Environment & Ecology 35 (3D) : 2602—2608, July—September 2017
Website : environmentandecology.com ISSN 0970-0420

Estimation of Runoff from a Hilly Watershed using SWAT Model

Asima Jillani, Anil Kumar

Received 24 November 2016; Accepted 26 December 2016; Published online 13 January 2017

Abstract Runoff is a very important phenomenon of hydrological cycle and it relevant for the watershed management program for conservation and development of natural resources. However, the availability of accurate information on runoff is scarce in India. Soil and Water Assessment Tool (SWAT) is a physically based distributed parameter model which was developed to predict runoff, erosion, sediment and nutrient transport from agricultural watersheds under different management practices. For the present study, a hilly watershed called Bino, with 300.907 km^2 area was selected for runoff assessment using SWAT. Geoinformatic techniques, such as ERDAS software and Shuttle Radar Topographic Mission (SRTM) data were used for execution of the model. Calibration of the model was done, using the observed data and then it was validated on selected study area. For calibration and validation, monthly observed runoff data from 1989 to 1998 and 1999 to 2007, respectively, were used. For calibration and validation periods, the Nash Sutcliffe efficiency was 0.75 and 0.62 and coefficient of determination was 0.83 and 0.72, respectively. This indicates good applicability of SWAT model in estimating runoff from the study watershed.

Keywords Hydrological modeling, Runoff, Bino watershed, SWAT.

Introduction

Water resources are the most valuable resources that are basic for the existence and development of the society, Proper utilization of this resource is important both in quality and quantity. The surface water in the form of river flows and lakes is predominantly obtained from rainfall after being generated by rainfall-runoff process. Simulation of runoff, soil erosion and sediment yield are essential for natural resources management and sustainable development. The reliable estimates of the various hydrological parameters including runoff and sediment yield for remote and inaccessible areas are tedious and time consuming by conventional methods. So it is desirable that some suitable methods and techniques are used for quantifying the hydrological parameters from all parts of the watershed. Runoff occurs when the rainfall intensities exceed the infiltration rate or any depression storage has been already filled. Soil infiltration rates are controlled by soil characteristics, vegetation cover and land use practices [1, 2].

The watershed models generally used as HSPE (hydrological stimulation program), HMS (hydrological modeling system),CREAMS (chemical runoff ero-

---

A. Jillani[1]*, A. Kumar[2]
[1]Research Scholar, [2]Professor
College of Technology, Department of Soil and Water Conservation Engineering, G B P U A and T Pantnagar, Distt US Nagar, Uttarakhand, India
e-mail: asima41189@gmail.com
*Correspondence

sion from agricultural management system), EPIC (erosion productivity impact calculator), AGNPS (agricultural non productive sources), were developed for watershed analysis. A relatively recent model developed by US Development of Agriculture (USDA) called SWAT has proved successive application in water assessment of hydrology and water quality. SWAT has been successfully used for simulating runoff, sediment yield and water quality of small watersheds for Indian conditions [3, 4] and for the watershed of various sizes and scales [5, 6]. The SWAT model has also been adopted for the study of impacts of nutrient transport to Lake Winnipeg from agricultural watersheds, in Canada [7]. SWAT model requires a large number of input parameters, which complicates model parameterization and calibration [8]. Land use land cover (LULC) map of a watershed is a critical input to the SWAT model [9] and has been found [10] that changes in land use affects the water discharge in the watershed. Various researchers have evaluated SWAT model and found that SWAT is capable of simulating hydrological processes with reasonable accuracy and can be applied to all types of ungauged basins. Therefore, to test the capability of the model in determining the runoff of the watershed, SWAT 2012 model with ARCGIS 10.2 interface was selected for the present study. SWAT employs the Curve Number (CN) method for estimating runoff and the Modified Universal Soil Loss Equation (MUSLE) for estimating sediment yield. Thus, SWAT can assess the effect of different topographic, soil and land cover combinations on runoff and sediment yield. For the calibration analysis sequential uncertainty fitting (SUFI-2) program linked with Arc SWAT-CUP was used. The main purpose of this study was runoff modelling using SWAT for Bino watershed in Uttarakhand, India.

