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Hydrological modeling of a sub-basin of Mahanadi river basin using SWAT model

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ABSTRACT

Hydrological modeling has important role for designing, planning and managing any water resource developmental project. In developing countries like India, it is more relevant to model the river basin as discharge measurement at various locations is a costly affair. Once a hydrologic model is calibrated for a basin, it may be used to produce the discharge time series at any location of interest. In the present study, an attempt has been made by using soil and water assessment tool (SWAT) model to understand different hydrological processes occurring in Andhiyarkhor basin of Hamp river, which is a tributary of Mahanadi river of western Chhattisgarh. Various hydro-climatic data and spatial data were used for the study, which were collected from different global and local databases. After data processing, the Arc-SWAT interface of Arc-GIS was used to build up the parameters alongwith hydrologic components, which are required in the SWAT model. The study was conducted for a period of 30 years (1984-2013). During the calibration period of 20 years (1983-2002), the model resulted into R^2, NSE, MSE, RMSE, NMSE and MAE values of 0.65, 0.50, 182.70, 13.52, 0.50 and 0.49, respectively. Similarly, during the validation period of 10 years (2003-2013), R^2, NSE, MSE, RMSE, NMSE and MAE values were calculated as 0.63, 0.40, 169.46, 13.02, 0.60 and 0.50, respectively. Sensitivity analysis of SWAT model was performed using LH-OAT technique, and out of twelve calibrated parameters, five parameters were found to be sensitive.

1. INTRODUCTION

Water resources present in earth are classified into green water and blue water resources (Falkenmark, 1995). Green water is the large fraction of precipitation, which is held in the soil and available for plant consumption and returns to the atmosphere through the process of evapo-transpiration (ET). Blue water is the portion of precipitation that enters into streams and lakes and also recharges ground water rivers. The water directly consumed by human beings for their domestic, industrial, and food production purpose is termed as blue water. We know water is a renewable resource, but now a days the withdrawal of water is increasing from 579 km^3 to 3179 km^3yr^{-1} whereas only 1277 km^3yr^{-1} is recharging the groundwater, and at the same time, water use in agricultural sector is estimated to be increasing only by 13% by 2050. We have to keep in mind that we have limited amount of blue water resources and a huge population which we have to feed. So keeping this fact in mind, there is a need for planning of efficient utilization of water (Rockstörm, 2009).

Hydrological modeling has important role for designing, planning and managing any water resource developmental project. In developing countries like India, it is more relevant to model the river basin as discharge measurement at various locations is a costly affair (Kumar *et al.,* 1998). Once a hydrologic model is calibrated for a basin, it may be used to produce the discharge time series at any location of interest. Numerous hydrologic models ranging from empirical to physically based distributed parameters have been developed to estimate runoff and sediment yield during the past three decades. The developments in computing technology and recent advances in the availability of digital datasets, and the use of geographic information systems (GIS) for water resources management have revolutionized the study of hydrologic systems.

The SWAT developed by the United States Department of Agriculture - Agricultural Research Services (USDA - ARS) is one such model that integrates the spatial analysis capabilities of GIS with the temporal analysis simulation abilities of hydrologic models (Bhatt *et al.,* 2016; Patil *et al.,* 2019; Sahoo *et al.,* 2019). SWAT is a small watershed to river basin-scale model to simulate the quality and quantity of surface and groundwater, and predict the environmental impact of land use, land management practices, and climate change. SWAT is widely used in assessing soil erosion prevention and control, non-point source pollution control and regional management in watersheds. SWAT uses the basic principles of hydrologic cycle for simulating the behavior of a watershed. SWAT divides a basin into sub-basins based on unique combinations of topography, soil type and land use, which helps in preserving the spatially distributed parameters of the entire watershed and the homogenous characteristics of the basin. SWAT has been extensively used for a variety of purposes and its applications have expanded worldwide in the last decade. About 1600 peer-reviewed journal articles have been published in the SWAT literature database that document various uses of SWAT. SWAT has been widely applied to evaluate hydrologic and water quality impacts of land management and agricultural practices. Hydrological modeling of Hamp river has been attempted in this study to simulate the river flows using SWAT model.

2. MATERIALS AND METHODS

Study Area and Data Used

General description of the study area

Andhiyarkhore watershed of Hamp river, a tributary of Mahanadi river of Western Chhattisgarh, India was selected for the study. It covers an area of 2141 km^2 and lies between 21°45′28.406″N and 22°30′19.798″N latitude and 81°1′49.796″E and 81°35′50.538″E longitude. Andhiyarkhore watershed starts from Kabirdham (earlier known as Kawardha) to Bemetara district of Chhattisgarh. This watershed also covers some parts of Bemetara and Kawardha districts of Chhattisgarh, India. Majority of the area of watershed falls in Kabirdham district. The location of Andhiyarkhore basin in India is shown in Fig. 1. Hamp river is one of the major tributaries of Seonath river, ultimately contributing to the Mahanadi river. The Hamp river emerges from Chilpi range in Kabirdham district Chhattisgarh and merges into Seonath river 3 km upstream of Nandghat. The Hamp river rises at an elevation of 457 m and runs 204 km before it meets Seonath river. The highest and lowest point elevation values from DEM are 973 m and 237 m, respectively, and average elevation values from DEM is 417 m. The North-western regions of the study area have higher elevation range, while southern and eastern parts have low altitude. The elevation map is also shown in Fig.1. The study area experiences hot moist / dry sub-humid climate. The average annual rainfall is around 1088 mm in

