



Water balance modeling of Tandula (India) reservoir catchment using SWAT

Rahul Kumar Jaiswal¹ · Ram Narayan Yadav^{2,3} · Anil Kumar Lohani⁴ · Hari Lal Tiwari⁵ · Shalini Yadav⁶

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Abstract

The water availability assessment is an important aspect for planning and management of water resources in the basin; however, non-availability of observed runoff is an important issue often found in the developing countries. The farmers of irrigation projects incur more expenditure due to assured supply and suffer huge economic loss in dry years. In the present study, a water balance of reservoir for computation of runoff coupled with the application of spatially distributed Soil and Water Assessment Tool (SWAT) model, the SWAT model and SWAT-CUP application have been proposed for hydrological modeling can be used assess the inflows for efficient reservoir operation and planning of releases. The proposed methodology has been applied on Tandula reservoir catchment in Chhattisgarh state of India, which is well-known for its paddy cultivation and any short supply affect the economic status of marginal farmers in the command. The water balance of Tandula reservoir has been carried out for the period of 1991 to 2015 using daily reservoir levels, releases, evaporation, seepage, supplies from other sources, and spillway information. The percentage error in water balance analysis of Tandula reservoir varied between -6.87 and 3.39% and seem reasonably well matched. The runoff obtained from water balance was checked with the SCS-CN technique and found close resemblance on the monthly and yearly basis. The digital image processing of remote sensing data has been used for determination of land uses and found that forest and agriculture land with rice cultivation are the principal land uses covering nearly 86% area of the catchment. The sensitivity analysis suggested that SCS curve number (r_CN_2), saturated hydraulic conductivity (sol_k), soil antecedent water content (sol_AWC), and Manning's N for the main channel (Ch_N2) are the most sensitive parameters. The sequential uncertainty fitting (SUFI2) technique has been used for calibration of model for the period of 1995 to 2007 and validated for 2008 to 2015. The model performance was adjudged using P -factor, r -factor, and Nash-Sutcliffe efficiency, and best-fit model parameters were determined. The Nash-Sutcliffe efficiency for calibration and validation were found as 0.75 and 0.65 respectively suggested that

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✉ Rahul Kumar Jaiswal
rkjaiswal.nih@gmail.com

Shalini Yadav
dryadava@gmail.com

- ¹ National Institute of Hydrology, WALMI Campus, Bhopal, M.P., India
- ² AISECT University, Ranchi Campus, Ranchi, India
- ³ Centre of Excellence in Water and Environmental, Dr. C. V. Raman University, Bilaspur, Chhattisgarh, India
- ⁴ National Institute of Hydrology, Jal Vigyan Bhavan, Roorkee, Uttarakhand, India
- ⁵ Department of Civil Engineering, MANIT, Bhopal, M.P., India
- ⁶ Department of Civil Engineering, RNT University, Bhopal, M.P., India

the developed model can be used for assessment of runoff from the catchment. The knowledge of the availability of water using the amalgamation of water balance, SWAT model, and SWAT CUP application can be used for reservoir operation, irrigation management, and assessment of the impact of climate and land use change on runoff from the catchment.

Keywords Water balance · Hydrological modeling · SWAT · SCS curve number · Efficiency

Introduction

The water resource assessment and management are important for sustainable development of water resources projects and water balance can be used as an effective tool to correlate local climate, geology, land use, hydrology, and soil with the availability of water for storage and groundwater recharge (Adie et al. 2012). The increasing population of developing countries exerts

more and more pressure to increase agriculture production. On the other hand, the changing land use, erratic behavior of rainfall, and increasing temperature due to plausible climate change are affecting the water supply situation for irrigation and other uses. The water resource projects, in general, are planned considering stationary condition will no longer be valid in the context of change in land use and climate (Amell and Delaney 2006; Brekke et al. 2009; Milly et al. 2008; Georgakakos et al. 2014). In developing countries like India, the gauging of the river is generally stopped after the construction of the dam and any change in reservoir operation and releases are not possible due to non-availability of recent records. The water balance of reservoir system considering all possible input and output components, implementation of a spatially distributed model capable of accommodated climate and land use parameters in hydrological processes can be used to determine present and future scenarios of incoming runoff to the reservoir.

The water balance study of catchments, reservoirs, lakes, and groundwater basins can be used for allocation, control and redeployment, and rational use of water resources in space and time (Sokolov and Chapman 1974). Fowe et al. 2015 carried out simple water balance study based on the principle of mass conservation on a small reservoir in Southern Burkino Faso using rainfall and climatic parameters for assessment of reservoir flux. The study concluded 32% reduced rainfall led to a reduction of 50% annual runoff with nearly 60% loss of water in evaporation. The inflows in the reservoir depend on precipitation and other climatological variables having seasonal variability and cyclical components (Chahinian and Moussa 2007; Awulachew 2006). Sriwongsitanon et al. (2009) developed a water budgeting model for Bung Boraphet reservoir, a large flood plain lake in Thailand. The developed model was calibrated and validated by comparing computed and observed loss/gain over the same period. In that way, it may be understood that water budgeting can be considered as a scientific technique for identification of system dynamics, and relative contribution of different components can be used for planning releases and requirements of different uses for water resource management.

The water balance of the reservoir can be used for determination of runoff from catchment which is basic input to any hydrological modeling. Most of the models use precipitation in the form of input and after accounting all intermediate processes within the watershed such as evapotranspiration, evaporation, groundwater/surface-water exchange, and routing; runoff is given in the form of output (Healy et al. 2007). These models when simulated using generated scenarios of precipitation and climatic variables are able to simulate different hydrological processes within the watershed and provide runoff, groundwater recharge, and base flow for future periods. Commonly used agricultural watershed models for runoff, sediment, and water quality are AGNPS (Young et al. 1989), ANSWERS (Beasley et al. 1980), MIKE SHE (Xevi

et al. 1997), WEPP (Ghidey & Alberts 1996), and SWAT (Arnold et al. 1999, Neitsch et al. 2002).

