Rainfall-Runoff modeling for Damodar river catchment using SWAT model

Subhashis Chowdhury, Rajashree Lodh

* *Subhashis Chowdhury[1], Assistant Professor, Dr. B. C. Roy Engineering College, Durgapur, India,*
**Rajashree Lodh[2], Assistant Professor, Heritage Insitute of Technology, Kolkata, India,*

(Corresponding Author)

Abstract
The runoff of Damodar river catchment is estimated using Soil and Water Assessment Tool (SWAT) Model in the present study. SWAT and ArcGIS works together with an extension ArcSWAT .Soil and Water Assessment Tool In order to predict erosion, runoff, sediment and nutrient transport from individual watersheds, ponds, wetlands, reservoirs and agricultural fields under different management conditions, SWAT model has been developed. Delineation of sub-watersheds is done based on DEM by using ArcSWAT2012. The soil map is extracted from raster world sil map and land use map is prepared using IRS-P6 LISS-III image. Then SWAT simulation is done by using 12 years of daily rainfall data and daily maximum and minimum temperature data to find out Runoff for corresponding Rainfall. The observed rainfall runoff correlation (r) in this study is 0.88.

Keywords: SWAT, Rainfall, Runoff; Rainfall; GIS

Introduction

Rainfall and runoff are two important variables in context to hydrologic design. There are different methods available for measuring rainfall and runoff, but determination of direct runoff is time consuming and difficult in case of unpaved river basins. There are different factors that affect the runoff such as climate change, change in topography, type of soil, river discharge etc. Based on meteorological and hydrological data, runoff can be predicted using conventional methods such as USLE, RUSLE etc. But in few developing countries there is lack of temporal and spatial data, so such methods don't work. In such cases remote sensing in combination with GIS can estimate peak discharge, direct runoff volume and hydrographs using appropriate rainfall-runoff models. The model will be able to predict runoff for any amount of rainfall for certain duration. In the present study, QGIS and ArcSWAT2012 are main sources of software used and runoff is estimated using SWAT model.

Study Area

The data used in the present study is from the upper catchment of the Durgapur barrage in the Damodar river sub-basin. Damodar river is flowing across Indian states of West Bengal and Jharkhand. Two reservoirs (Konar and Panchet) located on the river are used for flood control, hydropower generation, irrigation etc. Most of the times sub-tropical climate prevails over the ctachment. Durgapur Barrage (692m in L×12 m in H) is located across the Damodar river at Durgapur in Bankura district and is partly in Paschim Bardhaman district in West Bengal, India. The study area is at latitude 23.4754°N and longitude 87.3023°E. Durgapur barrage has 34 gates (including under-sluice).The size of gates are (18.3m×4.9m). The size of left and right under-sluices is (18.3m×5.5m). The length of right bank and left bank of the main canal originating from Durgapur Barrage is 88.5 km and 136.8 km respectively. The head regulator discharge for left bank and right bank of the canal is 260 cubic metres (69,000 US gal) per second and 64.3 cubic metres (17,000 US gal) per second. The total length of main and branch canals is 2,494 km.

