Estimation of Surface Runoff using SWAT Model

V. S. Malunjkar, M. G. Shinde, S. S. Ghotekar, A. A. Atre

Abstract— Runoff is a very important phenomenon of hydrological cycle and it is relevant for the watershed management programme for conservation and development or natural resources and its management. However, In India the availability of accurate information on runoff is scarce. Soil and Water Assessment Tool (SWAT) is a physically based distributed parameter model which has been developed to predict runoff, erosion, sediment and nutrient transport from agricultural watersheds under different management practices. For the present study, a small agricultural watershed has been selected for runoff assessment. Geoinformatic techniques such as ERDAS software and Shuttle Radar Topographic Mission (SRTM) data are used for execution of the model. Calibration of the model is done with the help of observed data and then it is validated on selected study area. For calibration and validation, daily observed runoff data of 1997 and 1998 were used. It is found from the results that, Nash and Sutcliffe efficiency was 0.62 and 0.74 respectively and coefficient of determination was 0.98 and 0.95 respectively for calibration and validation period.

Index Terms—Hydrological modeling, Runoff, Nash and Sutcliffe efficiency and SWAT.

I. INTRODUCTION

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 watersheds. Use of mathematical models for the hydrologic evaluation of watersheds is the current trend and extraction of watershed parameters using remote sensing and geographical information system (GIS) in high speed computers are the aiding tools and techniques for it.

Surface runoff is one of the major causes of erosion to the earth's surface and the location of high runoff generating areas are very important for making better land management practice. Runoff production in a watershed depend on the mechanism by which runoff is generated. Infiltration excess occurs when the rainfall intensities exceed to the soil infiltration rate or any depression storage has been already filled. Soil infiltration rates are controlled by soil characteristics, vegetation cover and land use practices. There are various rainfall-runoff models developed for accounting of hydrological processes. They are classified as physical, empirical and conceptual models [1]. Mathematical models are much more popular for runoff assessment as these are less data driven, simpler and cheaper [2]. Different types of Physical models have been developed for the purpose of water resources management and planning such as ANSWERS [3], WEPP [4], GUEST [5], EUROSEM [6] and LISEM [7] are now widely accepted models for simulating runoff and soil erosion.

The Soil and water Assessment Tool (SWAT) was developed to predict the effects of different management practices on water quality, sediment yield and pollution load in watersheds [8]. Various researchers have been evaluated SWAT model and their findings indicated 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 2005 model with ARCGIS 9.3 interface was selected for the present study.

II. MODEL DESCRIPTION

Soil and Water Assessment Tool (SWAT) is a river basin or watershed, scale model developed by Dr. Jeff Arnold for the United State Department of Agriculture Agricultural Research Service (ARS). SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watershed with varying soils, land use and management condition over long periods of time. Rather than incorporating regression equation to describe the relationship between input and output variables, SWAT requires specific information about weather, soil properties, topography, vegetation and land management practices occurring in watershed. The physical processes associated with water movement, crop growth, nutrient cycling etc are directly modulated by SWAT using this input data.

In SWAT, a watershed is partitioned into a number of sub-watershed or sub-basins. The use of sub-basins in a simulation is particularly beneficial when different areas of watershed are dominated by land uses or soils dissimilar enough in properties to impact hydrology. By partitioning the watershed into sub-basins, the user is able to reference different areas of watershed to one another spatially. Input information for each sub-basin is grouped or organized into different categories: climate; hydrologic response units (HRUs); ponds/wetlands, groundwater; and the main channel, draining the sub-basin.

Manuscript Received on March 2015.

Er. V. S. Malunjkar, Department of Soil and Water Conservation Engineering, Mahatma Phule Krishi Vidyapeeth, Rahuri [MH], India.

Dr. M. G. Shinde, Department of Soil and Water Conservation Engineering, Mahatma Phule Krishi Vidyapeeth, Rahuri [MH], India.

Er. S. S. Ghotekar, Department of Soil and Water Conservation Engineering, Mahatma Phule Krishi Vidyapeeth, Rahuri [MH], India.

Dr. A. A. Atre, Department of Soil and Water Conservation Engineering, Mahatma Phule Krishi Vidyapeeth, Rahuri [MH], India.

Hydrologic response units are lumped land areas within the sub-basin that are comprised of unique land cover, soil, and management combinations.