The Soil and Water Analysis Tool (SWAT) model being its simplicity, possibilities of changing source code can be considered one of the most commonly used models for scenarios assessment and analyze the effects of land use/land cover and climate change condition on different hydrological components (Gassman et al. 2007; Veith et al. 2010; Ghaffari et al. 2010). The SWAT model has an interesting feature of having default values of parameters along with realistic range where default values of parameters can be used for ungauged catchments for calibration and impact assessment analysis (Srinivasan et al. 2010). The SWAT model is well preferred and applied tool in the USA and other part of the world for rainfall–runoff–sediment and water quality modeling, point and non-point pollution, and impact assessment analysis (Engel et al. 1993; Bingner 1996; Arnold et al. 1998, 1999; Peterson and Hamlett 1998; Srinivasan et al. 1998; Saleh et al. 2000; Neitsch et al. 2001; Santhi et al. 2001; Weber et al. 2001; Fohrer et al. 2001; Tripathi et al. 2006; Arnold and Fohrer 2005; Santhi et al. 2006, Schuol et al. 2008; Qiao et al. 2013; Phuong et al. 2014; Labrière et al. 2015; Ben Salah and Abida 2016; Pandey et al. 2017; Emam et al. 2017; Himanshu et al. 2017, Yu et al. 2018). The latest developed SWAT–CUP has the capability of sensitivity and several optimization techniques like GLUE, ParaSol, SUFI2, MCMC, and PSO procedures. The model has weakness of a wide range of data needed for model building and non-spatial representation of the HRU inside each sub-catchment but able to model runoff, sediment, and water quality in ungauged catchments also.

After careful review, it has been found that the assessment of incoming runoff from the catchment of reservoirs may be the key factor for optimum planning and management of water both at the catchment and command area level. In developing countries where runoff records are seldom available in medium and minor projects, the water balance coupled with spatially distributed modeling approach can be used for generating future scenarios of reservoir operation under change of climate, land use, and other developmental activities. The application of the SWAT model and its extension SWAT–CUP can be used to assess the impact of the change of land use and provide a range of parameters to cover uncertainties of input, output, and modeling processes.

Material and methods

Study area and data used

The Chhattisgarh state of India is known as the rice bowl of the country for its large-scale paddy cultivation. The Tandula reservoir is part of a complex reservoir system comprising of

Tandula, Kharkhara, and Gondli reservoirs to supply water for large paddy growing commands and partial requirements of industries and drinking need. The rural population in the command of Tandula reservoir is mostly farmers and depends for their crops on supplies from Tandula reservoirs. Any reduction of supplies from this reservoir may hamper their livelihood of a major section of society which directly depends on crop production. The accurate and timely assessment of water availability from the catchment may be helpful to water resource managers to devise appropriate adaptive policies under deficit conditions. The Tandula reservoir project is situated on the confluence of rivers Tandula and Sukhi in the Chhattisgarh state, and the base map of the study area is presented in Fig. 1, Thiessen polygon map in Fig. 2, and weights of different rain gauge stations in Table 1.

The catchment area of Tandula dam is 827.2 km². The design cropping pattern of Tandula command is 68,219 ha of paddy in Kharif season. The study uses a wide range of climate data, reservoir information, and spatially distributed information of land use, topography, soil collected from diverse sources, and literature review. The details of the data used in the present study are presented in Table 2.

Methodology

The methodology for the assessment of water availability consists of computation of inflows/runoff using water balance for the reservoir, development of the SWAT model, and SWAT-CUP for rainfall-runoff modeling.

Water balance

The water balance can be computed for any sub-system of the hydrological cycle of any shape and size to compute one unknown component of water balance. The water balance is a form of “book-keeping” of a basin or reservoir where all significant components are taken into account for a specific period of time. The basin continuity equation used for the water balance of a system can be written as follows:

$$\left[\begin{array}{c} \text{Input} \\ \text{to the} \\ \text{system} \end{array} \right] - \left[\begin{array}{c} \text{outflow} \\ \text{from the} \\ \text{system} \end{array} \right] = \left[\begin{array}{c} \text{change} \\ \text{in} \\ \text{storage} \end{array} \right] \quad (1)$$

The hydrologic balance in case of water bodies provides stored water in controlled section and inflows from the basin and uses simple mass balance where sum of all outflows deducted from sum of inflows provides change in stored volume over a specific period (Thomann and Mueller 1987; Chapra 1997; Fetter 2001; Aparicio 2005; Yeung 2005; IAEA 2007). The components of water balance in a reservoir can be summarized as follows:

$$V_t = V_{t-1} + Q_{in} - Q_{out} - U_t - (P - E - S)A_t \quad (2)$$

Here, V_t and V_{t-1} are the volumes of at any time t and $t-1$ respectively. Q_{in} and Q_{out} are the inflow and outflow volume from the reservoir; U_t is the volume of water passes through spillway; P , E , and S are the depth of precipitation, evaporation, and seepage from the reservoir; and A_t is the area of reservoir at time t . The daily reservoir data including reservoir levels, elevation–area–capacity table, spillway capacity table, and outflows including irrigation release, seepage loss, and transfer to other reservoirs if any and evaporation data were used to determine daily runoff from the watersheds of Tandula reservoir.

SWAT and SWAT-CUP application for rainfall-runoff modeling

The SWAT model and its extension SWAT-CUP has been used for modeling hydrological processes in the basin. The SWAT (Arnold et al. 1998; Neitsch et al. 2002) is a physically based distributed parameter and continuous time simulation basin scale model supported by USDA Agricultural Research Service (USDA-ARS). The runoff volume in the SWAT model is estimated by soil conservation services (SCS) curve number technique (USDA 1972), sediment yield by modified universal soil loss equation (MUSLE) (Williams 1975), nutrient yield and nutrient cycle using EPIC model (Williams et al. 1984), and command structure is based on the HYMO model (Williams and Hann 1972). The runoff yield computed for individual HRU and then routed through river network with the help of variable storage or Muskingum routing method at outlets of sub-watersheds and basin. The SWAT model uses Manning’s equation to define the rate and flow velocity. The complete detail about the SWAT model and its application are available in Neitsch (2001) and Neitsch et al. (2005). The model having hundreds of parameters to define the spatial variability of hydrologic characteristics of the basin, out of which most of the parameters vary with sub-basin, land use, or soil type. The parameters can either be optimized or computed through field measurement, data, or literature.