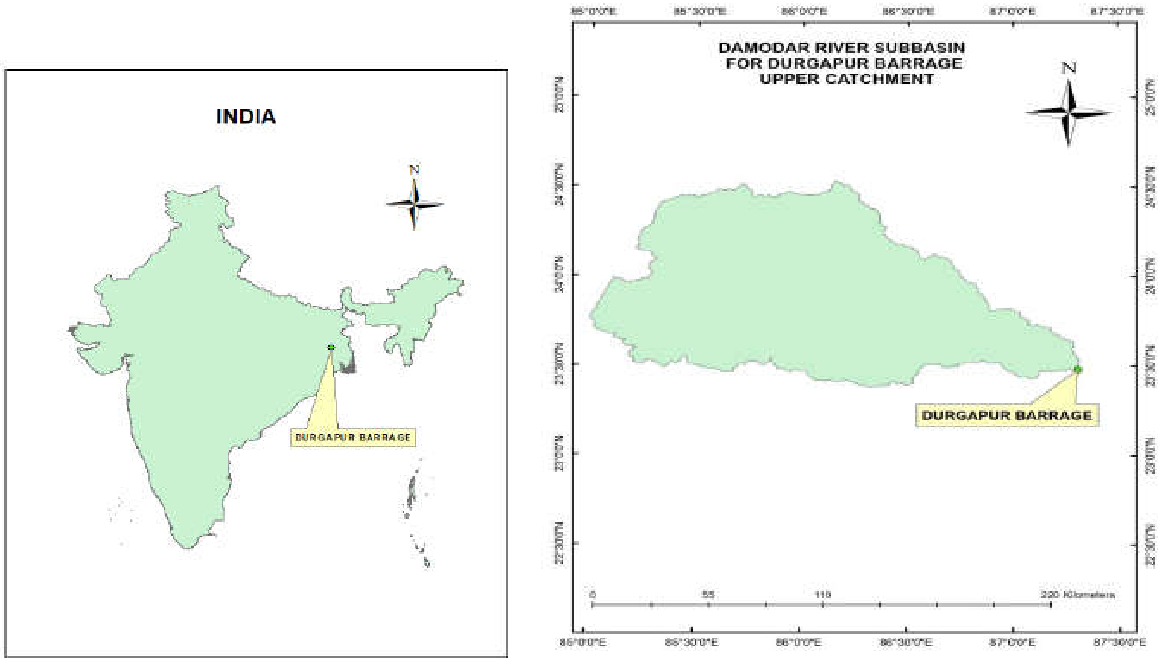

Figure 1: Study area

Methodology:

Description of SWAT model

In order to predict erosion, runoff, sediment and nutrient transport from individual watersheds, ponds, wetlands, reservoirs and agricultural fields under different management conditions, SWAT model has been developed. It is a physically and process-based distributed hydrological model that operates to simulate runoff and sediment using the Modified Universal Soil Loss Equation and Soil Conservation Service (SCS) Curve Number (CN) method respectively. The model divides the entire watershed into a number of sub-basins or sub-watersheds in order to identify different areas of landuses or soils different enough in characteristics to impact hydrology. The soil type of each land cover and slope present in the catchment area are the main determining factor used for predicting total runoff. Therefore in this modeling, the influence of each type of landuse is considered to calculate the runoff of the area. The distributions of the Hydrological Response Units (HRUs) were determined after the overlay of the soil maps, slope maps and land use maps. HRUs are used to divide the total area into similar soil type, land use type and slope type. For individual HRU, runoff is predicted separately and routed to obtain the total runoff of the basin. Thus the accuracy is increased and a much better physical description of the water balance is obtained.
SWAT and ArcGIS works together with an extension ArcSWAT. ArcSWAT is a graphical user input interface for SWAT tool. SWAT uses the water balance equation (1) to simulate the hydrologic cycle. Soil Conservation Service (SCS) curve number technique (USDA, 1972) is used here to estimate the runoff volume.

$$SW_t = SW_o + \sum_{i=1}^{t} \left(R_{day} - Q_{surf} - E_a - w_{sweep} - Q_{gw} \right) \qquad (1)$$

where, t is time in days, the amount of return flow, surface runoff, percolation and bypass exiting the soil profile bottom, evapotranspiration and precipitation is represented as Q_{gw}, Q_{surf}, w_{seep}, E_a, R_{day} in mm H2O on day i respectively, SW_o and SW_t are the initial and final soil water content (mm H2O).
Model Operation: The runoff modeling at the basin outlet using SWAT model is represented in the form of a flow chart (Figure 2). SWAT requires hydrological parameters, meteorological parameters, DEMs, Landuse/Landcover maps as input. As semi-distributed model, SWAT has to process,

combine and analyze these spatial data using GIS tools. Thus, in order to facilitate the use of the model, it was coupled with GIS software as free additional extension ArcSWAT for ArcGIS.

