__Original Research Article__

Hydrological Modeling of Krishna Upper Catchment area of India Using Multisite Calibration and Validation of SWAT Model

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ABSTRACT

. Multiple site calibration & validationof model reduce the uncertainty present in the model parameters and improve the SWAT model output. In the present study, an effort was made to set up SWAT model along with multisite calibration and validation for Kishna upper basin of India. A total of six gauging stations maintained by Central water commission across the area was selected for SWAT model calibration and validation. Sequential Uncertainty Fitting (SUFI-2)programme of SWAT-CUP (Calibration and Uncertainty Programme) was employed tocalibrate the SWAT model. During sensitivity analysis of SWAT model, parameters which are highly sensitive that influences flow characteristics of different gauging station were identified. These parameters along with parameter range were used to calibration and validation of SWAT model each of the sub basins. Observed flow and predicted stream flows were compared with certain model performance indices. These indices indicates that for all six gauging stations, the SWAT model found to be very good.. The performance indices like R^2, NSE, RSR and PBIAS were ranged from 0.70 to 0.84, 0.67 to 0.76, 0.49 to 0.57 and -11.7 to 24.0% respectively during model calibration period and 0.70 to 0.93, 0.67 to 0.83, 0.41 to 0.58 and 8.5 to 22.9% respectively during model validation period. A good agreement between observed and simulated flows at all the gauging stations were observed. It can be concluded that SWAT model output was improved with multisite calibration and validation of the model.

Key words: SWAT model, SWAT-CUP, SUFI 2, Multisite calibration, stream flow

1. INTRODUCTION

Water resource play key role in making agriculture more profitable and sustainable. The annual total water resources at the global level are estimated at 43754 km^{3}and distributed across the Globe. The distribution of water resources varies with climate and physiographic nature. India gets an annual precipitation of 4000 km^3 which is substantially variable with space and time. The annual runoff to river systems of India is about 1953 km^3 and rechargeable groundwater resources assessed as 432 km^3. Out of theses, the utilizable surface & groundwater reserves are 690 km^3 and 396 km^3 respectively (Kumar *et al.*, 2005). The Agriculture segment utilizes foremost share of water resources in India. It was estimated that the amount of water utilized for irrigation by last century was 428.0km^3 . Among the major catchments or basins of India, annual utilizable water resources of Ganga basin with

250 km^3 followed by Godavari basin with 76 km^3. Krishna basin is having the annual utilizable water resources of 58 km^3against potential water resources of 89 km^3 (CWC, 2021).

The Agriculture segment utilizes a major portion of 85-90% of water resources of India and 70 % Globally (Jain, 2021). The impact of climate change on water requirements of crops in Krishna basin is more significant and certain adaptative water strategies in Krishna upper Basin also required to mitigate the adverse effect of climate change (Rao, *et al.*, 2021). The periodical review of water resources availability and requirement with respect to time and space is essential. Jain (2019) stated that a large temporal irregularity in water accessibility in India because of 70% of precipitation takes place in the rainy season (Monsoon season) in a four-month period. The water availability in the remaining eight months period accounted for 25-30%. A difference between requirement and availability water resource is cumulative as there is no significant increasing trend in annual rainfall in India. A similar trend was also observed in the Krishna Upper catchment area with respect to rainfall (Rao, *et al*., 2023).

Hydrological simulation models are used to evaluate availability of water resources with reference to space & time. These models are used for assessment of water availability in the existing conditions and also be utilized for influence of climate change on hydrological components. In the modern era, numerous researchers utilized lumped, semi distributed and distributed models. These hydrological models established on conceptual & physical principles in nature to analyze the water resource availability at larger river basin to macro and micro catchment level. Various studies used Soil & Water Assessment Tool (SWAT) (Arnold et al., 1998), Storm Water Management Model (SWMM) (Jang et al., 2007), Water Erosion Prediction Project (WEPP) (Singh et al., 2011), Hydrologic Engineering Centers Hydrologic Modelling System (HEC-HMS) (Halwatura and Najim, 2013), Generalized River Modelling Package - Système HydrologiqueEuropéen (MIKESHE) & Hydrologic Simulation Program Fortran (HSPF) (Yazdi et al., 2019), Some of the lumped models which are conceptual models such as Simple Hydrology (SIMHYD) (Chiew et al, 2018; Rao et al., 2024) and Australian Water Balance Model (AWBM) are also used for simulating the stream flows (Yu and Zhu, 2014).