For modeling purpose, the SWAT model divides a basin into the number of sub-basins to assess the impact of dissimilar land uses and soil distribution on hydrology in the basin. Further, a sub-basin consists of the number of HRUs and each HRU is a lumped land area having the unique slope, land use, soil, and management practices within sub-basin. The SWAT model works on the principle of water balance, and two major components of the hydrological cycle are computed considering physical processes within the basin. The first phase computes runoff, sediment, nutrients, and pesticide loading to the main channel of each basin, while the second phase concentrates on routing for the movement of generated runoff,

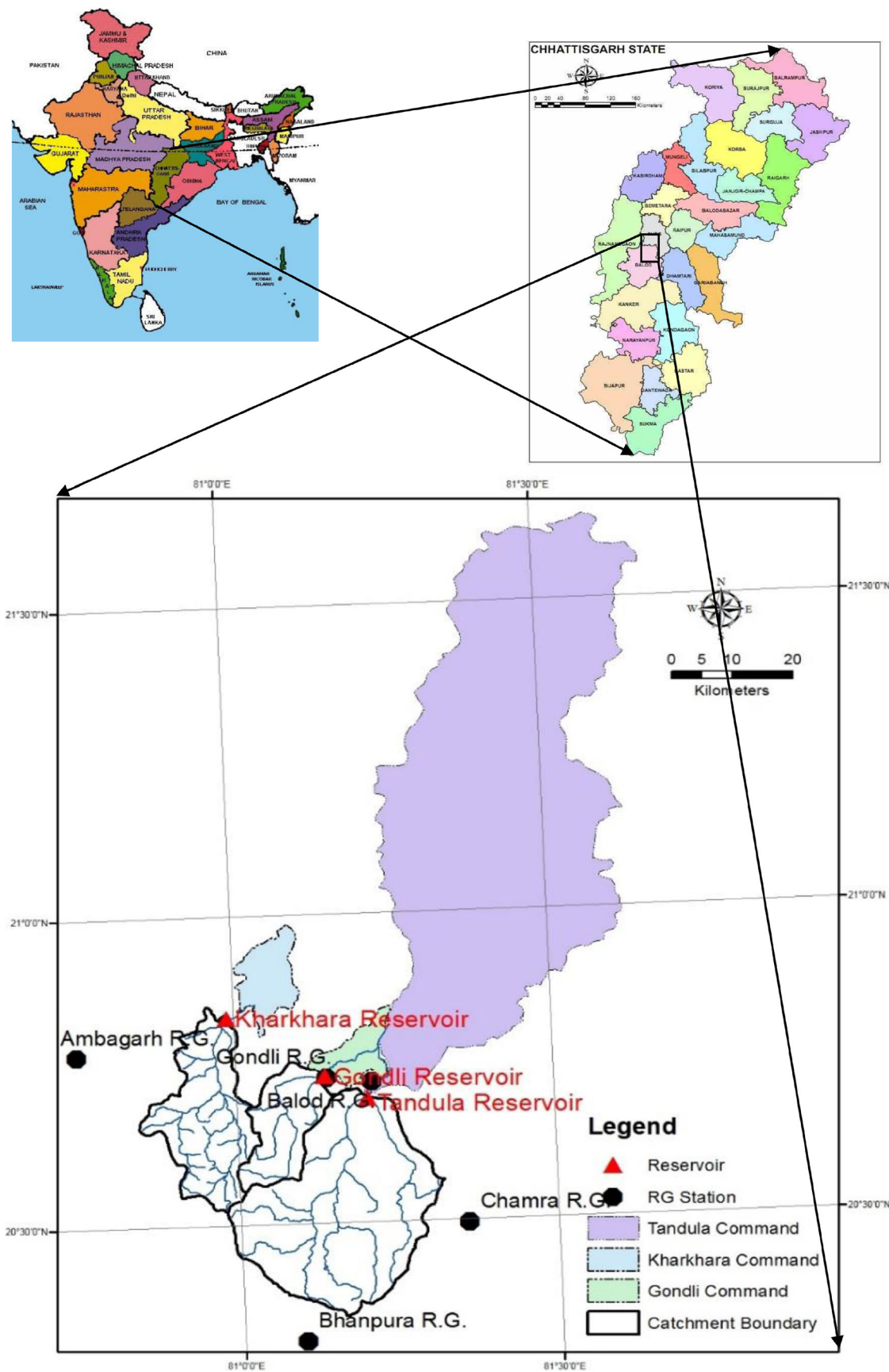
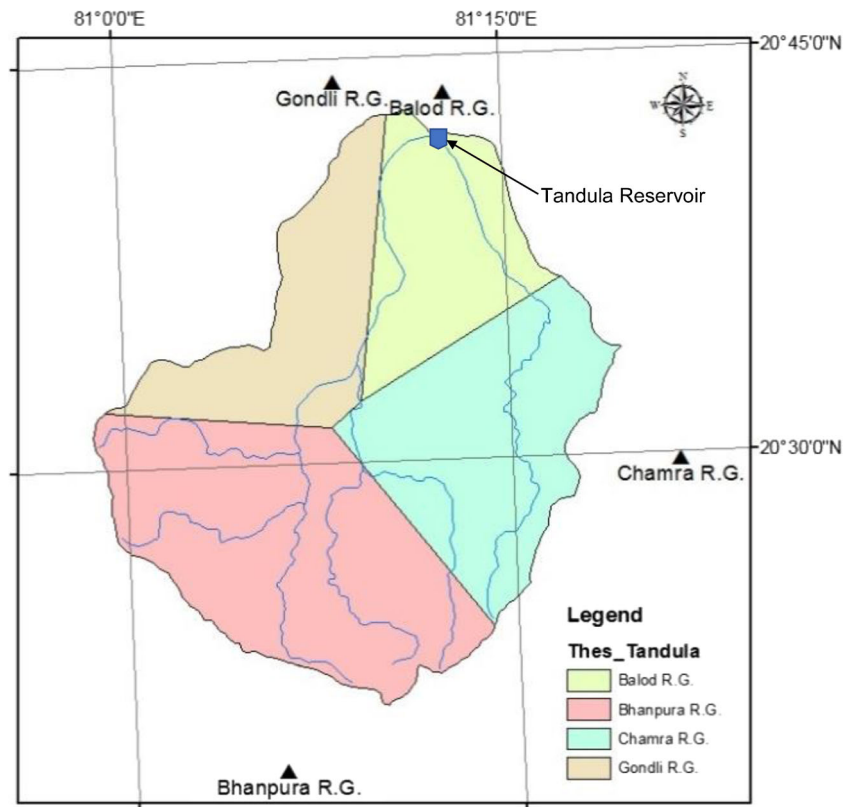