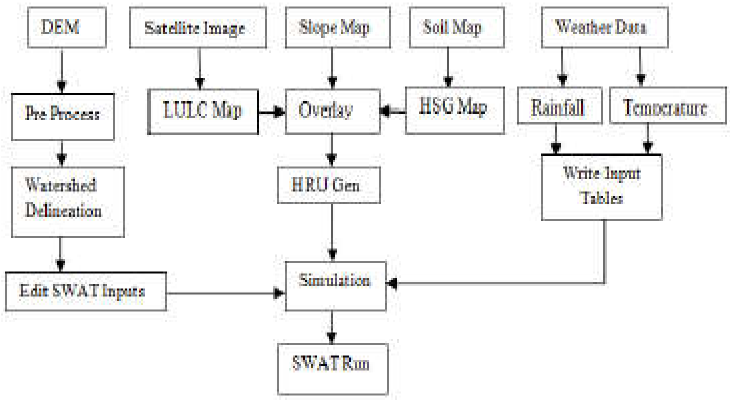

Figure 2: Methodology for rainfall-runoff modelling

Watershed Delineation in ArcSwat:

The application of Digital Elevation Model (DEM) helps the user to delineate sub watersheds. User specified parameter provides the limits that influence the size and number of sub watershed created. Moreover, users also may import pre-defined catchment boundary and related stream network. The watershed delineation carries out advanced GIS function to aid the user in segmenting watersheds in to several hydro-logically connected sub-watersheds for use in watershed modeling with SWAT.

Source of different data

1. Digital Elevation Model (DEM): DEM is extracted from the website of (USGS) EARTH EXPLORER. Delineation of the river basins as the stream network, drainage surfaces and longest reaches is done using DEM. The topographical parameters such as channel slope, terrain slope or reach length were also derived from the DEM.

2. Land use/ Land cover map: Land use map (Figure 3) for the study area has been derived from satellite IRS-P6 LISS-III image using Supervised Classification technique. This technique helps to derive, identify and classify the different land use classes in the Damodar river basin. Twelve major landuse classes were recognized for the present study area and the dominant categories are irrigated areas (26.14%) and forest areas (19%).

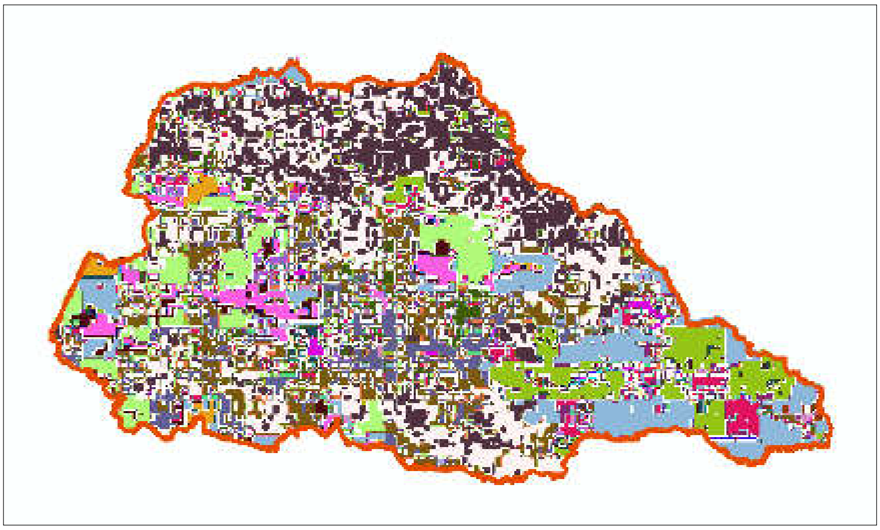

Figure 3: Classified landuse map of the study area

Slope Map: The Slope map (Figure 4) was generated from the contours of the toposheets. The resulting slope indicates the degree of slope for individual cell location.