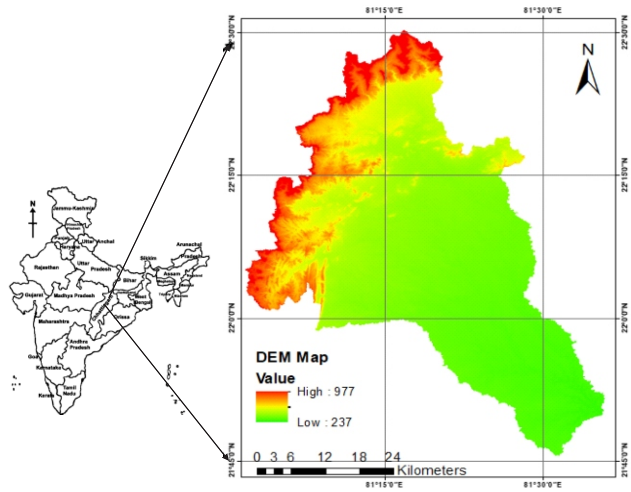

Fig. 1. Location and elevation maps of Andhiyarkhor basin

this watershed. About 88% of rainfall occurs in the monsoon season, and month of May is the warmest month. January and December are the coldest months of the study area. The maximum temperature ranges from 22.12-47.23°C during summer, and the minimum temperature ranges from 9.77-23.79°C during winter.

Data used

In the study, a variety of data were used such as soil, land use information, digital elevation data, meteorological and hydrological, etc. Brief description of these data are discussed below:

Soil data: For the estimation of the runoff, sedimentation, and groundwater, the soil characteristic is needed to be known. It mainly depends upon the percentage of sand, silt, clay particle present in the soil. For the study, soil data were obtained from the ICAR-National Bureau of Soil Survey and Land use Planning (ICAR-NBSS&LUP), Nagpur. Digitized soil map of Chhattisgarh were obtained at 1:50000 scale. The soils in the Andhiyarkhor basin can be broadly classified as sandy loam and clay loam.

Land use information: In order to prepare land use / land cover (LU/LC) maps of the study area, satellite data of LANDSAT8 was used. The combination of unsupervised and supervised image classification was performed with the image processing software ERDAS Imagine 9.0. Major part of the land use in Andhiyarkhor sub catchment is agriculture (60.04%), forest-mixed area (24.69%), forest-evergreen (6.87%), pasture area (7.71%), residential area (0.12%) and water (0.57%). The major crops grown in the area are rice, cotton, sugarcane, lentil, gram and groundnut.

Digital elevation data: Shuttle Radar Topography Mission (SRTM) void filled data at a resolution of 1 Arc-second (30 meters resolution) and open distribution of this high-resolution global data set was used to get the digital elevation data for the study area. DEM processing is an essential part of hydrological modelling in Arc-SWAT. It has been used to delineate the watershed boundaries and drainage network.

Meteorological data: SWAT uses daily precipitation, air temperature, solar radiation, relative humidity and wind speed in driving hydrological balance. The model can read these inputs directly from the file or generate the values using average monthly data analyzed for a number of years. Daily gridded rainfall data (0.25-degree × 0.25 degree) for study period from India Metrological Department (IMD), Pune was used for the study. Other meteorological data such as minimum temperature (°C) and maximum temperature (°C), wind speed (m s^{-1}), solar radiation (w m^{-2}) and relative humidity (fraction) were collected from one of the metrological observatory at Kabirdham.

Hydrological data: In order to validate the simulated results, daily stream-flow data from 1983-2013 were collected from the Water Resources Information System of India (WRIS) website for the surface flow gauging station at Andhiyarkhor, Chhattisgarh, which is being maintained by Central Water Commission (CWC). Runoff data from 1983 to 2002 were used for calibration, and from 2003 to 2013 were used for validation purpose, and all the hydrological simulations were performed upto Andhiyarkhore.

3. METHODOLOGY

Digital Elevation Model (DEM) Processing

DEM provides the elevation (asl) at pixel level. After mosaicking and pre-processing, the DEM was resampled using nearest neighbor resampling method to interpolate continuous elevation data. The study area was clipped out from the mosaicked DEM and re-projected to UTM Zone 44N projection with datum WGS 1984. Quality control of DEM processing is of great importance as the DEM layer plays a crucial role for flow direction, stream network, watershed delineation, sub-basin delineation, drainage patterns, etc.

Arc-SWAT Model

Arc-SWAT, which is embodied in Arc-GIS, is a graphical user interface for SWAT model. It is a river basin or watershed scale model developed by Arnold *et al.* (1998) jointly for USDA-ARS and Agriculture Experiment Station in Temple, Texas (USA). The model can be applied in various watersheds and for water quality modeling like national and regional scale watershed assessment for current and project management condition, impact assessment of global climate, simulation of land management practices, sediment contamination, poultry waste analyzation, and evaluation of pesticide registration (Winchell *et al.*, 2010). The actual aim of developing this model is to predict the impact of land management practices on water, sediment and agriculture chemical yields in large complex watershed with varying soil, land use and management conditions over a long period of time (Shivhare *et al.*, 2014).

Model Process of the SWAT

The general sequence of processes used by SWAT to model the land phase of the hydrologic cycle is shown in Fig. 2. Model processes include calculations of water balance that is the driving force behind everything that happens in a watershed for accurately predicting runoff, sediment or nutrient movement. Land phase and routing phase are the components of the model processing.

Land phase controls the amount of runoff and sediment which flows to the main channel of the watershed, so that the control measures can be applied to conserve both soil and water. This phase follows the basic water balance equation principle.

$$SW_t = SW_0 + \sum_{i=1}^{n} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad ...(1)$$

Where, Sw_t = Final soil water content (mm), SW_0 = Initial soil water content (mm), t = Time in days, R_{day} = Amount of precipitation on day I (mm), Q_{surf} = Amount of surface runoff on day I (mm), E_s = Amount of evapo-transpiration on day I (mm), W_{seep} = Amount of percolation and bypass exiting the soil profile bottom on day I (mm) and Q_{gw} = Amount of return flow on day I (mm).