Materials and Methods

Study area

Bino watershed was selected for this study to examine the applicability and performance of SWAT model in determining the runoff. The Bino watershed is a part of Ramganga river catchment that originates in the outer Himalayas in Chamoli district of Uttarakhand. The Bino watershed is located between 29^0 47´ 0´´ and 30^0 2´ 15´´ N latitudes and 79^0 6´ 15´´ E and 79^0 17´ 15´´ E longitudes in Almora and Pauri Garhwal districts of Uttarakhand, India. The location of Bino watershed is shown in Figure 1. The Bino watershed comprises of an area of 300.907 km^2 (SWAT) generated area), with its mean length as 30 km and the mean width as 12 km. It has shallow soil depth and inadequate vegetal cover with varying surface slopes, ranging from gentle to steep. The watershed is thus susceptible to soil crosion. Most of the area of the watershed is under cultivation even at steep slopes. Forests are confined mostly to hilltops and grass lands of degraded type are found in patches spread over the entire area. Rainfall data of the watershed indicated that about 73.5% of rainfall occurs in the rainy season (June-September). The soil texture varies from gravelly loamy sand to loamy skeletal. Soil pH is mostly on the acidic side, varying from 5 to 7 with medium to high organic matter depending on the land use. The water holding capacity of the soil is generally low because of the dominance of coarser fractions. Figure 2 shows (a) DEM map, (b) Slope map, (c) Landuse map, and (d) Soil map of Bino watershed.

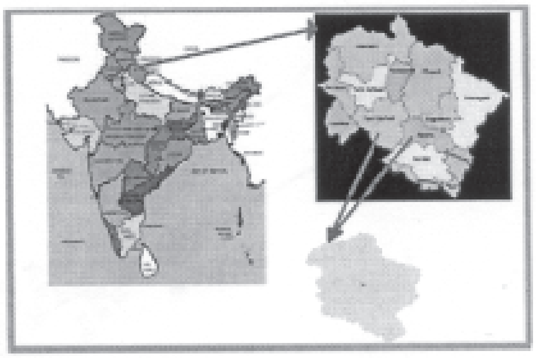
Fig. 1. Location map of Bino watershed, Uttarakhand.

Model description

SWAT is a river basin scale model that operates on a daily time -step [8]. It was developed at the University of Texas, USA and is freely distributed on the internet. SWAT model was developed to quantify the influence of land use practices on large, complex watersheds and to predict the effect of management

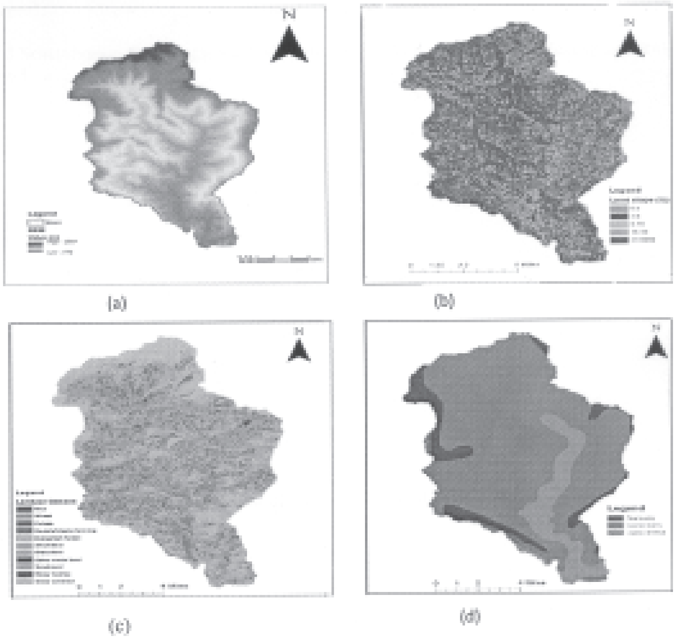

Fig. 2. (a) Dem map, (b) Slope map, (c) Landuse map (d) Soil map of Bino watershed.

decisións on the water production. Major components of the model include hydrology, weather, erosion, Soil temperature, crop growth, nutrients, pesticides, and agricultural management. SWAT was selected for its ability to simulate runoff from a watershed. A comprehensive description of all the components in SWAT can be found in the literature [11].

Input data selection

SWAT model needs a lot of data to be defined for the physical watershed representation. These are the data about topography (Digital Elevation Model), climate (daily measured weather data), and both soil and land use (maps and physical parameters). Data availability as well as quality for a watershed increases the accuracy of model predication. Precipitation is the key input variable that drives flow and mass transport in hydrological systems. Runoff data for the period of 1989-2007 were collected from the Divisional Office of the Forest Department, Ranikhet, Uttarakhand, weather data were collected from the global weather data base of SWAT. The land sat data were classified by supervised classification to generate the landuse classes. DEM (Digital Elevation Model) of 90 m × 90 m was downloaded from the Shuttle Radar Topography Mission (SRTM) located in USGS website (seamless. usgs.gov) which was later resampled to 30 m resolution.