Fig. 1 Base map of Tandula reservoir in Chhattisgarh state (India)

Fig. 2 Thiessen polygon map of Tandula catchment (not to scale)



sediment, nutrient, and pesticide through the network of the channels to the outlet of the basin. The different components of the hydrological cycle in the SWAT model can be represented by the following water balance equation (Neitsh et al. 2005):

$$SW_i = SW_0 + \sum_{i=1}^t (P_i - SQ_i - ET_i - W_{seep_i} - Q_{gw_i}) \quad (3)$$

where SW_0 and SW_i is the soil water content in millimeters of H_2O at initial and t th day/time step respectively; P_i , SQ_i , ET_i , W_{seep_i} , and Q_{gw_i} are the precipitation, surface runoff, evapotranspiration, water entering the vadose zone, and return flow in terms mm of H_2O on i th day respectively, and t is the day/time step for which computations are being made. The runoff computed for each HRU is routed to get total runoff at the

outlet of the basin. The SWAT model has options for computation of surface runoff either using the modified SCS curve number technique or Green and Ampt method. The input precipitation in the model first undergoes through interception and computed by the canopy as given in the SCS curve number method or user-defined leaf area index in case of the Green and Ampt method. The following formulae are used to predict surface runoff using the SCS-CN method.

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)} \quad (4)$$

where $I_a = 0.2S$ for antecedent moisture condition II (AMC II), Q is the surface runoff in mm, P is the rainfall in mm, I_a is the initial abstraction, and S is the surface retention can be computed by the following equation:

$$S = \frac{25,400}{CN} - 254 \quad (5)$$

where CN is the curve number depends on soil type, land use, management practices, and antecedent moisture condition. The CN values as defined in SCS technique for AMC II are used in the model and modified for antecedent moisture condition I (dry condition) or III (wet condition) in the model based on 5-day antecedent moisture. The setting up of the SWAT model can be made through six different menus present

Table 1 Thiessen weights of different rain gauge stations in Tandula reservoir catchment

Rain gauge station	Area under the rain gauge (km ²)	Weight (W_i)
Balod	148.9	0.18
Bhanpura	322.6	0.39
Chamra	206.8	0.25
Gondli	148.9	0.18

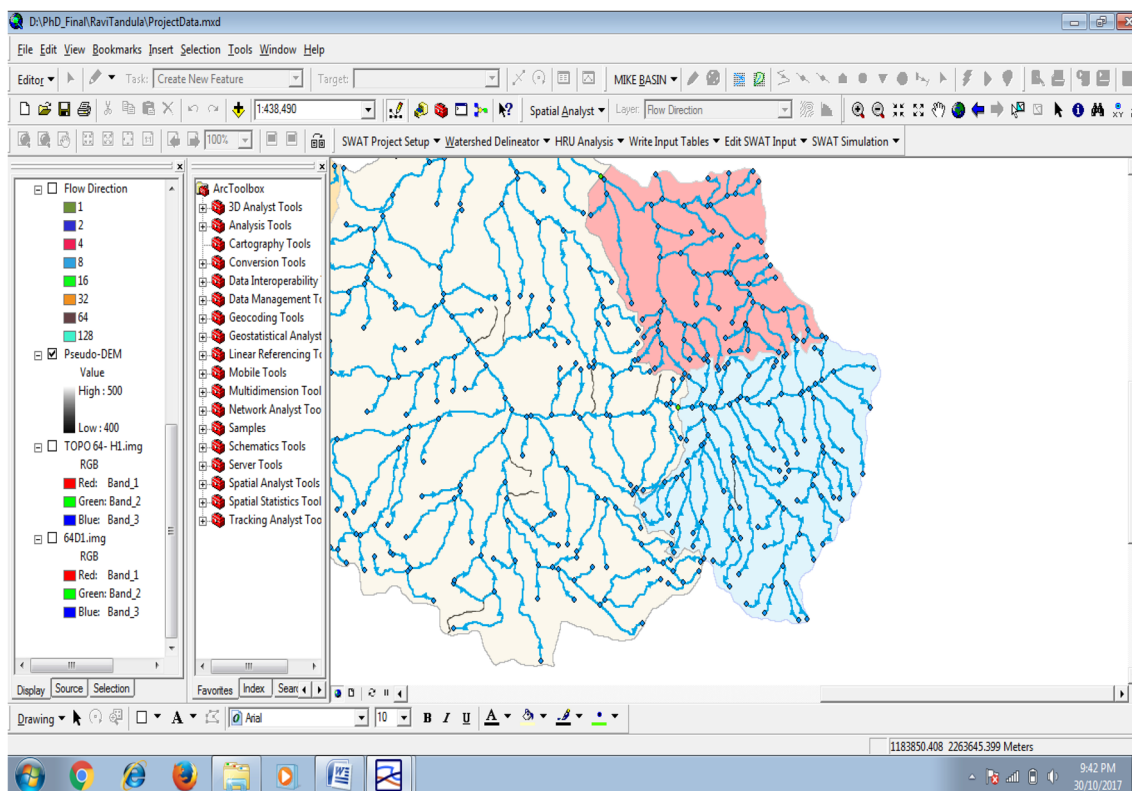
Table 2 Data used in water balance and modeling

S.N.	Data used	Period	Purpose	Source
1.	Daily reservoir levels, releases, spill, inflows from Gondli reservoir, elevation–area–capacity table	1991–2015	Water balance of reservoir	Water Resources Department, Raipur (India)
2.	Daily rainfall of Balod, Bhanpura, Chamra, and Gondli rain gauge stations	1971–2015	SWAT model	Water Resources Department, Raipur (India)
4.	Daily climate data of Raipur including min and max temperature, relative humidity, wind speed, sunshine hour, and pan evaporation	1991–2015	Water balance and SWAT model	Indira Gandhi Krishi Agriculture University, Raipur (India)
5.	ASTER DEM and survey of India toposheets	-	Delineation of catchment, sub-watersheds, drainage for SWAT model	https://asterweb.jpl.nasa.gov/gdem.asp & Survey of India
6.	The IRS 1D data of Path 102, Row 58	Dec 24, 2000, and Apr 03, 2001	Land use map for the SWAT model	National Remote Sensing Agency, Hyderabad (India)
7.	Soil map	-	SWAT model	National Bureau of Soil Survey & Land use Planning, Nagpur (India)

in Arc SWAT GUI including SWAT project setup, watershed delineator, HRU analysis, write input tables, edit SWAT input, and SWAT simulation. The GUI representing all the menus available in the SWAT model is given in Fig. 3.