Simulation of hydrology of a watershed can be separated into two major divisions. The first division is the land phase of the hydrologic cycle. The land phase of the hydrologic cycle controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub-basin. The second division is the water or routing phase of the hydrologic cycle which can be defined as the movement of water, sediment etc, through the channel network of the watershed to the outlet.

III. STUDY AREA

For the present study, Maheshgad watershed was selected, it is located towards South of Central Campus of Mahatma Phule Krishi Vidyapeeth, Rahuri (190 19' N longitude and 740 38' E latitude), Maharashtra. It is having 45.04 ha area and the average annual rainfall in the study area is 553 mm.

Soil and land use pattern: Selected watershed is having loamy soil, murum and stony waste (exposed rock). Slope of watershed varies from 8 % to 1.95 %. It is divided into eight sub-watershed namely W1A, W1B, W1, W2, W3, W4, W5 and water body (W6). The area and average slope of each sub-watershed are given in Figure 1. and Table 1.

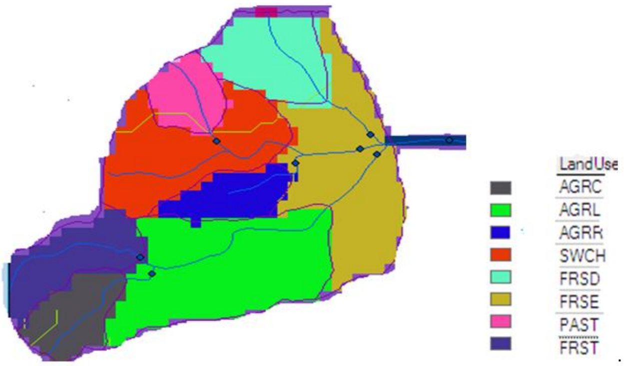

Figure 1. Land use pattern map of the study area

Table 1. Characteristics of sub-watersheds

Sub-watershed	Area (ha)	Slope (%)	Soil type	Land use
W1A	2.38	8.00	Rock	Horticulture
W1B	16.28	2.12	Murum	Horticulture
W1	18.66	8.77	Murum	Horticulture
W2	2.74	1.95	Loam	Agriculture
W3	9.97	2.54	Murum	Pasture
W4	4.75	3.07	Murum	Horticulture
W5	8.92	-	Loam	Water body
W6	2.44	3.97	Murum	Horticulture and Pasture

IV. SWAT SIMULATION

Hydrologic response units (HRUs): SWAT model divide the eight sub-watersheds into twenty-eight HRUs. Its classification is dependent upon slope range. In study, four slope ranges are selected 0-2 %, 2-4 %, 4-6 % and 6-99 %. These HRU's are presented in Figure 2.

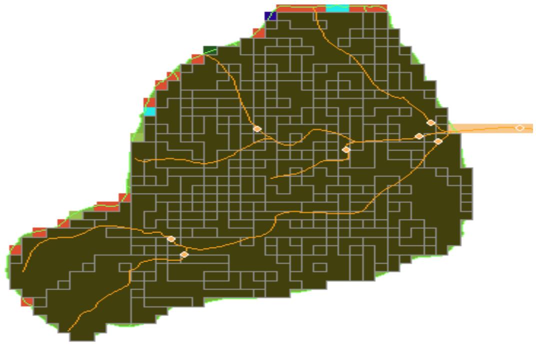

Figure 2. HRUs map generated by SWAT

Curve numbers: In SWAT model surface runoff simulation is done by NRCS-CN method. Different curve number use by SWAT for all the sub-watersheds are presented in Table 2.

Table 2. CN use by SWAT for runoff simulation

Sub-watershed	Slope (%)	Land use	SWAT code	Soil code	HSG	CN
W1A	8.00	Horticulture	FRSD	ABRAM	C	77
W1B	2.12	Horticulture	ORCD	AQUENTS	C	77
W1	8.77	Horticulture	FRST	ADAMS	C	73
W2	1.95	Agriculture	AGRL	ADRIAN	C	83
W3	2.54	Pasture	PAST	AGAWAM	C	79
W6	3.97	Horticulture and Pasture	RNGB	AURES	C	74
W4	3.07	Horticulture	RNGE	AMENIA	B	69
W5	-	Water body	WATR	BEACHES	C	92

Calibration and validation: Physically based distributed watershed models should be calibrated before they are made use of in the simulation of hydrologic processes. This is reducing to uncertainty associated with model prediction. Hence, before going for the determination of the hydrologic components, a thorough attempt has been made to tune the parameters of the model so that the predicted values are in very close agreement with available measured data.