SWAT simulation

For modeling the Bino watershed, input data such as DEM, Land use map, soil map, rainfall and weather data were extracted and generated using the ARCSWAT built in ARCGIS 10.2 platform. The first step was watershed delineation which split the basin into 83 subbasins. Further, division into multiple hydrological response units (HRUs) comprising of unique land use, soil type and land slope was based on user-defined threshold percentages. The next step was the rainfall and weather data files upland. The final step was writing input files with required input data for the project. General watershed parameters were need to be selected and aadjusted according to user knowledge and historical basin hydrologic information such as PET, rainfall-runoff and channel routing methods until getting reasonable annual simulated flow compared to observed flow to save time during calibration.

Model calibration and validation

Understanding the model processes checking various components such as rainfall to runoff ratio, ET, base flow contribution are very important to make sure that all the major components are represented well for a watershed before attempting calibration. The simulation part of the Bino watershed was completed using the Arc SWAT interface of SWAT model, whereas model calibration and sensitivity analysis have been done using SWAT-CUP tool. Fifteen parameters were considered and tested for the model parameterization and sensitivity analysis. The model uncertainties were tested and analysed using SUFI-2 uncertainty analysis procedures.

The parameters responsible for runoff assessment from the Bino watershed, were r_ SOL_K. sol (soil hydraulic conductivity), r_HRU_SLP.hru (average slope stecrpness), v_RCHRG_DP.gw (deep aquifer percolation fraction), r_CN2.mgt (curve number), v_ALPHA_BF.gw (base flow alfa factor), v_ GW_DELAY.gw (groundwater delay time), r_ SOL_BD.sol (moist bulk density.), v_CH_N1. sub (mannings value for the tributary chanels), v_ ESCO.hru (soil evaporation compensation factor), v_ SURLAG. bsn (surface runoff lag time), v_ GW_REVAP.gw (groundwater revap coefficient), v_ CH_K1.sub (effective hydraulic conductivity in tributary channels), v_GW_SPYLD.gw (specific yield of the shallow aquifer, v_CH_K2.rte (effective hydraulic conductivity in main channel) and r_SLO_AWC.sol (soil avajlable water capacity) which were considered for model parameterization and calibration process in SWAT.

Calibration was performed for the monthly flows using observed flows for the period from 1989 to 1998. Surface runoff was calibrated and parameters were adjusted many times and compared with observed data. The calibration was stopped when the coefficient of determination (R^2) was more than 0.6 and Nash–Sutcliffe efficiency (Ens)was more than 0.5. In the validation process , the model was operated with input parameters set during the calibration process without any changes for the period from 1999 to 2007. For running the SWAT model, four major input data were used such as Digital Elevation Model (DEM), land use map, soil map, climatic data and stream gage data.

Model performance evaluation

The goodness-of-fit of the model that was quantified by the coefficient of determination (R^2) and Nash–Sutcliffe efficiency (E*ns*) between the observations and the final best simulations. The R^2 value is an indicator of relationship strength between the observed and simulated values. Nash-Sutcliffe simulation efficiency (E*ns*) indicates how well the plot of observed versus simulated values fit the 1 : 1 line. Model prediction is considered unaceptable or poor if the R^2 and E*ns* values are less than or close to zero, while it would be perfect if the values are one.

The Nash–Sutcliffe efficiency (E*ns*) is expressed as :

$$E_{ns} = 1 - [\sum_{i=1}^{n} (O_i - P_i)^2 / \sum_{i=1}^{n} (O_i - \bar{O}_i)^2])$$

where, O_i = observed values, P_i = predicted values and, O_i = mean of observed values.

The range of E*ns* values is from -∝ to 1, with 1 indicating a perfect fit. The formula for Coefficient of determination (R^2) is expressed as :

$$R^2 = \frac{\{ \sum_{i=1}^{n} (O_i + \bar{O}_i)) (P_i - \bar{P}_i)) \}^2}{\sum_{i=1}^{n} (O_i - O_i))^2 \sum_{i=1}^{n} (P_i - \bar{P}_i))^2}$$

where, $\bar{P}_i$ = mean of predicted values

Results and Discussion

Watershed delination was the first step of SWAT model, followed by land-use classification and soil classification for the entire watershed. DEM showed the elevation ranges from 772 to 2907 m above the mean sea level. Watershed delination resulted into 83 sub-watersheds and land-use classification resulted in eleven classes of distinct land-uses, as given in Table 1. The shrubland was found on large area (23.986%), followed by double/triple farming (22.756%) and then evergreen forest (22.464%). The least area

Table 1. Land-use distribution in the Bino watershed.