For setting up of a basin model in SWAT, the digital elevation model (DEM) or user-defined sub-watersheds with drainage, soil, and land use maps are required. Based on land use, soil, and slope classes, the model divides the whole area into

watersheds, sub-watersheds, and hydrological response units (HRUs). The watershed and HRU reports provide information regarding area, soil, slope, and land use classes in each sub-watershed and HRU. The write input tables menu generates database and enable the user to write default values of different parameters in different tables and climatic parameter values in the weather generator. The edit SWAT input menu is an important option used for changing different values,

**Fig. 3** SWAT GUI in Arc SWAT

which after rewriting can be used for sensitivity, calibration, and simulation run through the SWAT simulation menu. In the present study, SWAT models for different catchments were set up in Arc SWAT 2009, while sensitivity, calibration, and validation have been carried out using the SWAT-CUP as an associated public domain program having several optimization techniques like SUFI2, PSO, GLUE, ParaSol, and MCMC.

The SWAT-CUP is an associated generic interface program (Abbaspour 2015) for calibration, validation, uncertainty, and sensitivity analysis. The thought process for the development of the SWAT-CUP is based on large uncertainties in hydrological modeling mainly due to model, input, and parameter uncertainties. The uncertainties analysis helps to select a set of parameters which produce best possible results or contains a maximum portion of observed data using inverse modeling (Abbaspour et al. 1997, Abbaspour et al. 2007; Duan et al. 2003). The SWAT-CUP has five optimization techniques including sequential uncertainty fitting (SUFI2), generalized likelihood uncertainty estimation (GLUE) (Beven & Binley 1992), parameter solution (ParaSol) (Van Griensven and Meixner 2006), Markov chain Monte Carlo (MCMC), and particle swarm optimization (PSO) for calibration, and any one of these need to be specified during setting up of model.

The uncertainty analysis carried out in the calibration process to determine the degree to which all uncertainties can be represented by p -factor and r -factor. The p -factor is measure of how well measured data come within the data bracket of by 95% prediction uncertainty (95 PPU) and varies between 0 to 100% and prediction error can be indicated by measured data which are not bracketed by 95 PPU (Arnold et al. 2012). The r -factor may be defined as the ratio of the average width of 95 PPU band and standard deviation of the observed data. The different processes in SWAT model are expressed using many parameters, and all the parameters are not necessarily important or sensitive for a watershed. Therefore, a sensitivity

analysis in the SWAT-CUP can be carried out using the Latin hypercube generated one-factor-at-a-time (LH-OAT) technique regressed through a multiple regression system to get t -stat and p value for a parameter. The t -stat value of a parameter can be compared with the Student's t distribution which is used to test how the mean of a sample of certain numbers is expected to behave. The p value of each parameter is used to test the null hypothesis which indicates the low value (generally less than 0.05) and can reject the hypothesis, which finally gives the impression that the parameter is not very sensitive.

The calibration and validation are important tasks in any hydrological modeling, and in SWAT-CUP, the calibration can be done by optimizing any one among various goodness of fit parameters given in the program and 95 PPU plot are used to select the best-fit value and a suitable range of all selected parameters. The SWAT-CUP has nine goodness of fit criteria for optimization including multiplicative form of squared error (mult), sum of squared error (sum), coefficient of determination (R^2), Chi-squared (χ^2), Nash-Sutcliffe efficiency (NS), coefficient of determination multiplied by the coefficient of the regression line (\emptyset), sum of squared residual (SSQR), percent bias (PBIAS), and ratio of the RMSE to the standard deviation of measured data (RSR), and can be selected as per their availability for different optimization techniques.

Results and discussions

Application of water balance model for computation of runoff

The water balance of Tandula reservoir has been carried out in excel worksheet where reservoir levels, outflows, spill, losses due to evaporation, and seepage were used to determined inflow on daily basis for the water year (June 01 to May 31 next year). The yearly water balance along with different components has been presented in Fig. 4 and