Flow is routed through the channel using the variable storage routing method or the Muskingum method. SWAT uses hourly and daily time steps to calculate surface runoff. The Green and Ampt equation is used for hourly and an empirical SCS curve number (CN) method is used for the daily computation. For this estimation of runoff, basin is delineated into sub-basins, which are then further subdivided into hydrologic response unit (HRU). Here, SCS

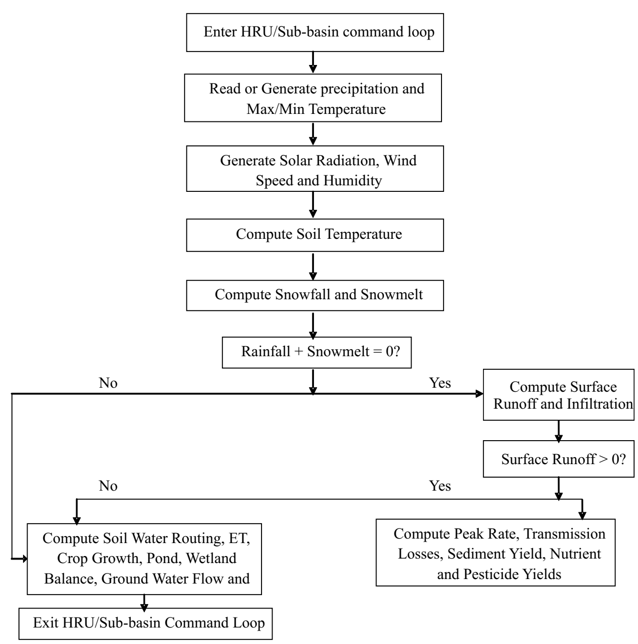

Fig. 2. Components of land phase of the hydrologic cycle precipitation

CN method was adopted for the estimation of surface runoff. The SWAT model involves various steps and process depicted in the Fig. 3.

Model Calibration and Validation

In this study, a calibration period of twenty years was considered from 1983-2002, including one year of warm up period *i.e.* 1983. In total, 12 parameters were used for performing the calibration process. Observed runoff data of outlet station located at Andhiyarkhor were used as inputs. A set of parameters that are more influencing to runoff process were set for performing the calibration process, like surface runoff parameters, base flow parameters, sub-basins parameters, evaporation parameters, etc. These sets of parameters were given as inputs in SWAT-calibration and uncertainty programme (CUP) for the calibration. These calibrated parameters set aims at minimizing the difference between simulated and observed stream flows. Calibration was considered to be necessary because there may be presence of some uncertainties in the model input, and because models give only simplified representations of the catchment's physical processes, operating at a range of scales which are not always compatible with the catchment or grid scale.

Model validation was performed, after the model calibration, at the same observation station used for calibration. In this process, all the input parameter ranges used for calibration remain unchanged. Evaluation was performed in a similar way as in model calibration process, *i.e.* visual comparison of hydrographs, statistical index of NSE and with the analysis of residuals. This was used to test whether the calibrated parameters were appropriate for the study basin or not. For the present study, a validation period of ten years was considered *i.e.* from 2003-2013.

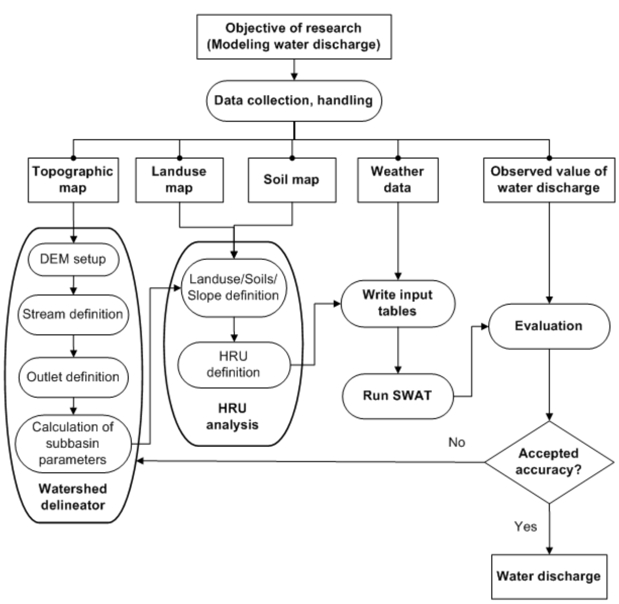

Fig. 3. SWAT model approach applied to the study area of Andhiyarkhore sub-basin

SWAT-CUP and Sensitive Analysis

In accessing the performance of any modeling approaches, quantifying the uncertainty inherent in the obtained results is crucial, especially when the model outcomes might be used as means for watershed planning and management practices. Various approaches exist for the analysis of uncertainty in distributed watershed models. Popular methods are: generalized likelihood estimation (GLUE) (Beven and Binlley 1992), parameter solution (Parsol) (Van Griensven and Meixner, 2007), Markov chain Monte Carlo (MCMC) (Vrugt *et al*., 2003), and sequential uncertainty fitting (SUF12) (Abbaspour *et al.*, 2007). To perform calibration and uncertainty analysis for SWAT, the software package SWAT-CUP (Abbaspour *et al.*, 2007) was developed.