Land-use classes	Percentage area
Rice	0.299
Wheat	0.008
Pulses	0.056
Double/triple farming	22.756
Evergreen forest	22.464
Shrubland	23.986
Grassland	21.741
Other waste land	0.31
Scrubland	8.375
Water bodies	0.002
Snow covered	0.002

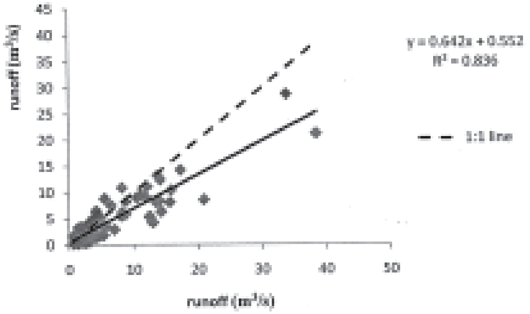

Fig. 3. Scattergram for comparison of simulated and observed runoff during calibration period.

was covered by snow (0.002%), water bodies (0.002%) followed by wheat (0.008%), pulses (0.056%) and rice (0.299%). The soil map was separated into three main soil types; viz coarse loamy (78.6%) area), loamy skeletal (11.673% area) and fine loamy (9.727% area). Than five slope ranges were defined ranging from 0 to 33%. After the three-layer classifications, 1438 HRUs were generated for the entire watershed using the threshold values of 10%, 0% and 5% for land-use, soil and slope, respectively. The monthly runoff data of 1989 to 1998 were selected for the calibration of model. Figure 3 shows the scattergram of observed and simulated runff during the calibration period and Figure 4 shows the scattergram for the validation period of 1999 to 2007. For both calibration and validation pe-

Table 2. Parameters subjected for the final calibration and uncertainity analysis. *r is the existing parameter value that is multiplied by (1+a given value) and **v is the existing parameter that is to be replaced by the given value.

Parameters Code	Description	Range (min to max)	Fitted value	Global sensitivity t-value	p-value	Rank
*r_SOL_K.sol	soil hydraulic conductivity	0.1 to 0.6	0.1375	-4.9365	0.00003	1
r_HRU_SLP.hru	average slope steepness	0.05 to 0.3	0.2062	-4.0036	0.00013	2
**v_RCHRG_DP.gw	deep aquifer percolation fraction	0.2 to 0.8	0.3830	-3.4543	0.0008	3
r_CN2.mgt	curve number	-0.7 to -0.1	-0.5650	-3.3270	0.0013	4
v_ALPHA_BF.gw	base flow alfa factor	0.1 to 0.5	0.1140	-2.0108	0.0475	5
v_GW_DELAY.gw	groundwater delay time	2 to 10	7.160	1.8796	0.0636	6
v_SOL_BD.sol	moist bulk density	± 0.01	-0.0083	-1.7405	0.0854	7
v_CH_N1.sub	mannings value for the tributary channels	0.02 to 0.5	0.4832	-1.4582	0.1484	8
v_ESCO.bsn	soil evaportion compensation factor	0.1 to 0.8	0.7475	1.4241	0.1581	9
v_SURLAG.bsn	surface runoff lag time	6 to 30	29.40	-1.0914	0.2782	10
v_GW_REVAP.gw	groundwater 'revap' coefficient	0.1 to 0.6	0.5925	0.9530	0.3433	11
v_CH_K1.sub	(effective hydraulic conductivity in tributary channels)	0.03 to 0.9	0.4084	-0.2872	0.7746	12
v_GW_SPYLD.gw	specific yield of the shallow aquifer	0.4 to 0.7	0.4915	-0.1882	0.8511	13
v_CH_K2.rte	effective hydraulic conductivity in main channel	0.4 to 0.9	0.8375	-0.1866	0.8523	14
r_SOL_AWC.sol	soil available water capacity	-0.02 to -0.2	-0.0677	-0.1252	0.9006	15

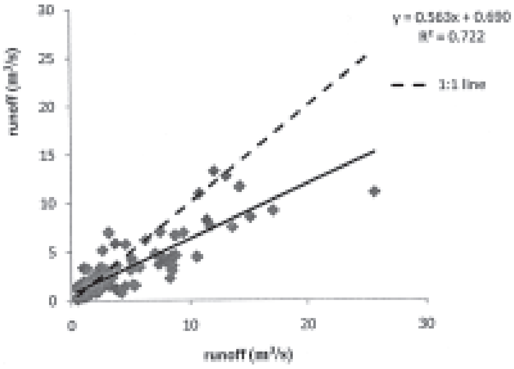

Fig. 4. Scattergram for comparison of simulated and observed runoff during validation period.