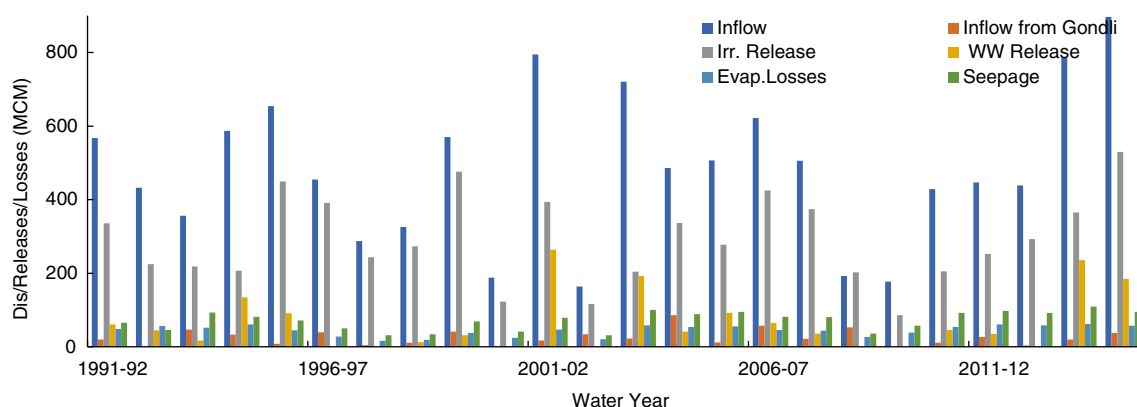


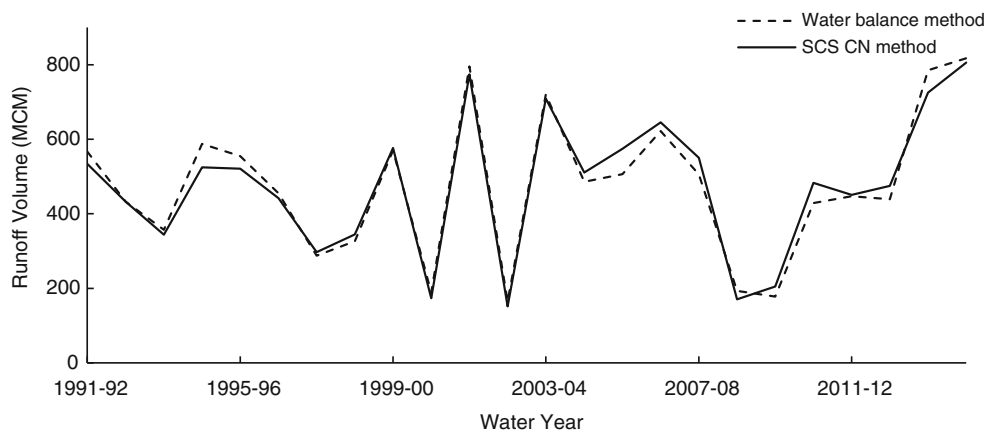
Fig. 4 Different components of the water balance of Tandula reservoir

Table 3 Characteristics of different components of water balance in Tandula reservoir (all values in MCM)

Water balance component	Minimum	Maximum	Average
Inflow from Tandula catchment	164.23	897.12	483.00
Inflow from Gondli catchment	0.00	85.96	25.46
Irrigation release	85.85	530.07	291.96
Release from the waste weir	0.00	264.31	66.17
Evaporation loss	16.57	61.72	44.78
Seepage	31.20	109.01	71.72
Change in storage in the reservoir	-33.03	179.24	31.53
Incoming in the reservoir	177.61	935.17	508.46
Outgoing from the reservoir	169.33	867.29	474.63
Change in storage in the reservoir	-19.78	187.63	33.83
Percentage error	-6.87	4.01	-0.51

Table 3. The percentage of errors for each water year has been computed as the difference between total inflows, outflow, and change of storage based on volumes on the first and last day of the water year.

From the analysis, it has been observed that percentage errors in water balance varied in the range of -6.87 to 4.04% and found well within the range (less than 10% of inflow); the inflow computed from water balance of Tandula reservoir can be used for rainfall-runoff modeling. The seepage and evaporation are the major losses from Tandula reservoirs depend on the area of contact and water spread respectively. The results of water balance for reservoirs indicated average annual inflow may be 483 ± 202.8 MCM from Tandula which has a close agreement with the computed runoff from the SCS-CN method using spatially distributed land and soil maps. The composites CN for basin have been computed as 69.3, and yearly computed runoff from water balance and SCS-CN method are presented in Fig. 5

Fig. 5 Comparison of computed runoff from water balance and SCS-CN method

SWAT model for rainfall-runoff modeling

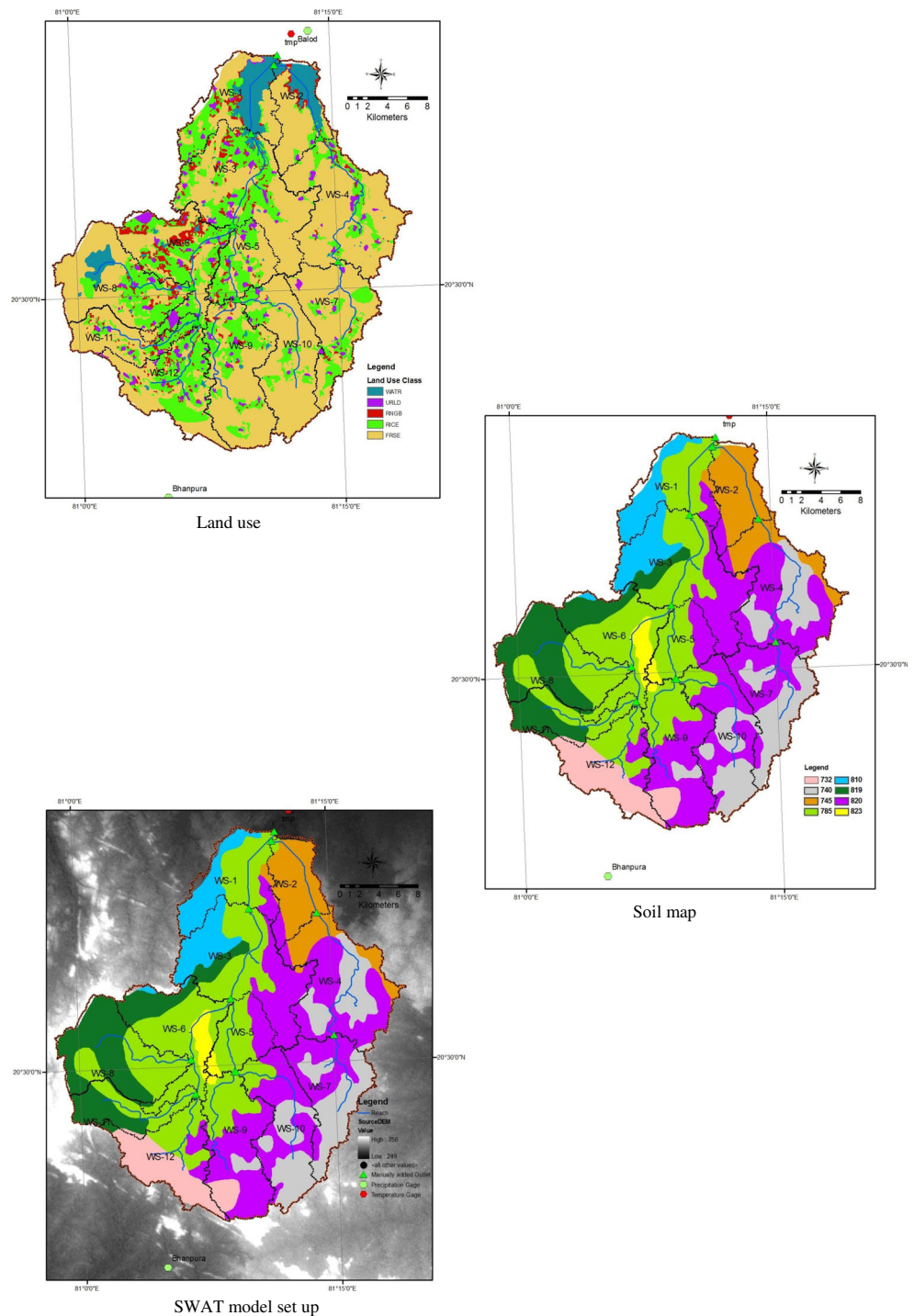
The SWAT model for Tandula reservoir catchment was developed using the digital elevation model (DEM) from ASTER DEM, toposheets, land use, and soil maps. A weather generator for the catchment was developed using historical series of climatic data of min and max temperature, wind speed, sunshine hour, and rainfall. The land use, soil, DEM, and SWAT setup for Tandula catchment are presented in Fig. 6. The land uses have been divided into five groups, namely deciduous forest (FRSD), low density urban (URLD), scrub (RNGB), agriculture (RICE), and water body (WATR). Similarly, different soils found in these catchments have been included in the SWAT database (Tamgadge et al. 2002; Kumar et al. 2015). Using DEM of these catchments, the slope map was divided into 5 groups, namely 0 to 2%, 2 to 5%, 5 to 10%, 10 to 25%, and more than 25%. The area falling under different groups of land use, soil, and slope for Tandula catchment are presented in Tables 4, 5, and 6. From the analysis, it has been observed that Tandula catchment is forested catchment having the loamy and clayey type of soils and sloppy land with 2 to 25% slope.