Sensitivity analysis was performed to estimate the rate of change in model outputs with respect to change in model inputs. There are many parameters in SWAT model because it considers the spatial heterogeneity. The sensitivity analysis of this study was done using latine hypercube sampling and one-at-a-time (LHS-OAT) method. The inputs were the observed daily flow data, the simulated flow (obtained from model) during the period (1984-2002), and the sensitive parameters in relation to flow with the absolute lower and upper bound and default type of change to be applied. The sensitivity analysis was performed based on the simulation results at different runoff stations, and sensitive parameters were identified and ranked on the basis of measure of sensitivity. 12-parameters for runoff were used for sensitivity analysis as shown in Table 1.

SWAT Model Performance Evaluation

The time-series plots of measured and simulation flow data were evaluated by using three statistical indicators, and they are given as follows:

Nash-sutcliffe efficiency (NSE): It is a normalize statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information") (Nash and Sutcliffe, 1970). NSE indicates how well the plot of observed versus simulated data fits 1:1, and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance. It can be calculated as:

$$NSE = 1 - \frac{\sum_{i=1}^{n}(\mathrm{Oi} - \mathrm{Pi})^2}{\sum_{i=1}^{n}(\mathrm{Oi} - \mathrm{Om})^2} \quad ...(2)$$

Where, n is the number of measured data, O_i and P_i are the measured and predicted data, respectively at time I, and O_m is the mean of measured.

Root mean square and standard deviation ratio (RSR): RSR incorporates the benefits of error index statistics, and

Table: 1
Parameter sets used in the calibration process showing their range of Calibration

Parameter	Name of parameter	Minimum range	Maximum range
R_CN2.mgt	Initial SCS runoff curve number II	-0.02	0.2
V_ALPHA_BF.gw	Base flow alpha factor	0	1
V_GW_DELAY.gw	Groundwater delay time	30	450
V_GWQMN.gw	Threshold depth of water in shallow aquifer for return flow	0	25
R_SURLAG.bsn	Surface runoff lag co-efficient	0.05	24
R_GW_SPYLD.gw	Specific yield of the shallow aquifer	0	0.4
R_CH_K2.rtc	Effective hydraulic conductivity in main channel alluvium	5	130
R_ESCO.bsn	Soil evaporation compensation factor for basin	0	2
R_SLSUBBSN.hru	Average slope length (m)	0	0.2
R_CH_N2.rte	Manning's n value for main channel	0	0.3
R_SOL_AWC.sol	Available water capacity factor	-0.2	0.1
R_SOL_BD.sol	Soil bulk density	-0.5	0.6

includes a scaling/normalization factor so that the resulting and reported values can apply to various constituents. RSR varies from the optimal value of 0 to a large positive value; zero value indicates zero RMSE or residual variation, and therefore perfect model simulation. Lower the RSR, lower the RMSE, and better the model simulation performance. RSR is calculated as the ratio of the RMSE and standard deviation of measured data. It can be calculated as:

$$RSR = \frac{RMSE}{STDEVobs} = \frac{l\sqrt{\sum_{i=1}^{n}(\mathrm{Oi}-\mathrm{Pi})^2}}{l\sqrt{\sum_{i=1}^{n}(\mathrm{Oi}-\mathrm{O}\prime)^2}} \quad ...(3)$$

Coefficient of determination (R^2): The coefficient of determination (R^2) is one of the frequently used criteria to describe the proportion of the total variance in the measured data that can be explained by the model (Jain *et al.*, 2010). It ranges from 0.0 to 1.0 with higher values indicating better agreement. It is calculated as follows:

$$R^2 = \frac{\left(\sum_{i=1}^{n}(\mathrm{Oi}+\mathrm{O}'(\mathrm{Pi}-\mathrm{P}')2\right.}{\sum_{i=1}^{n}(\mathrm{Oi}-\mathrm{O}')2\ \sum_{i=1}^{n}(\mathrm{Pi}-\mathrm{P}')2} \quad ...(4)$$

MAE, MSE and RMSE: Several error indices are commonly used in model evaluation. These include MAE, MSE, and RMSE. These indices are valuable because they indicate error in the units (or squared units) of the constituent of interest, which aids in analysis of the results. RMSE, MAE, and MSE values of 0 indicate a perfect fit. Singh *et al*. (2002) state that RMSE and MAE values less than half the standard deviation of the measured data may be considered low, and that either is appropriate for model evaluation. A standardized version of the RMSE was selected for recommendation and is described later in this section.

The value of the Nash-Sutcliffe coefficient of efficiency (NSE) and the coefficient of determination (R^2) closer to one indicates a better model performance. NSE ranges from $-\infty$ to 1.0, and the model with values near to one supposed to have good agreement with observed values. NSE has been widely used to evaluate the performance of hydrological models. According to Moriasi *et al*. (2007), the model performance for monthly basis is considered to be satisfactory when NSE and RSR lie between 0.5 to 0.65, and 0.6 to 0.7, respectively. The model performance is considered to be good when NSE, NMSE and MAE lie between 0.65 to 0.75, 0.5 to 0.6 and ±10% to ±15%, respectively and it is said to be very good when the model with NSE, NMSE, and MAE lies between 0.75 to 1.0, 0.0 to 0.6 and less than ±10% The same criteria have been used for model evaluation in the present study.

4. RESULTS AND DISCUSSION

Spatial Data Inputs

Digital elevation model (DEM): DEM, which was used in the study area was downloaded from the USGS earth explorer website. The resolution of USGS-DEM was 30 m, and UTM zone 44 N projection with datum WGS 1984 was applied to DEM. The highest and lowest point elevation values from DEM are 973 m and 273 m, respectively. DEM is a good array of elevations, in its raw form it is an ASC-II or text, or an image file. DEM was used to derive slope, aspect, flow direction and accumulation and stream network information. The DEM of study area is shown in Fig. 1.