Soil Map: The soil map (Figure 5) is extracted from the HWSD (Harmonized World Soil Database) raster world soil map. There are three types of textural classes present in the study area namely laterite soil with rock solids denoted by A, alluvial soil denoted by B and laterite soil denoted by D in the figure.

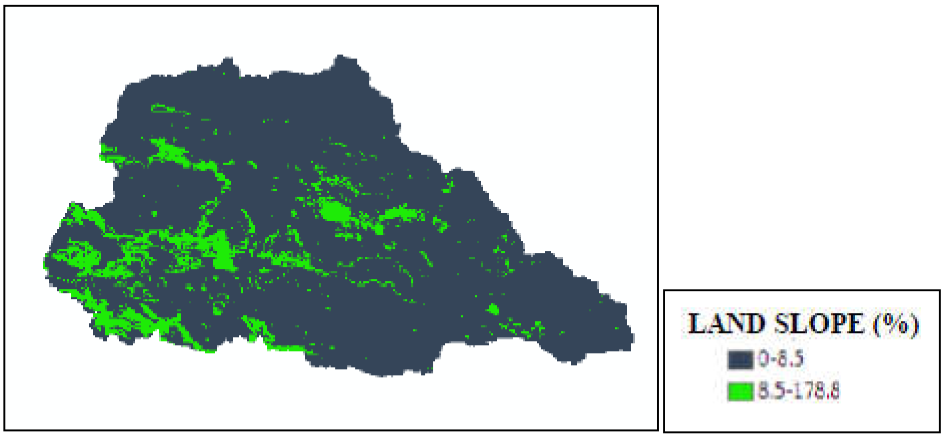

Figure 4: Slope map of the study area

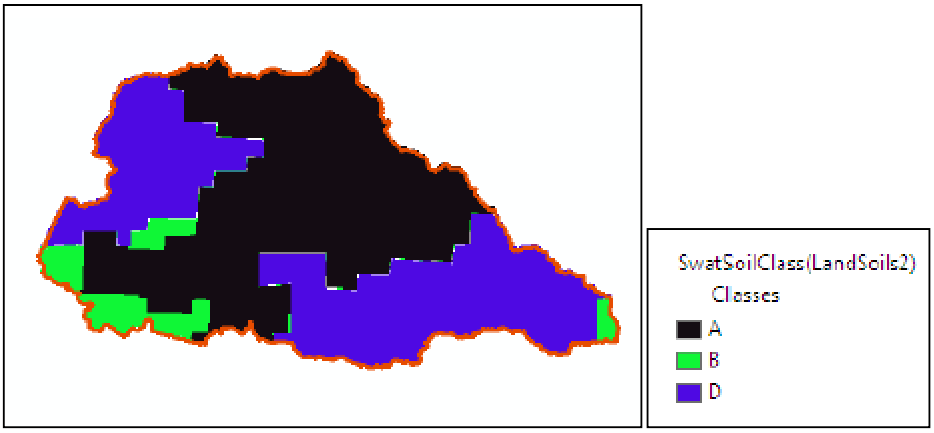

Figure 5: Soil map of the study area

Hydro meteorological data: SWAT requires daily values for minimum and maximum temperature, precipitation, solar radiation, wind speed and relative humidity for modeling of different physical processes. Temperature data and precipitation data of Damodar river catchment has been downloaded from http://swat.tamu.edu and Indian Meteorological Department, Pune respectively. Here 12 years of 0.5 degree gridded daily precipitation data and also 12 years of 1 degree gridded daily minimum and maximum temperature data is used from the year 1997 to 2008 for the present study. Figure 6 shows the monitoring points of weather data in the study area.

