commission, Mahanadi Bhawan, Bhubaneswar and ASCO Office Bemetara, Department of Agriculture, Govt. of Chhattisgarh. Groundwater data were collected from CGWB, NCR, Raipur. The cadastral/revenue map of Dhangaon village is been acquired from the Office of the Tehsildar, Govt. of Chhattisgarh. Most of the thematic maps like watershed, sub-watersheds, drainage, DEM, soil and land use have been prepared using GIS technique. The maps were traced, scanned and exported to the ArcSWAT for registration, digitization and further processing. Digitizing the contour map of Dhangaon watershed using topographic map of Survey of India having 10m contour intervals. Digitized contour map was then used for preparing the DEM. The DEM of the watershed was prepared in 24m by 24m resolution.

Watershed can be subdivided on the basis of natural topographic boundaries, smaller relatively homogenous areas and grids or cell (Arnold *et al.*, 1998). The ArcSWAT model can work on sub-watershed basis, so that the watershed was divided into 10 sub-watersheds on the basis of drainage and elevation information of corresponding watershed. Area corresponding to different sub-watersheds of Dhangaon watershed was determined. The sub-watersheds were given different colors for easy identification. Sub-watersheds are watersheds but are referred to as sub-watersheds in the context of being part of a larger watershed. The watershed and sub-watersheds boundary, drainage networks and slope map were generated using the procedure described by Jenson and Domingue (1988).

Land use/cover classification was done using satellite image of kharif 2009 and 2012 by adopting supervised method of classification in the environment of ERDAS imagine. The grid size 24 × 24 m was considered for image classification. Area occupied by different land use during the *kharif* season of the years 2009 and 2012 are given in Table 1. Accuracy of image classification was judged after performing the land use/cover classification. A high value of overall accuracy 87.7 and 86.2%, respectively for the year 2009 and 2012; and Kappa coefficient (*KHAT*) of 0.85 and 0.84 respectively for the year 2009 and 2012 of Dhangaon watershed indicated that the land use/cover classification was appropriate for the study watershed. Land use/cover classification was matched well with the land use/cover actually mentioned in the field. In many previous studies similar range of classification accuracy and Kappa coefficient were observed and accepted for further use (Yifang *et al.*, 1995; Pratt *et al.*, 1997; Tiwari *et al.,* 1997; Tripathi *et al.*, 2003).

Table 1. Statistical results of the observed and simulated monthly rainfall (2007-2012)

Statistical parameters	Rainfall (mm)	
	Observed	Simulated
Mean	75.22	91.12
Standard deviation	104.39	110.73
Maximum peak	422.60	375.85
Total	5415.80	6560.99
Count	72	72
t-cal	-2.070	
t-critical (two-tail)	1.990	
r^2	0.669	
% deviation	-21.14	

Sub-watershed wise soil texture land use information was used by the ArcSWAT for determining the runoff Curve Number (CN) for each sub-watershed (Dhruva Narayana, 1993). Therefore, model overlaid sub-watershed map was with the soil map, land use/cover map and slope of the watershed to get the resultant statistics. Other input parameters of the delineated sub-watersheds, such as overland and channel slope, channel length and average slope length were extracted by the model using the various maps including DEM, sub-watershed map, slope map and drainage map. Sub-watershed wise input parameters were analyzed using the standard procedure and are given in Table 2.

Soil texture map was prepared using soil resources data which was collected personally using PRA technique. In the study watershed there is mainly one series of soil known as Boda series.

Table 2. Monthly runoff and sediment yield using generated rainfall (2007-2012)

Month / Year	Rainfall (mm)		Runoff (mm)		Sediment yield (t/ha)	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
August 07	215.8	315.7	131.1	187.7	2.38	2.04
September 07	231.9	126.0	118.6	93.8	2.36	1.28
July 08	132.4	352.3	151.9	175.9	1.06	2.37
August 08	180.7	296.3	112.4	144.1	1.14	1.63
September 08	150.80	189.64	90.35	97.83	0.10	0.15
July 09	265.50	282.23	138.95	161.87	2.86	3.45
August 09	263.60	244.18	130.25	145.58	3.24	1.57
July 10	292.00	252.01	170.81	141.54	3.18	1.87
August 10	77.90	133.73	15.44	48.59	0.06	0.14
September 10	189.00	208.92	83.81	104.08	2.57	1.42
July 11	187.00	269.59	75.52	154.19	2.34	2.61
August 11	311.70	203.31	188.99	194.47	2.65	1.29
September 11	137.90	223.28	61.82	104.16	0.55	0.43
August 12	204.30	148.46	117.68	82.43	0.64	0.29
September 12	166.80	182.08	100.48	108.74	1.63	0.96