Land use and land cover map (LU/LC): LU/LC map was prepared by using Land-Sat TM 8 (OLI) image. In the present study, the supervised classification method was used for preparation of the LU/LC map. Six different classes have been reported in the study area. After land-use classification, it was found that agriculture area was the dominating portion, which covers 128557.77 ha of the total watershed (about 60.04%), followed by mixed-forest land-use class with 52856.76 ha of land. The pasture land, ever-green forest, water bodies, and residential areas cover 16497.49, 14714.15, 1215.99, and 264.95 ha, respectively. The LU/LC distributions inside the Andhiyarkhor basin with percentage area of the classes are shown in Table 2. LU/LC map of the study area, which was used for the SWAT model setup, is shown in Fig. 4.

Soil map: Soil map of Chhattisgarh was obtained at 1:50000 scale from ICAR-NBSS&LUP. Some of the associated soil properties were also derived from it. This soil database was used for soil classification in SWAT resulting in four distinct soil classes. The soil map, which was used for the delineation of watershed, is shown in Fig. 5. The soils have developed from rocks like granite, schist, gneiss, phyllites, shales, slate etc. Majority of the soil in the study area belong to C and D hydrological soil groups. Most of the study area soils are deep, moderately well drained, and clayey soils on gentle to moderate slopes.

SWAT Model

Watershed delineation: Watershed delineation was the first step of SWAT model. Before that, the SWAT project was setup with selection of project dictionary. After creating of new SWAT project, SWAT project geo-database and raster storage geo-database were initialized automatically under the project directory. After the SWAT model setup, the automatic watershed delineation process was done. For that, the DEM grid was loaded for modeling with SWAT. DEM based flow direction and accumulation process was chosen to generate streams and outlets. The outlet definition was edited manually for the predefined outlet point at Andhiyarkhor, and the watershed was delineated.

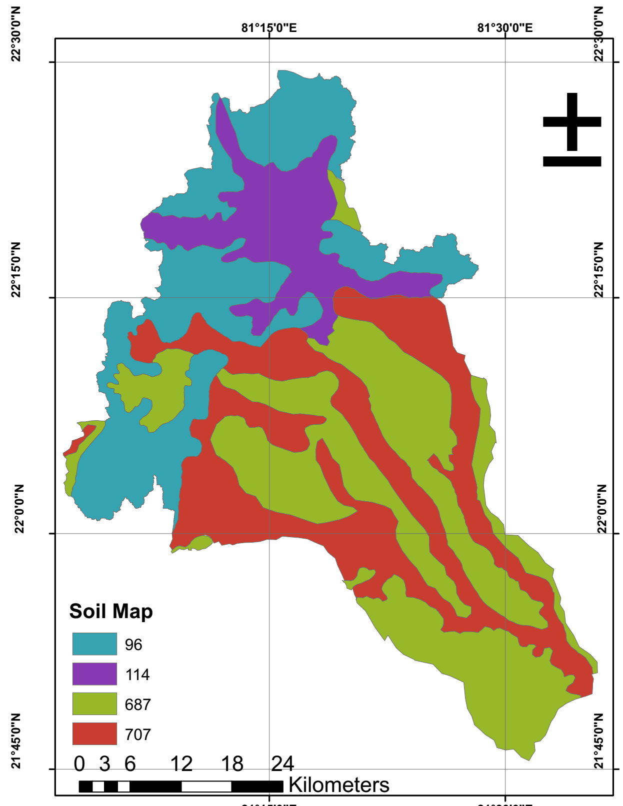

Fig. 5. Soil map of the watershed

Table: 2
Percentage of area of the land use classes

S.No.	Land Use Classes	Area (ha)	Percentage Area (%)
1	Agriculture land (AGRL)	128557.77	60.04
2	Pasture land (PAST)	16497.49	7.71
3	Forest- Evergreen (FRSE)	14714.15	6.87
4	Forest-Mixed (FRST)	52856.76	24.69
5	Water (WATR)	1215.99	0.57
6	Residential (URHD)	264.95	0.12
	Total	214107.10	100.00

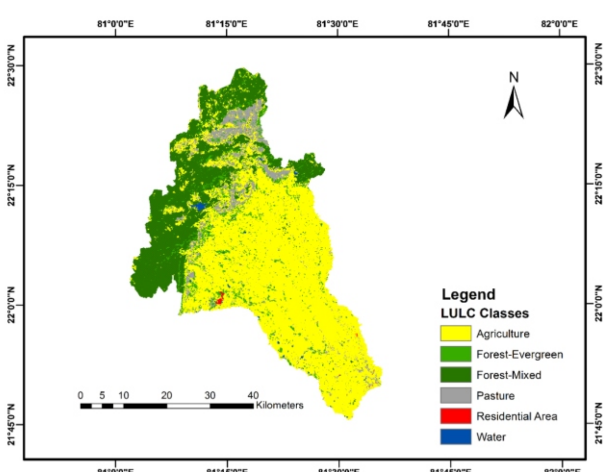

Fig. 4. Land use and Land cover map of the watershed

HRU analysis: For HRU analysis, the land use, soil and slope information of the study area were required as inputs. In land use theme, land use grid was inserted and reclassified by different classes as per SWAT definition. Similarly, in soil theme, soil grid (soil map) was inserted and reclassified by different classes as per SWAT definition. In the slope theme, three slope ranges were defined. After the reclassifications of these three layers, 4 HRUs were generated for the entire basin from unique combinations of slope, landuse and soil type.