riods, runoff was under predicted using SWAT with coefficient of determination (R^2) as 0.836 and 0.722, respectively. Calibrated parameters were constrained within the ranges, their fitted values, global sensitivity and ranks achieved as given in Table 2. Out of fifteen parameters, three parameters were found more sensitive and these were; SOL_ K (soil hydraulic conductivity), HRU_SLP (average slope steepness), RCHRE_DP (deep aquifer percolation fraction). Out of these three parameters; SOL_K (soil hydraulic conductivity) was found to be the most sensitive because of lower p-value i.e., 0.000003. SOL_AWC (soil available were capacity) was found least sensitive followed by CH_K2 (effective hydraulic conductivity in main channel) because highest (0.9006) and second highest (0.8523) *p*-value were found for SOL_AWC and CH_K2, respectively.

Nash-Sutcliffe efficiency (E*ns*) and coefficient of determination (R^2) were used for model performance evaluation and were within the permissible limits, both for calibration and validation period. The results suggest that the SWAT model is accurate and very well be used to predict the runoff for the Bino watershed.

Conclusion

SWAT model was used for the assessment of runoff from for Bino watershed. Two performance evaluation indices were used to test the results obtained by SWAT simolation.For the calibration period, Nash – Sutcliffe efficiency and coefficient of determination were 0.75 and 0.83, respectively; and for validation period, Nash-Sutcliffe efficiency and coefficient of determination were 0.62 and 0.72, respectively. The results were higher than the recommended minimum values in the literature ($R^2 > 0.6$ and $E_{ns} > 0.5$), which illustrated that SWAT simulated runoff was fairly close to the observed output. Also, the smaller *p*-value (or higher t-value) indicated more sensitive parameter in SWAT modelling. The observation of sensitive parameters revealed that the flow characteristics of study area were affected by both surface water and groundwater flow characteristics. Thus, the study revealed that, SWAT model is capable of simulating runoff from a small hilly watershed under study.

References

1. Descroix L, Viramontes D, Estrada J, Gonzalez Barrios JL, Asseline J (2007) Investigating the spatial and temporal boundaries of Hortonian and Hewiletian runoff in Northern Mexico. J Hydrology 346 : 144—158.
2. Schneiderman EM (2007) Incorporating variable source area hydrology into the curve number based generalized watershed loading function model. Hydrological Processes 21 : 3420—3439.
3. Pandey VK, Panda SN, Sudhakar S (2005) Modelling of an agricultural watershed using remote sensing and a geographic information system. Biosystems Eng 90 : 331—347.
4. Tripathi MP, Panda RK, Raghuwanshi NS (2003) Identification and prioritisation of critical sub-watersheds for soil conservation management using the SWAT model. Biosystems Engg 85 : 365—379.
5. Kannan N, Santhi C, Arnold JG (2008) Development of an automated procedure for estimation of the spatial variation of runoff in large river basins. J Hydrology 359 : 1—15.
6. Kannan N, White SM, Worrall F, Whelan MJ (2007) Hydrological modelling of a small catchment using SWAT-2000-ensuring correct flow partitioning for contaminant modelling. J Hydrology 334 : 64—72.
7. Shrestha RR, Dibike YB, Prowse TD (2009) Application of SWAT in hydrologic and nutrient transport modeling of the lake winnipeg watershed. Int SWAT Conf Proc, Boulder, Colorado, pp 269—277.
8. Arnold JG, Moriasi DN, Gassman PW, Abbaspour KC, White MJ, Srinivasan R, Santhi C, Harmel RD, Van Griensven A, Van Liew MW, Kunnan N, Jha MK (2012) Swat: model use, calibration, and validation. Am Soc Agric and Biol Engg 55 : 1491—1508.
9. Pai N, Saraswat D (2013) Impact of land use and land cover categorical uncertainty on SWAT hydrologic modeling. Am Soc Agric and Biol Engg 56 : 1387—1397.

10. Quyen NTN, Liem DN, Loi KN (2014) Effect of land use change on water discharge in Srepok watershed, Central Highland, Viet Nam. Int Soil and Water Conserv Res 2 : 74—86.

11. Santhi C, Srinivasan R, Arnold JG, Williams JR (2006) A modelling approach to evaluate the impacts of water quality management plans implemented in a watershed in Texas. Environ Modell Softw 21 : 141—157.