There are four type of soil texture existing in the watershed. They are locally known as Bhata (sandy loam), Matasi (sandy clay loam), Dorsa (loam) and the Kanhar (clay), which occupied 198, 2542, 49 and 4955 ha area, respectively. The predominant soil of watershed is clay. Sandy clay loam, sandy loam and loam are also found in this watershed.

The observed surface runoff and sediment yield for monsoon season (June to October) were collected, analyzed and used for evaluation of model calibration and validation performance. The input parameters in the calibration run were given for each sub-watershed. Most of the parameters showed negligible variation in fortnightly surface runoff and sediment yield therefore those were not calibrated and taken as suggested in the User's Manual (Arnold *et al.*, 1996). The weighted average values for the parameters such as curve number, surface slope, channel length, average slope length, channel width, channel depth, soil erodibility factor and other soil layer data were taken for each sub-watershed. Initial soil water storage and Manning's 'n' value for overland flow and channel flow were calibrated and sensitivity analysis were also performed to observe the effect of these parameters on runoff and sediment yield.

The model performance was evaluated on the basis of test criterion recommended by ASCE Task Committee (1993). Various other methods such as graphical and linear regression method, statistical tests of significance and Nash-Sutcliffe simulation efficiency (Nash and Sutcliffe, 1970) were also used. The validation of a calibrated model is an essential part of the model testing. Therefore, the model was validated using the observed daily rainfall and temperature data for the years 2011-2012. Similarly, for fortnightly validation, the observed runoff and sediment yield for the years 2011 and 2012 of monsoon season from June to October for the Dhangaon watershed were analyzed and compared with the simulated results for the evaluation of model validation performance in respect of surface runoff and sediment yield. The model was also used to test the capability of simulating daily rainfall using weather generator (wgn). Using generated daily rainfall, runoff and sediment yields were also simulated and performance of the wgn was evaluated. The monthly validation of the model was performed for the year 2007 to 2012 using generated daily rainfall.

Theoretical Consideration

A brief description of sub-basin components and the mathematical relationships used to simulate the processes and their interactions in the model as described by Arnold *et al.* (1996) are considered in this study. The mathematical relationships used in the model for simulating runoff volume and sediment yield are described in this paper.

Runoff Volume

ArcSWAT predicts surface runoff for daily rainfall by using the Soil Conservation Service (SCS) Curve Number (CN) method (USDA-SCS, 1972). The model adjusts curve numbers based on Antecedent Moisture Condition (AMC). The basic equations used in SCS curve number method are as follows;

$$Q = \frac{(R - 0.2s)^2}{R + 0.8s}, \quad R > 0.2s \qquad \ldots(1)$$

$$Q = 0.0, \quad R \leq 0.2s \qquad \ldots(2)$$

where, Q is the daily runoff, R is the daily rainfall, and s is the retention parameter. The retention parameter varies in space because of varying soil, land use, management, and slope; and in time because of changes in soil water content. The parameter s is related to CN as follows;

$$s = 254\left(\frac{100}{CN} - 1\right) \qquad \ldots(3)$$

The constant, 254, in Eq. 3 gives s in mm. Thus, R and Q are also expressed in mm.

Sediment yield

Sediment yield is computed for each sub-basin with the Modified Universal Soil Loss Equation (MUSLE) (Williams and Berndt, 1977);

$$Y = 11.8\,(V\,q_p)0.56\,(K)(C)(PE)(LS) \qquad \ldots(4)$$

where, Y is the sediment yield from the sub-basin in tonnes, V is the surface runoff volume for the sub-basin in m^3, q_p is the peak flow rate for the sub-basin in $m^{3\times}s^{-1}$, K is the soil erodibility factor, C is the crop management factor, PE is the erosion control practice factor and LS is the slope length and steepness factor.