Weather stations and simulation: After proper distribution of HRUs based on landuse, soil and slope data, the weather database files were given as input. Run SWAT was selected under SWAT simulation menu and the starting and ending date were given from Jan 1984 to Dec 2013. The printout setting was chosen monthly wise with one number of year skip option and 64-bit SWAT.exe version. After the setup, Run SWAT processing was done to execute the output files. From read SWAT output, the files were imported to database and saved. Table 3 and Fig. 6 show output of the SWAT water balance after the model execution.

Sensitivity analysis

Sensitivity analysis was carried out for the period of calibration and warming up with the objective of number of parameter and their properties as input for modelling. A total of 12 parameters were initially selected and 50 iterations were performed to get better sensitive analysis. For this, new project was set in SWAT-CUP with browsing *Text-in-Out* location and giving information of SWAT version and process architecture. SWAT parameters related to discharge were estimated using the SUFI-2 algorithm. In calibration, the input parameter information, number of simulations, file information, and objective of the functions were given properly. Global sensitivity analysis was performed using LH-OAT technique that highlighted the sensitive parameters for runoff generation process inside Andhiyarkhor basin, as given in Table 1; though initially 12 parameters were considered for the calibration process, only 5 were found sensitive to the model given in the Table 4.

Ranks were obtained according to the objective function - the P-value of calibration between observed and simulated values. It was clearly seen that the stream flow is affected by both groundwater and management parameters of the study area. This revealed that the study area has a very diverse hydrological variability. Effective hydraulic conductivity in main channel, initial SCS runoff CN II (R__CN2.mgt), and available water capacity of the soil layer (SOL_AWC) got very high sensitivity values showing that the stream flow of this area is mainly governed by main channel, management and soil characteristics.

Management characteristics of the basin always play a vital role in channel water routing. Here also, management characteristics like Initial SCS runoff CN II (R__CN2.mgt) had second very high sensitivity value by showing for planting, harvesting, irrigation applications, tillage operation, soil permeability, land use, and soil water condition of the basin that influence the runoff flow. Groundwater delay (GW_DELAY), a parameter that talks about the time it takes in days for water to percolate from the upper layer of the soil profile to the shallow aquifer, and Base flow alpha factor (ALPHA_BF), a parameter which describes groundwater flow response to changes in recharge of stream flow, were found to be highly sensitive. In this sensitivity analysis, they indicate the stream flow of this area is also governed by ground water flow. Groundwater "revap" coefficient (V__GW_REVAP.gw) is the other parameter which was found less sensitivity compared to others among ten parameters. In this study, the parameter - available water capacity of the soil layer (SOL_AWC) was found to be the third sensitive parameter, and it indicates that there might be a possibility of the runoff from this region, which depends upon soil properties like soil texture and composition as it is important for vegetation growth, nutrient transport. The calibration range and best-fitted value of different parameters are given in Table 5.

Table: 3
Water balance of watershed generated by SWAT

S.No.	Component of hydrological cycle	Quantity (mm)
1	Average Annual Precipitation	1088
2	Evaporation and Transpiration	541.7
3	Potential Evapotranspiration	1913.6
4	Surface Runoff	265.44
5	Lateral Flow	60.96
6	Return Flow	170.33
7	Percolation to Shallow Aquifer	219.6
8	Revap from Shallow Aquifer	38.27
9	Recharge to Deep Aquifer	10.98
10	Average Curve Number	80.14

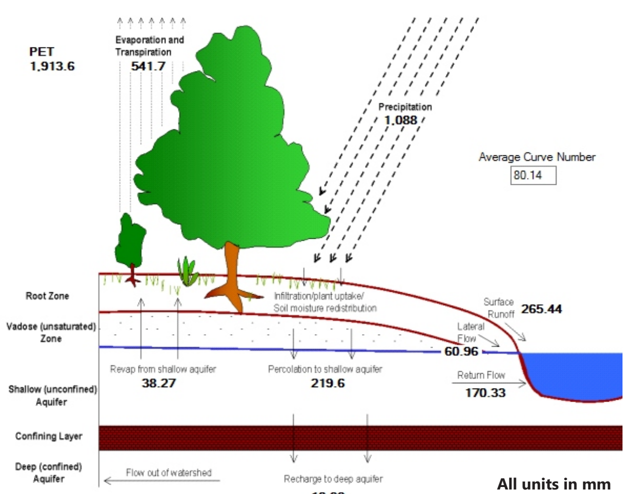

Fig. 6. Pictorial form of water balance by SWAT check

Table: 4
Sensitivity Analysis Result of Andhiyarkhor basin

Parameter Name	Parameter Name in SWATCUP	P-value	Sensitivity rank
Initial SCS runoff curve number II	R__CN2.mgt	0.00	1
Base flow alpha factor	V__ALPHA_BF.gw	0.00	2
Groundwater delay time	V __GW_DELAY.gw	0.00	3
Groundwater "revap" coefficient	V__GW_REVAP.gw	0.03	4
Available water capacity factor	R__SOL_AWC(..).sol	0.03	5

Table: 5
Calibration range and fitted value of different parameters

Parameter Name	Bound		Fitting value	Method
	Lower	Upper		
Initial SCS runoff curve number II (R__CN2.mgt)	-0.2	0.2	0.14	Relative
Base flow alpha factor (V__ALPHA_BF.gw)	0	0.1	0.15	Replace
Groundwater delay time (V__GW_DELAY.gw)	30	450	34.2	Replace
Groundwater "revap" co-efficient (V_GW_REVAP.gw)	0.2	0.258	0.23	Replace
Available water capacity factor (R__SOL_AWC.sol)	0.38	0.54	0.44	Relative

Calibration

For carrying out calibration, the observed data of outlet point, which was located at Andhiyarkhor, Chhattisgarh, was used. Observed data for a duration of 19 years *i.e.* from 1984-2002 were used for the calibration process. However, one-year data (1983) was considered during model warm up. With successive simulation, the final values of statistical parameters of calibration were improved to a R^2 value of 0.65. Final simulation stream flow statistics for the river basin are presented in Table 6.