SWAT 2005 has been calibrated and validated using daily runoff flow data and monthly Potential evapotranspiration of two years 1997 and 1998. Data pertaining to year 1997 has been used for calibration and 1998 for validation. The calibration simulation period for runoff flow and monthly Potential evapotranspiration was started from January to December 1997. The related SWAT model parameters were adjusted to correct the overestimation of average daily runoff flow. After calibration, the curve number (CN2) was determined.

V. SWAT EVALUATION

Coefficient of efficiency (CE): The relative performance of two approaches could be compared effectively based on standardization of residual variance with initial variance. The coefficient of efficiency, CE is determined by following mathematical relationship [9];

$$E = 1 - \frac{\sum_{i=1}^{n} (q_{obs} - q_{swat})^2}{\sum_{i=1}^{n} (q_{obs} - q_{mean})^2} \quad (1)$$

Where, q_{obs} is observed value, q_{swat} is simulated value and q_{mean} is the mean of observed value.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

The perfect agreement between observed and estimated values yields CE as 1. Zero values of CE signify the estimate equals to mean of observed values. The negative value of CE implies estimate values to be less than observed mean.

Coefficient of determination: Coefficient of determination calculated by formula [10],

$$R^2 = 1 - \frac{SS_{res}}{SS_{tot}} = 1 - \frac{\sum_i (y_i - f_i)^2}{\sum_i (y_i - \overline{y}_i)^2} \quad (2)$$

Where, SS_{res} is the sum of squares of residuals, also called the residual sum of squares and SS_{tot} is the total sum of squares (Proportional to sample variance).

VI. RESULTS AND DISCUSSIONS

The results obtained after SWAT simulations are depicted in following figures. The daily runoff data of 1997 was selected for the calibration of model. Figure 3 shows the scattergram of observed and simulated runoff during the calibration period. It is observed that, few values are over predicted and under predicted. However, maximum points are on 1:1 line which is indicating very close agreement between observed and simulated results.

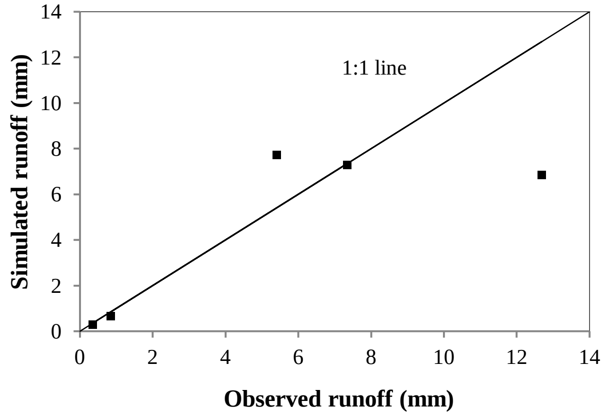

Figure 3. Scattergram for comparison of simulated and observed runoff (mm) during calibration period.

Similarly, Figure 4. shows the scattergram for the validation period (1998). It is observed that, few values are on 1:1 line but maximum points are under predicted which indicates there is less agreement between observed and simulated runoff results. It may be due to less storm events selection for the study.

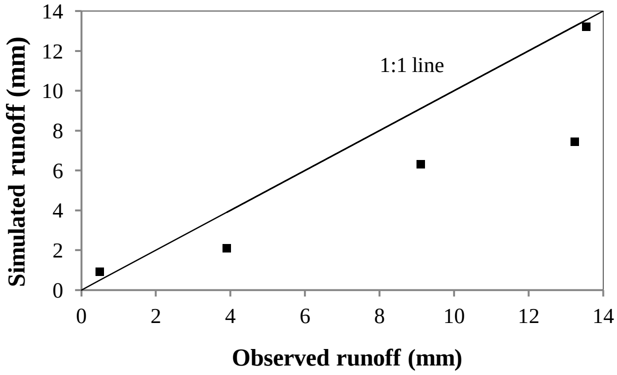

Figure 4. Scattergram for comparison of simulated and observed runoff (mm) during validation period.