The LS factor is computed with the equation (Wischmeier and Smith, 1978);

$$LS = \left(\frac{\lambda}{22.1}\right)^{\xi}\left(65.41S^2 + 4.465S + 0.065\right) \qquad \ldots(5)$$

where, λ is the average slope length and S is the average slope of the sub-basin.

The exponent ξ varies with slope and is computed with the equation;

$$\xi = 0.6\left[1 - \exp(-35.835S)\right] \qquad \ldots(6)$$

The crop management factor, C, is evaluated for all days when runoff occurs using the equation;

$$C = \exp[(-0.2231 - CVM)\exp(-0.00115CV) + CVM] \qquad \ldots(7)$$

where, CV is the soil cover (above ground biomass + residue) in kg ha^{-1} and CVM is the minimum value of C. The value of CVM is estimated from the average annual C factor using the equation;

$$CVM = 1.463\ln(CVA) + 0.1034 \qquad \ldots(8)$$

The value of average annual C factor CVA for each crop and PE factor for each sub-basin can be determined from tables and information prepared by Wischmeier and Smith (1978).

Weather Generation

The weather variables for driving hydrology balance are precipitation, air temperature, solar radiation, wind speed, and relative humidity. If daily precipitation and maximum and minimum air temperature data are available, they can be input directly to the model. If not, the weather generator can be used to simulate daily rainfall and temperature. Solar radiation, wind speed, and relative humidity are always generated by the weather generator and used by the model. One set of weather variables may be simulated for entire basin, or different set of weather variables may be simulated for each subbasin. Weather generators can be extremely useful when measured data is unavailable and management scenarios are being compared.

Precipitation

The precipitation model developed by Nicks (1974) is a first-order Markov chain model. Input for this model includes monthly probabilities of receiving precipitation if the previous day was dry and if the previous day was wet. Given the wet-dry state, the model determines stochastically if precipitation occurs or not. A random number (0-1) is generated and compared with the appropriate wet-dry probability. If the random number is less than or equal to the wet-dry probability, precipitation occurs on that day. Random numbers greater than the wet-dry probability give no precipitation. Since the wet-dry state of the first day is established, the process can be repeated for the next day and so on throughout the simulation period. If wet-dry probabilities are not available, the average monthly number of rainy days may be substituted (Arnold *et al.*, 1996). The probability of a wet day is calculated directly from the number of wet days:

$$PW = \frac{NWD}{ND} \qquad \ldots(9)$$

where, *PW* is the probability of a wet day, *NWD* is the number of rainy days, and *ND* is the number of days, in a month. The probability of a wet day after a dry day can be estimated as a fraction of PW.

$$P(W/D) = \beta\, PW \qquad \text{...(10)}$$

where, P(W/D) is the probability of a wet day following a dry day and where b is a fraction usually in the range of 0.6 to 0.9. For many locations, β = 0.75 gives satisfactory estimates *of P(W/D)*. The probability of a wet day following a wet day *P(W/W)* can be calculated directly by using the equation:

$$P(W/W) = 1.0 - \beta + P(W/D) \qquad \text{...(11)}$$

When precipitation event occurs, the amount is generated from a skewed normal daily precipitation distribution

$$R_i = \left(\frac{\left(\left(SND_i \frac{SCF_k}{6.0} \right) \left(\frac{SCK_k}{6.0} \right) + 1 \right)^3 - 1}{SCF_k} \right) RSDV_k + \overline{R}_k \qquad \text{...(12)}$$

where, R is the amount of rainfall on day i, in mm, *SND* is the standard normal deviate for day i, *SCF* is the skew coefficient, *RSDV* is the standard deviation of daily rainfall in mm, and R is the mean daily rainfall in month k.