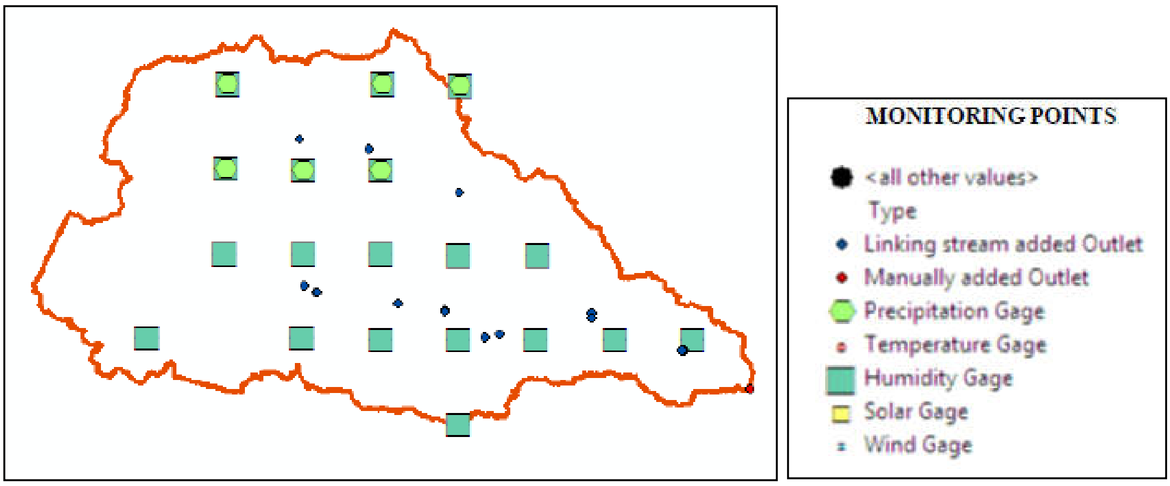

Figure 6: Location of weather stations in study area

Model Setup: SWAT model has been setup for the present study area by developing all the required database. Delineation of sub-watersheds is done based on DEM by using ArcSWAT2012. DEM is used in the model and the mask is created manually to extract out the sub-catchment area of Damodar basin. The outlet for the study area is defined for the river catchment and the watershed was delineated (Figure 7) and all the parameters are estimated for individual sub basins.

SWAT allows the users to import the soil map and land use map to the model, then calculate slope characteristics and evaluate the land Hydrologic Response Unit (HRU) for individual sub-watershed. Land use category is used for identifying the land use layer and soil type table is used for categorizing the type of soil to be modeled for individual category.

The LULC map is reclassified into 12 different types, the soil map reclassified the database into 3 different HSG (hydrological soil group) named as A, B and C depending on the rate of infiltration. The slope map is reclassified into 2 classes i.e. 0-8.5%, 8.5-178.8%. Then the slope, soil and land use data layers have been overlaid. The distribution of HRUs (Hydrologic Response Units) within the catchment has been developed. In the Damodar river catchment a total of 223 HRUs were generated. For all the soil, slope and land use classes, a threshold percentage of 10% has been adopted to eliminate minor soil, slope and land use. The SWAT model requires daily data for temperature and precipitation. Weather data is imported using the "Write Input Tables" menu on the ArcSWAT toolbar. It allows the user to import locations of weather station into the present project and provide the weather data to the sub-watersheds. Each sub-watershed is linked to one gauge for each type of imported weather data. The input values of the watershed must be defined before running the SWAT model. Based on the characterization of Land use\ slope\ soil and the watershed delineation, these values are set automatically. At last, the model was run to simulate the values of surface runoff.