Validation

For validation purpose, the data of same observation station were used. A period of ten years was considered for validation purpose, from 2003 to 2013. By providing the proper input to SWAT-CUP, graphical representation of comparison between observed and simulated streamflow during calibration (1984-2002) and validation (2003-2013) were carried out. Fig's 8 and 9 shows the graphical representation of calibration and validation respectively. By observing the figures, it was revealed that the model was able to reproduce the historical data with good accuracy. For calibration, R^2, NSE, MSE, RMSE, NMSE and MAE are 0.65, 0.50, 182.70, 13.52, 0.50 and 0.49, respectively. Similarly, for validation, they are 0.63, 0.40, 169.46, 13.02, 0.60 and 0.50, respectively.

In Fig's 7 and 8, during pre-calibration (January 1984 to December 2002), the model estimated the observed flow but with poor accuracy. Here we can see that the model is capturing the observed trend but the magnitude is differing significantly. With successive calibration (fine-tuning) of the model, the computed observed flow for the calibration period improved. There are few mismatches in the calibration period in the peaks during the monsoon months, which may be due to high amount of rainfall occurring in the month of Aug and Dec because of some climatic disturbances.

After analyzing the calibration result at Andhiyarkhor station, similar trend was observed in the validation graphs (Fig's 9 and 10). At the start of the analysis, model predicted the streamflow with very good accuracy. But later on, it was observed that during the months of monsoon in the years of 2003, 2008 and 2012, the model was unable to predict the output as there is a sudden increase in the value of stream flow. Here the computed flow is over estimated in comparison to the observed flow. Rest of the time the model completely estimated the observed stream flow in good accuracy. As the variability of stream flow and the ability of

Table: 6
Statistical evaluation of SWAT model during calibration (1984-2002) and validation (2003-2013) at Andhiyarkhor station

Model Run	R^2	NSE	MSE	RMSE	NMSE	MAE
Pre-calibration	0.59	-2.47	1260.49	35.50	3.47	-0.52
Post-calibration	0.65	0.50	182.70	13.52	0.50	0.49
During validation	0.63	0.40	169.46	13.02	0.60	0.50

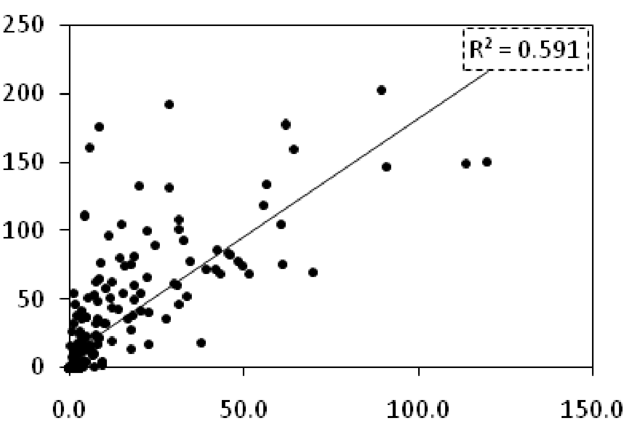

Fig. 7. Scatter plots of monthly observed and simulated stream flow during calibration (1984-2002) for Andhiyarkhor station

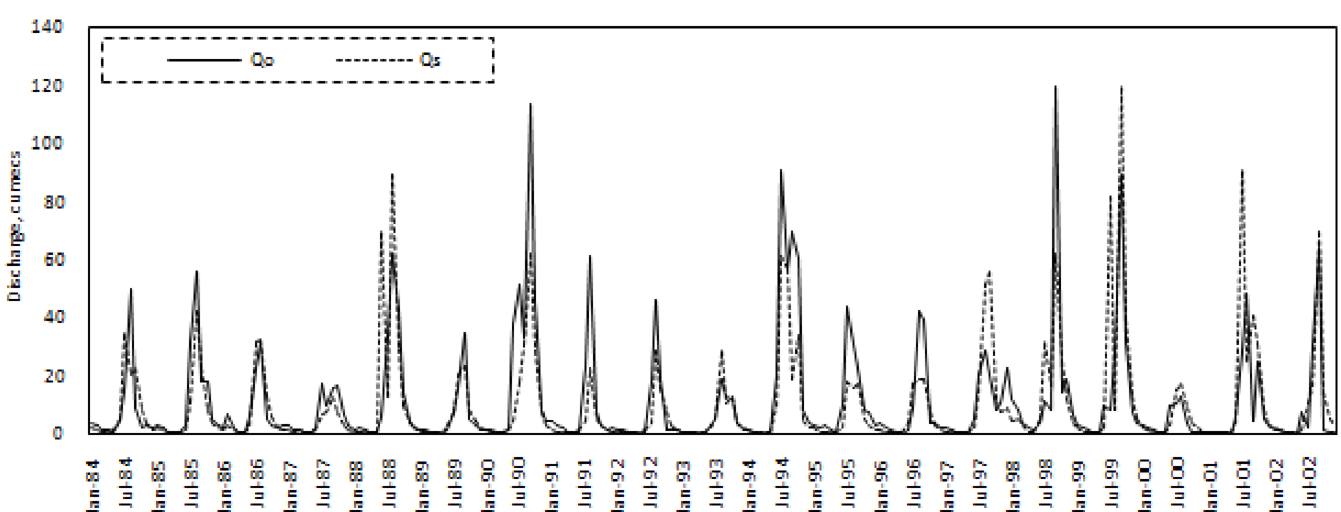

Fig. 8 . Comparison between observed and simulated stream-flow during calibration (1984-2002) for Andhiyarkhor station