If the standard deviation and skewness coefficients are not available, the model simulates daily rainfall by using a modified exponential distribution.

$$R_i = \frac{(-\ln(\mu))^{\zeta}\, \overline{R}_k}{\int_{0.0}^{1.0} (-\ln(\chi))^{\zeta}\, dx} \qquad \text{...(13)}$$

where, m is a uniform random number (0.0-1.0) and z is a parameter usually in the range of 1.0 to 2.0. The modified exponential is usually a satisfactory substitute and requires only the monthly mean of daily precipitation as input. Amount of daily precipitation is partitioned between rainfall and snowfall using average daily air temperature.

Air Temperature and Solar Radiation

Daily maximum and minimum air temperature and solar radiation are generated from a normal distribution corrected for wet-dry probability state. The model developed by Richardson (1981) is used because it simulates temperature and radiation, which are mutually correlated with rainfall. The correction factor is used to provide more deviation in temperatures and radiation when weather changes on rainy days. Conversely, deviations are smaller on dry days. The correction factors are calculated to ensure that long-term standard deviations of daily variables are maintained.

The temperature model requires monthly means of maximum and minimum temperatures and their standard deviations as inputs. The model estimates standard deviation as 0.25 of the difference between the extreme and the mean for each month. The solar radiation model uses the extreme approach extensively. Thus, only the monthly means of daily solar radiation are required as inputs.

Wind Speed and Relative Humidity

Daily wind speed is simulated using a modified exponential equation given the mean monthly wind speed as input. The modified exponential equation is as follows:

$$V_i = b_{1,k} V_k \left[-\ln(RN) \right]^{b_{2,k}} \qquad \text{...(14)}$$

where, V_k is the mean wind speed for month k, RN is a random number, b_1 and b_2 are parameters for month k. The value of b_1 can be closely approximated with the equation:

$$b_1 = 1.5567\, (b_2)^{0.1508} \exp(-0.4336\, b_2) \qquad \text{...(15)}$$

The relative humidity model simulates daily average relative humidity from the monthly average by using a triangular distribution. As with temperature and radiation, the mean daily relative humidity is adjusted to account for wet- and dry-day effects. The assumed relation between relative humidity on wet and dry days is

$$REW_k = RHD_k + \Omega_H\, (1.0 - RHD_k) \qquad \text{...(16)}$$

where, *RHW* is the daily mean relative humidity on wet days for month k, *RHD* is the daily mean relative humidity on dry days, and Ω_H is a scaling factor ranging from 0.0 to 1.0. An Ω_H value of 0.9 seems appropriate for many locations. The appropriate value (*RHW* or *RHD*) is used as the peak of a triangular distribution to generate daily relative humidity. The model determines long-term average relative humidity for month k using the continuity equation.

RESULTS AND DISCUSSION

The weather variables necessary for running the ArcSWAT model are the daily values of rainfall, air temperature (maximum and minimum), solar radiation, wind speed and relative humidity. If daily rainfall and air temperature data are not available or data are not adequate, the weather generator component of the model can simulate daily rainfall and temperature. The weather parameters such as solar radiation, wind speed, and relative humidity can be simulated by the model using *.wgn input data file and weather generator model attached with the SWAT model.

Since the model uses generated daily values of solar radiation, wind speed and relative humidity it was required to test the performance of the model for generating weather parameters. To develop long-term management scenarios for the critical areas of the watershed, rainfall and temperature and other weather parameters are also required by the model. Therefore, the model was tested with respect to generation of daily rainfall. The daily surface runoff and sediment yield from the watershed were also simulated using generated rainfall. The observed and simulated rainfall (for entire year), runoff and sediment yields (for monsoon seasons) were compared on monthly basis for evaluating the performance of the weather generator.

The comparison of observed and simulated daily rainfall for the years 2007 to 2012 and the results of statistical test showed poor performance of the model. The t-test showed that the simulated means of daily rainfall were significantly different than the observed means at 95 % level of confidence. Also, the coefficient of determination (r^2) was found to be 0.066 and the per cent deviation of -23% indicated that model could not simulate daily rainfall satisfactorily. It was also confirmed from the coefficient of simulation efficiency, which was found to be very less (-0.786), therefore, model performance was evaluated for the prediction of monthly rainfall for the Dhangaon watershed.