After setting up the model, the weather generator for the model was assigned and all the files were written with default values. The model was then imported in the SWAT-CUP software for sensitivity, uncertainty, calibration, and validation of the model.

SWAT-CUP application for sensitivity, calibration, and validation

The rainfall-runoff modeling for Tandula catchment has been carried out using data from 1991 to 2015. The daily data from 1991 to 1994 was used for warm up, 1995 to 2007 for calibration and 2008 to 2015 for validation of the model. In the present study, sequential uncertainty fitting (SUFI2)

Fig. 6 Land use, soil, and DEM with SWAT setup for Tandula reservoir catchment



algorithm has been used for analysis. The sensitivity analysis has been carried out using *t*-stat (larger absolute value) and *p* value (smaller absolute value). The results of this analysis suggested that the SCS curve number (r_CN_2), saturated hydraulic conductivity (sol_k), soil antecedent water content (sol_AWC), Manning’s *N* for main channel (ch_N_2), base flow alpha factor (Alpha_bf), soil evaporation

compensation factor (ESCO), and threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN) are the most sensitive parameters for Tandula reservoir catchment. The test statistics of uncertainty analysis along with best-fit value and ranges of different sensitive parameters have been depicted in Table 7. The 95 PPU graph for Tandula catchment is presented in Fig. 7 a, b. The

Table 4 Distribution of land uses in Tandula catchment

S.N.	Land use	Area (ha)	Percentage
1.	Deciduous forest (FRSD)	500.5	60.6
2.	Scrub land (RNGB)	36.9	4.4
3.	Agriculture (RICE)	218.7	26.5
4.	Urban land of low density (URLD)	28.1	3.4
5.	Waterbody (WATR)	43.0	5.2
Total		827.2	100

optimized values of different sensitive parameters have been kept constant and validated with independent inputs from 2008 to 2015. The computed and observed runoff during calibration and validation have been used to compute several goodness of fit criteria including coefficient of determination (R^2), Nash–Sutcliffe efficiency (NS), mean square error (MSE), sum of squared residual (SSQR), percentage bias (PBIAS), mean of simulated and observed runoff, and standard deviation of simulated and observed runoff. The values of the goodness of fit criteria during calibration and validation are given in Table 8.

From the analysis of different goodness of fit tests, it has been observed that Nash–Sutcliffe efficiencies for Tandula catchment were found as 0.75 and 0.65 during calibration and validation respectively which can be considered as good performance of the model as per the criteria suggested by Moriasi et al. (2007) and Boskidis et al. (2012). As different goodness of fit criteria used in the analysis and 95 PPU graph suggested a satisfactory match between observed and computed runoff, the developed model can be used to generate future runoff series from Tandula catchment using projected climatic variables and rainfall.

Conclusions

Non-availability of runoff data due to the involvement of huge operation and maintenance cost is one of the biggest problems

Table 6 Different slope classes in Tandula catchment

S.N.	Slope	Area (ha)	Percentage
1	0 to 2%	19.9	2.4
1	2 to 5%	160.9	19.5
2	5 to 10%	320.0	38.7
3	10 to 25%	308.4	37.3
4	More than 25%	18.0	2.14
Total		827.2	100

in developing countries like India. The present study suggested a framework with the incorporation of the water balance of reservoir and application of spatially distributed SWAT and SWAT–CUP modeling for hydrological modeling where no gauging records were available. The water balance model developed in the study used all incoming and outgoing components for Tandula catchment on daily basis and compared with runoff computed from the SCS–CN method and the percentage difference between total incoming and outgoing volume and volume at beginning and end of each water year. The percentage of error was found within 10%, and daily runoff computed was used for the SWAT model. From the analysis, it may be concluded that evaporation loss is one of the major loss components in the water balance of Tandula reservoir. The SWAT model for the Tandula reservoir catchment was set up and exported in the SWAT–CUP application for sensitivity, calibration (1195–2007), and validation (2008–2015) using the SUFI2 optimization technique. The sensitivity analysis suggested that the SCS curve number (r_CN2) and saturated hydraulic conductivity (sol_k) are the most sensitive parameters for runoff computation, and Nash–Sutcliffe efficiency of the developed model during calibration and validation was found as 0.75 and 0.65 and indicated a satisfactory performance on daily basis. The SWAT model developed in this study can be used for reservoir operation, irrigation planning and assessment of the impact of climate, and land use change on runoff from Tandula catchment for planning adaptation measures.