Nash coefficient of efficiency and coefficient of determination was used for model evaluation. Table 3 shows the results of SWAT model evaluation. Nash efficiency and coefficient of determination gave higher and within the permissible limit values, both for calibration and validation period. The result suggests that the model is accurate and very well, be used to predict the runoff for the selected study area.

Table 3. Evaluation of SWAT model

Statistical indices	Calibration period	Validation period
Coefficient of efficiency	0.62	0.74
Coefficient of determination	0.98	0.95

VII. CONCLUSION

The basic module, SWAT 2005 was used for the assessment of surface runoff for Maheshgad watershed. The simulated annual runoff by SWAT model is 42 mm and 81.24 mm, respectively for the calibration and validation period. Two evaluation indices were tested the results obtained by SWAT simulation. For the calibration period, Nash efficiency and coefficient of determination was 0.62 and 0.98, respectively. For validation period Nash efficiency and coefficient of determination was 0.74 and 0.95, respectively.

The study reveals that, SWAT model is accurate and capable of simulating surface runoff from a small watershed.

ACKNOWLEDGMENT

This study is based on the work supported by Department of Science and Technology, Government of India. Also technical guidance from the Department of Soil and Water Conservation Engineering, MPKV, Rahuri has made this project possible.

REFERENCES

1. C. W. Dawson and R. L. Wilby, "Hydrological modeling using artificial neural networks. Prog. Phys. Geog. 2001, 25, pp: 80-108.
2. T. A. Fontaine, T. S. Cruickshank, J. G. Arnold and R. H. Hotchkiss, "Development or a snowfall-snowmelt routine for mountain- terrain for the soil water assessment tool (SWAT)." *J. Hydrol.* 2002, 262, pp: 209-223.
3. D. B. Beasley, L. F. Huggins and E. J. Monke, "ANSWERS: a model for watershed planning." *Trans. ASAE,* 1980. pp: 938– 944.
4. M. A. Nearing, G. R. Foster, L. J. Lane and S. C. Finkner, "A process-based soil erosion model for USDA-water erosion prediction project technology." 1989. *Trans. ASAE,* 32 (5), pp: 1587– 1593.
5. R. K. Misra and C. W. Rose, "Manual for use of program GUEST." Division of Australian Environmental Studies Report. Griffith Univ., Brisbane, Australia, Queensland. 1990.
6. R. P. C. Morgan, J. N. Quinton, R. E. Smith, G. Govers, J. W. A. Poesen, K. Auerswald, G. Chisci, D. Torri and M. E. Styczen, "The European soil erosion model (EUROSEM): a dynamic approach for predicting sediment transport from fields and small catchments." *Earth Surface Processes and Landforms*, 1998. 23, pp: 527–544.
7. A. P. J. De Roo and R. J. E. Offermans, "LISEM: a physically-based hydrological and soil erosion model for basin-scale water and sediment management." *Proc. Boulder Symp*., 1995. IAHS Publ. no. 231. pp: 399-407.
8. G. J. Arnold, R. Srinivasan, R. S. Muttiah and J. R. Williams, "Large area hydrologic modeling and assessment Part I: Model development." *J. Am. Water Resour. Assoc.* 34. 1998. (1), pp; 73–89.

9. J. E. Nash and J. V. Sutcliffe, "River flow forecasting through conceptual models, Part-1: A discussion of principles". *J. Hydrol.* 1970. 10 (3), pp: 282–290.
10. S. A. Glantz and B. K. Slinker, "Primer of Applied Regression and Analysis of Variance." McGraw-Hill, Vol.07, 1990. pp: 407-412.

AUTHORS PROFILE

Er. V. S. Malunjkar, Ph.D. Scholar, MPKV Rahuri and INSPIRE fellow (DST-GOI), Email:.

Dr. M. G. Shinde, Associate professor, Department of Soil and Water Conservation Engineering, MPKV, Rahuri.

Er. S. S. Ghotekar, M.Tech Student, Department of Soil and Water Conservation Engineering, MPKV, Rahuri.

Dr. A. A. Atre, Associate professor, Department of Soil and Water Conservation Engineering, MPKV, Rahuri.