Simulations were performed for six years (2007 to 2012) and the monthly simulation results are given in Table 1. The graphical comparison as shown in Fig. 2 indicated a close agreement between observed and simulated monthly rainfall. The scatter gram of observed and simulated monthly rainfall as shown in Fig. 3 indicated that the observed and simulated monthly rainfall values were uniformly distributed along 1:1 line. The coefficient of determination (r^2) of 0.669 indicated that weather generator model was able to generate monthly rainfall close to the observed rainfall. The mean values of observed

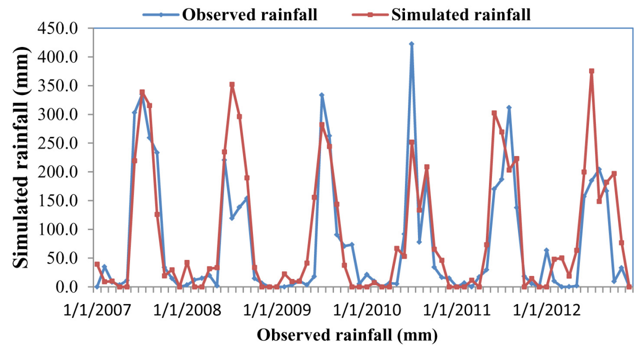

Fig. 2. Comparison between observed and simulated monthly rainfall (validation years 2007-2012)

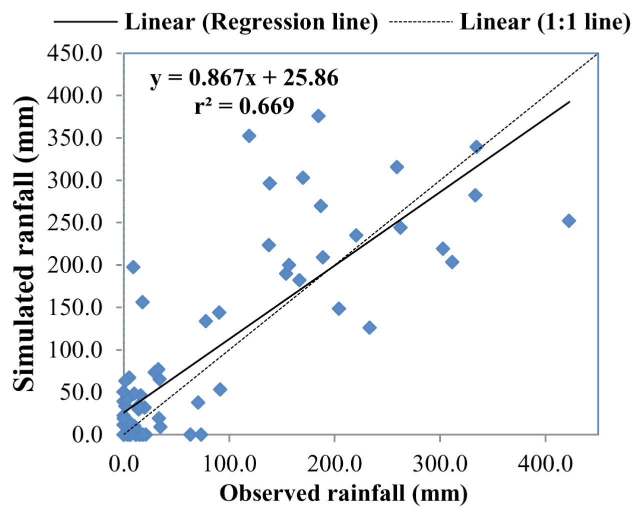

Fig. 3. Scatter gram between observed and simulated monthly rainfall (validation years 2007-2012)

(75.22 mm) and simulated (91.12 mm) rainfall were compared statistically by applying Student's t-test. It was found that the means of monthly observed and simulated rainfall were marginally comparable at 95 % level of confidence because t-cal (-2.070) was found to be little more than t-critical (1.990). The standard deviation for the observed and simulated monthly rainfall was found to be 104.39 and 110.73, respectively. Similarities in mean and standard deviation indicated that the frequency distribution of predicted rainfall was similar to the observed rainfall during the period of simulation. The value of deviation (21.14 %) indicated that the model predicted monthly rainfall values were marginally closer to the observed values.

The model performance was also tested for the monthly simulation of runoff and sediment yield for the monsoon period of 2007-2012 using generated daily rainfall Table 2. Results showed in Table 3 that

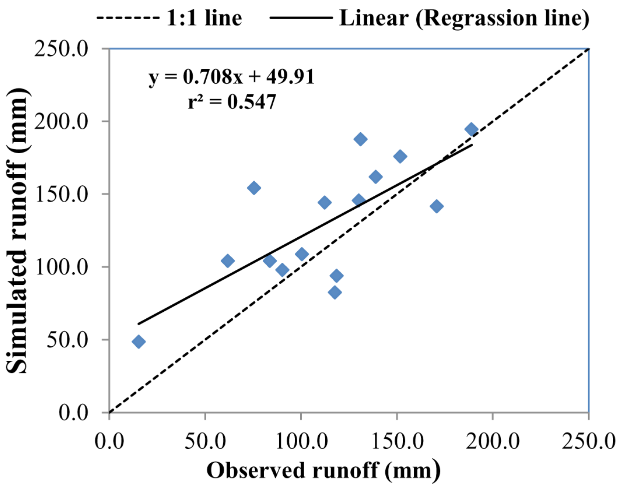

Fig. 4. Scatter gram between observed and simulated monthly runoff (monsoon season of the years 2007-2012)