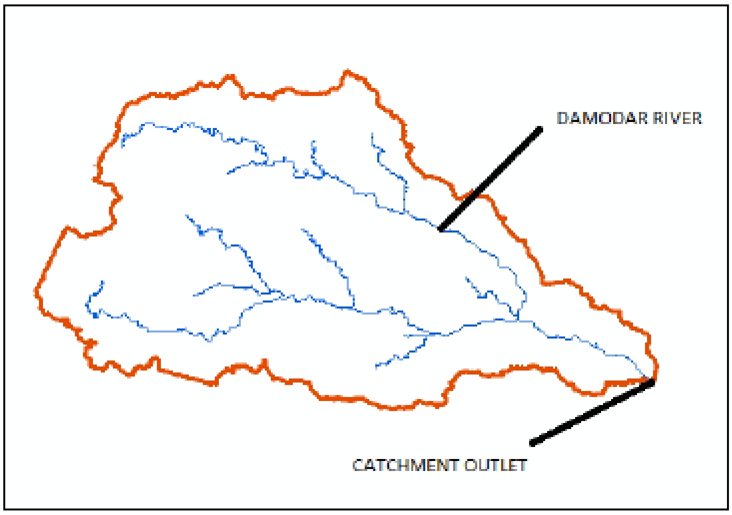

Figure 7: Delineation of sub-basins of upper Damodar river catchment

SWAT simulation: The SWAT Simulation toolbar is required to finalize the input parameters and run the SWAT model, perform auto-calibration and sensitivity analysis.

Results and discussions

This study explains the modeling of the Rainfall Runoff process using SWAT-based model. The simulation is done for daily, monthly and yearly basis. For daily rainfall values, SWAT model provides corresponding daily Runoff values throughout the year. Figure 8 represents the monthly comparison of rainfall and runoff for the year 1997. Figure 9 shows the graphical presentation of daily maximum Rainfall-Runoff values for each year for period of 12 years and the maximum runoff occurred in 1999. A good rainfall runoff correlation with r2 value of 0.75 was found by considering 12 years data.

Conclusions

The SWAT simulation model derived good results of daily, monthly and yearly runoff values for the catchment as well as for the other components of water balance equation. The observed rainfall runoff correlation (r) in this study is 0.88. The model performance was evaluated successfully using the recommended statistical factors. Moreover, these performances were improved by using more accurate input values especially for the landuse, soil and DEM data that were calculated in this study using global data. The accurate rainfall-runoff correlation can be computed by integration of different climatic data such as temperature and rainfall data. The model validation is done with the help of observed runoff data of the study area.