Table 5 Distribution of soils in Tandula catchment

S.N.	Soil class code	Soil texture	Soil group	Area (ha)	Percentage
1	732	Fine sandy loam	A	44.7	5.4
2	740	Clayey loam	B	105.4	12.7
3	745	Sandy clay loam	B	62.3	7.5
4	785	Fine sandy loam	A	237.7	28.7
5	810	Silty clay	C	48.9	5.9
6	819	Sandy clay	C	94.4	11.4
7	820	Loamy clay	C	221.2	26.7
8	823	Loamy fine sand	A	12.5	1.5
Total				827.2	100

Table 7 Results of sensitivity, calibration, and validation for Tandula catchment

Parameter name	Description of parameter	Sensitivity results		Calibration and validation results	
		<i>t</i> -stat	<i>p</i> value	Best value	Range
<i>R</i> _{CN₂}	SCS curve number	- 14.429	0.00	- 0.015	- 0.1226 to 0.0927
<i>So</i> _{<i>k</i>}	Saturated hydraulic conductivity	- 13.648	0.00	0.748	0.0267 to 1.5227
<i>So</i> _{AWC}	Soil antecedent water content	- 1.449	0.015	0.058	- 0.3133 to 0.4293
<i>Ch</i> _{<i>N</i>₂}	Manning's <i>N</i> for main channel	- 1.341	0.018	0.032	0.001 to 0.1662
<i>Alpha</i> _{bf}	Base flow alpha factor	- 0.988	0.032	0.514	0.2567 to 0.7713
ESCO	Soil evaporation compensation factor (days)	- 0.914	0.036	0.773	0.3858 to 1.1591
GWQMN	Threshold depth in the shallow aquifer required for return Flow to occur (mm)	- 0.676	0.050	33.75	33.75 to 2268.801

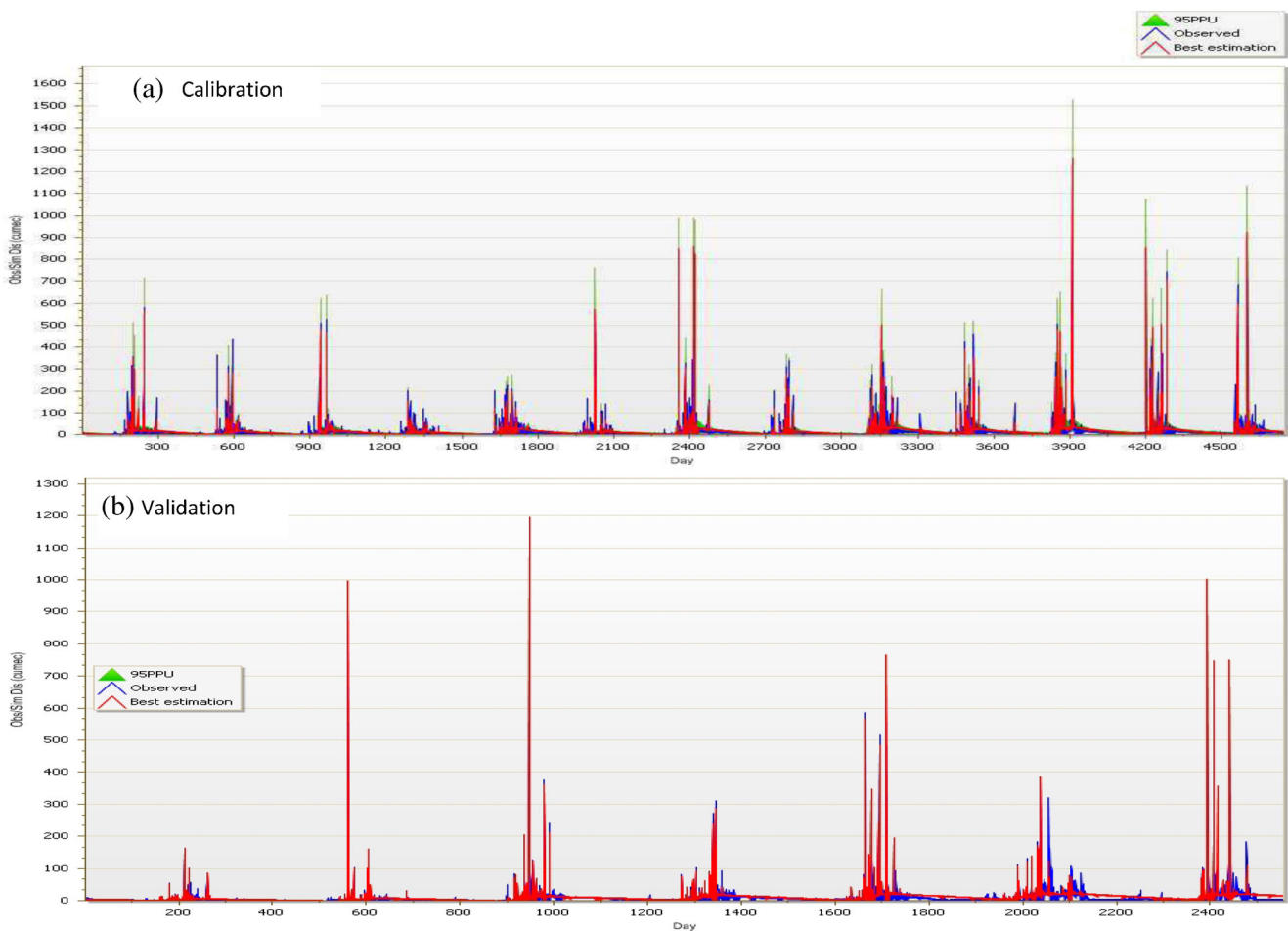


Fig. 7 Observed, computed runoff with 95 PPU for Tandula catchment for the SWAT model

Table 8 Goodness of fit criteria in the SWAT model for Tandula catchment

Goodness of fit criteria	Calibration	Validation
Coefficient of determination (R^2)	0.76	0.81
Nash–Sutcliffe efficiency (NS)	0.75	0.65
Mean square error (MSE)	0.07	0.06
SSQR	0.018	0.029
PBIAS	42.8	44.0
Mean simulated runoff (mean observed runoff)	19.75 (21.94)	17.58 (15.50)
Std. dev. of simulated runoff (std. dev of observed runoff)	50.38 (53.78)	56.08 (43.57)

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