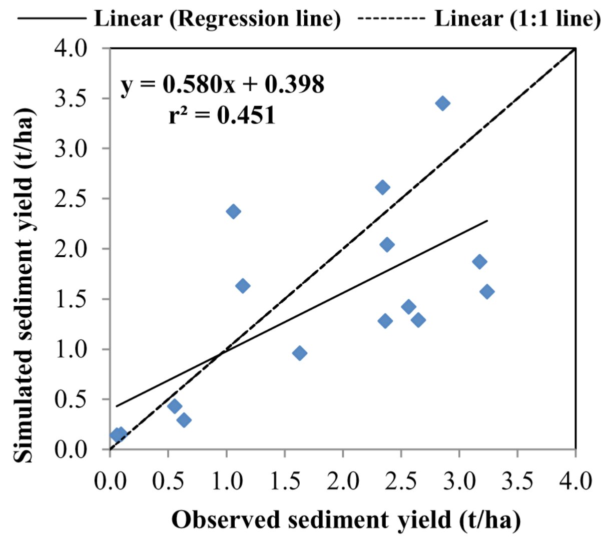

Fig. 5. Scatter gram between observed and simulated monthly sediment yield (monsoon season of the years 2007-2012)

the model could predict monthly values of runoff close to the observed values for the monsoon period of year 2007-2012 in Fig. 4. The differences between the means of observed and simulated rainfall were not statistically significant at 95% level of confidence. The coefficient of determination was found to be 0.547 for the monsoon season of the validation period. Arnold and Williams (1987) also reported similar results. They tested the same weather generator, which was attached with the SWRRB model. Overall results showed that the model in general predicted monthly runoff values satisfactorily using simulated rainfall for the monsoon seasons of the years 2007-2012 (Table 2).

Furthermore, the statistical test results (Table 3) indicated that the means of predicted monthly sediment yield (using generated rainfall) were matching with the means of observed sediment yield at 95 % level of confidence for the monsoon season of the years 2007-2012 in Fig. 5. The per cent deviations was found to be 16.4 indicated that model could simulate monthly sediment yield well closer to the observed sediment yield for the validation period. Also coefficients of determination (0.859) indicated that the sediment yield predicted by the model during validation period was having good agreement with the observed sediment yield. In the light of the results discussed above, it can be stated that the ArcSWAT in general is capable of predicting daily rainfall and thereby runoff and sediment yield properly since it performed well for the monsoon season of the years 2007-2012.

Above results indicated that the weather generator attached with ArcSWAT model is capable of predicting daily and monthly runoff and sediment yield adequately using generated rainfall for the

Table 3. Statistical analysis for the monthly observed and simulated runoff and sediment yield during monsoon season (2007-2012)

Statistical parameters	Runoff (mm)		Sediment (t/ha)	
	Observed	Simulated	Observed	Simulated
Mean	112.53	129.67	1.78	1.43
Standard deviation	43.94	42.08	1.12	0.96
Maximum peak	188.99	194.47	3.24	3.45
Total	1688.02	1945.06	26.75	21.50
Count	15	15	15	15
t-cal	-2.140	0.556		
t-critical (two-tail)	2.140	1.976		
r^2	0.547	0.859		
% deviation	-15.23	16.4		

Dhangaon watershed. On the basis of these results it can be inferred that the model can be used for long-term simulation of hydrological parameters and for assessing their impact on agricultural activities in the Dhangaon watershed.

CONCLUSION

The ArcSWAT model generated daily, monthly and annual rainfall using first order Markov chain model were close to the observed rainfall. The model predicted monthly rainfall values were quite close to the observed rainfall for all the seasons during 2007 to 2012. The model predicted monthly runoff and sediment yield for the monsoon season using generated rainfall was also having close agreement with the observed runoff and sediment yield. The weather generator can be used to simulate daily rainfall and thereby monthly runoff and sediment yield. The model can be used for planning and management of critical sub-watersheds of a small watershed on a long-term basis using generated daily rainfall.

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