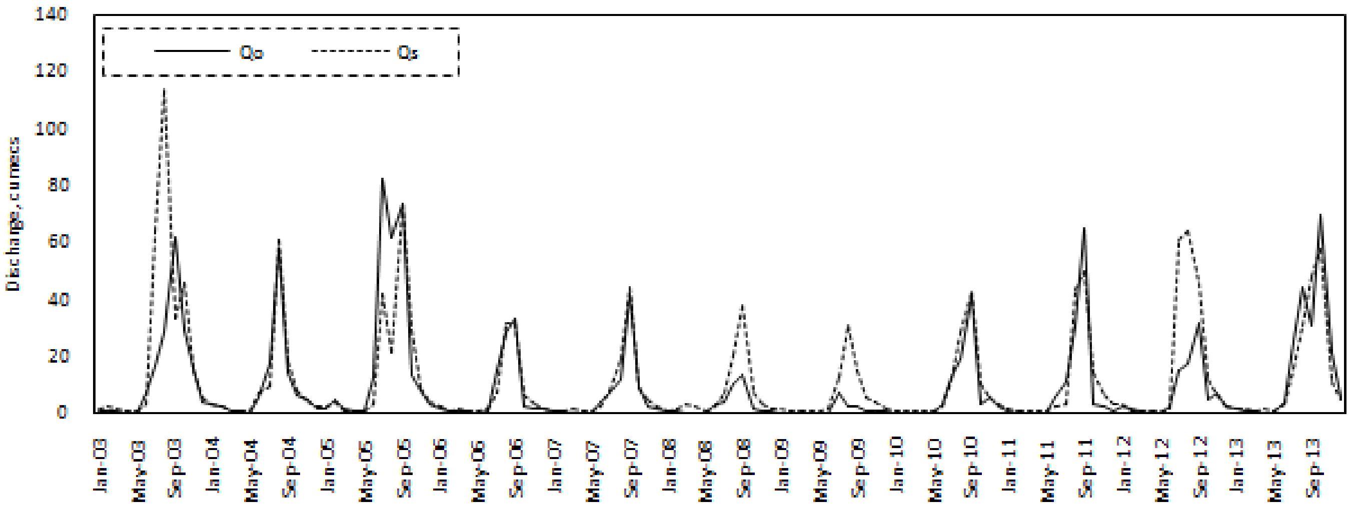

Fig. 9. Comparison between observed and simulated stream flow during validation (2003-2013) for Andhiyarkhor station

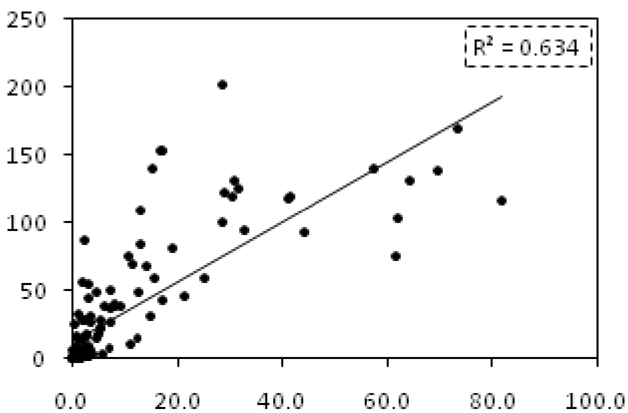

Fig. 10. Scatter plot of monthly observed and simulated stream flow during validation (2003-2013) for Andhiyarkhor station

the model to predict that outflow show similar trend, both in calibration and validation period, it can be concluded that rainy season is predominant in Hamp river catchment, particularly in the month of July, August and some times in the month of October.

Though a good result is achieved, both in calibration and validation period, it could have been better in the absence of instant rainfall variation. Fig. 9 shows the comparison of the monthly simulated stream flow with their observed counterparts for validation period. It can be seen that model captures the shape of hydrograph nicely but at some peak flows it overestimates. Based on the statistical performance indices it can be concluded that SWAT model performs well for the study area.

5. CONCLUSIONS

Hydrological modeling of a sub-basin of Mahanadi was performed using SWAT model with Arc-GIS interface. The calibration process was carried out using SWAT-CUP tool with SUFI-2 algorithm. Observed stream-flow data at the outlet of the Andhiyarkhor watershed for a period of 20 years (1983 to 2002) were used for calibration, which had R^2, NSE, MSE, RMSE, NMSE and MAE of 0.65, 0.50, 182.70, 13.52, 0.50 and 0.49, respectively. Similarly, during the validation, R^2, NSE, MSE, RMSE, NMSE and MAE were calculated as 0.63, 0.40, 169.46, 13.02, 0.60 and 0.50, respectively. Sensitivity analysis was performed using LH-OAT technique, and out of 12 calibrated parameters, 5 parameters were found to be sensitive. A close observation of these sensitive parameters revealed that the flow characteristics of this area were affected by both surface water and groundwater flow properties.

The following conclusions were drawn from this study:

- The above study reveals that use of SWAT model in conjunction with remote sensing and GIS can be used to assess crucial hydrological parameters like runoff from medium to large basins.
- This model technique helps in different aspects such as analysis of watershed hydrology, identification of hydrological sensitive parameters and can assign the effective management practices in the basin.
- Land management and ground water parameters are most critical and governing factors for runoff.
- As a semi-distributed catchment scale model, SWAT is capable of studying climatic, spatial and temporal variations occurring inside the study area and can co-relate it with the real world with a very good accuracy.

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