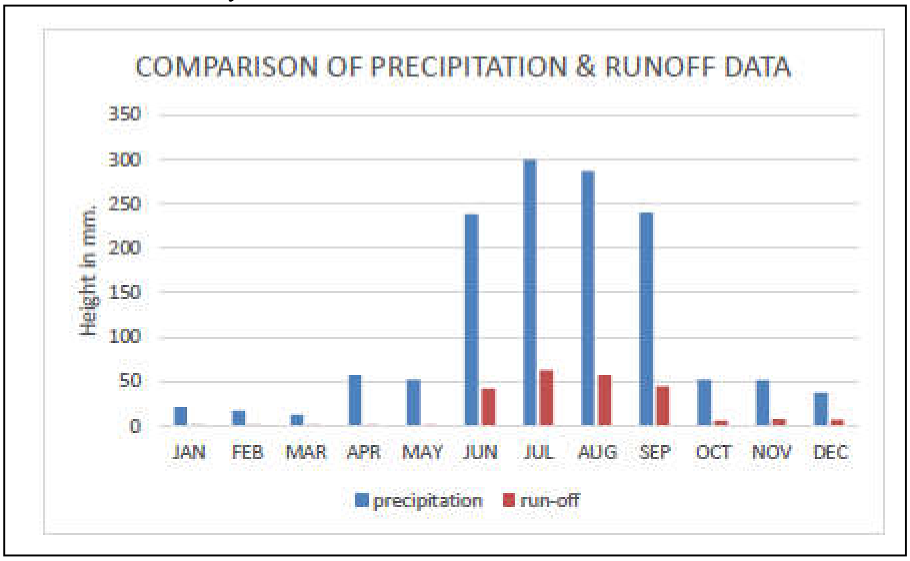

Figure 8: Monthly comparison of precipitation and runoff for 1997

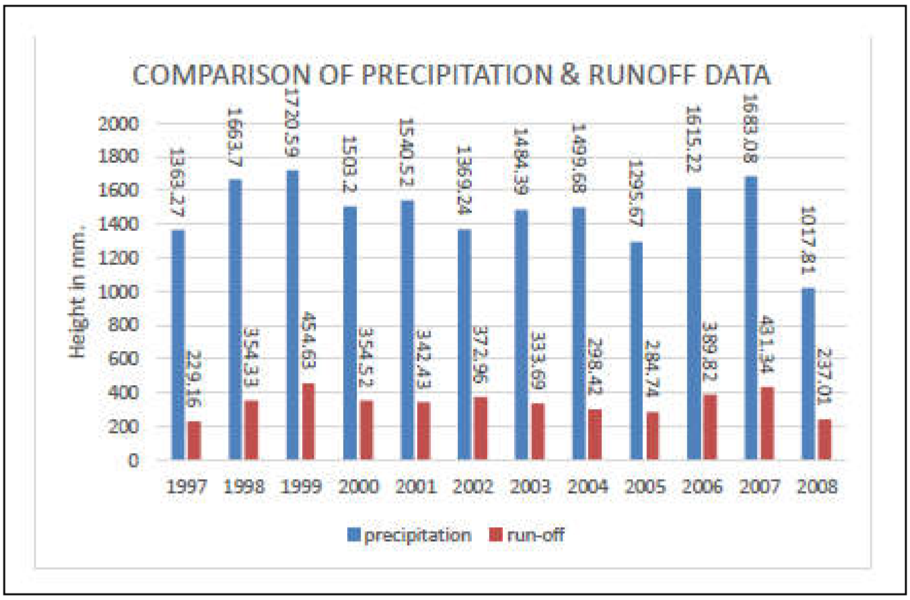

Figure 9: Yearly comparison of total precipitation and runoff

References

- Arnold, J.G. and Fohrer, N. (2005) SWAT2000: Current Capabilities and Research Opportunities in Applied Watershed Modelling. Hydrological Processes, 19, 563-572. https://doi.org/10.1002/hyp.5611

- Chong Y X 2002 “TEXT BOOK OF HYDROLOGIC MODELS”, Uppsala

- Khare, D, Singh, R and Shukla, R (2014) Hydrological Modelling Of Barinallah Watershed Using Arc-Swat Model, International Journal of Geology, Earth & Environmental Sciences, Vol. 4 (1) pp. 224-235, ISSN: 2277-2081
- Fadil, A., Rhinane, H., Kaoukaya, A., Kharchaf, Y. and Bachir, O.A. (2011) Hydrologic Modeling of the Bouregreg Watershed (Morocco) Using GIS and SWAT Model. Journal of Geographical Systems, 3, 279-289. http://dx.doi.org/10.4236/jgis.2011.34024
- Kangsabanik S, Murmu S, (2017) Rainfall-runoff modelling of Ajay river catchment using SWAT model. 7th International Conference Series: Earth and Environmental Science.
- Setegn, S.G., Srinivasan, R. and Dargahi, B. (2008) Hydrological Modelling in the Lake Tana Basin, Ethiopia Using SWAT Model. The Open Hydrology Journal, 2, 49-62. https://doi.org/10.2174/1874378100802010049

- Singh, V., Bankar, N., Salunkhe, S.S., Bera, A.K. and Sharma, J.R. (2013) Hydrological Stream Flow Modeling on Tungabhadra Catchment: Parameterization and Uncertainty Analysis Using SWAT CUP. Current Science, 104, 1187-1199.
- Winchell, M., Srinivasan, R., Di Luzio, M. and Arnold, J.G. (2013) Arcswat Interface for SWAT2012: User’s Guide. Blackland Research Center, Texas AgriLife Research, College Station, 1-464.”
- Z.M. Easton, D.R. Fuka, E.D. White, A.S. Collick, B. Biruk Ashagre, M. McCartney, S. Awu lachew, A.A. Ahmed, T.S. Steenhuis (2010) A multi basin SWAT model analysis of runoff and sedimentation in the Blue Nile, Ethiopia. Hydrology and earth system sciences, 14, 1827-1841