Among the above models, SWAT model is one of the popular semi distributed & continues time scale hydrological model (Arnold et al., 1998). SWAT model is utilized for field scale to regional or basin scale. Many scholars used SWAT model across the world for assessing the water availability and water budget components such as runoff, percolation, groundwater, evapotranspiration, and lateral flow at basin to micro watershed level (Maliehe and Mulungu, 2017; Ayivi and Jha, 2018; Jimeno et al., 2018). Many investigators in India also tested this model and modelled surface water availability (Perrin et al., 2012; Anand et al., 2018; Jothiprakash et al., 2017).

Biggs *et al.* (2007) revealed that the annual stream flow of Krishna river is 69.8 km^3 . The consumption of flows of Krishna river amplified from 14 km^3 to 57 km^3 during the period 1901-1960 to the period 1994-2003 with no substantial change in rainfall. The Western Ghats offers 57% of basin runoff from its 9.5% basin area because of high precipitation and runoff coefficient. The consumption and demand of water resources are growing year by year. Over last four decades, Krishna & Koyna river flow characteristics were changed due to differences in rainfall, slope, relief, , catchment drainage, reservoir and catchment area (Shinde *et al.*, 2020). Chanapathi*et al*., (2018) stated that the Krishna River Basin is more susceptible to climate change, due to the inconsistent rainfall distribution and hotter climatic conditions. A periodical evaluation of availability of water resources is required for any basin through hydrological models to comprehend the behaviour of flow regime and water budget components.

The present study area is a part of Krishna basin and also one of the major sub basins with more dams and reservoirs. Multisite calibration &validation is required for such subbasins for better estimation of flow regime and hydrological water balance components. However, very few investigations have focused on this multisite calibration using SWAT model particularly in Krishna basin. Keeping in view of the above points, this paper focused on setting up SWAT model with multisite calibration & validation using SWAT-CUP.

2. MATERIAL AND METHODS

2.1 STUDY AREA

The study was carried out on Krishna Upper sub-basin located between latitude longitude of 15°3′0″ - 18°6′0″ N I and 73°39′0″ - 77°23′0″ E respectively , spread over Maharashtra & Karnataka states. The study area with an extant of 54,230 km^2 and main sub basin outlet at Huvenhedigi located in Raichur district in the state of Karnataka of India. The elevation (msl) is between 343 m to 1456 m with highly undulated. This basin present between Tungabhadra & Bhima river subbasins of Krishna basin. Western Ghats which is high-altitude in the study area receives high rainfall and eastern parts comes under semi-arid climate and receives low rainfall. The study area location , sub-basin boundaries and administrative boundaries of districts are depicted in Fig 1. Precipitation of characteristics and distribution of study area is unreliable and having more spatial variability. Upper Krishna sub-basin receives more annual rainfall (long-term average) of about 981 mm followed by Ghataprabha sub-basin(778 mm), Middle Krishna sub-basin (580 mm), and Malaprabha sub-basin(660 mm)respectively.

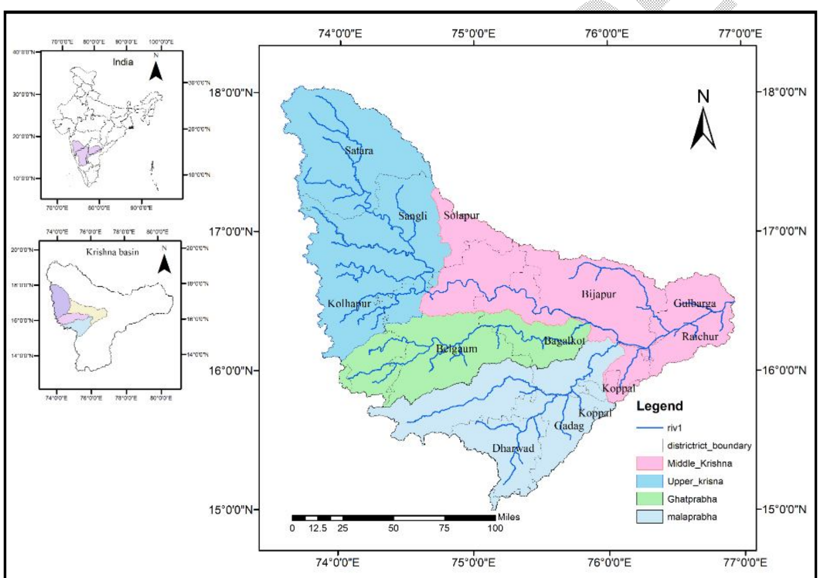


Fig. 1 Location of study area

2.2 Data sets for SWAT model

SWAT model needs detailed spatial data of topography, soil characteristics and land use land cover in addition to the parameters related to weather on daily time step basis to build hydrological model that mimics physical process such as runoff, , nutrient movement along with soil transport and growth of crop.

2.2.1 Digital Elevation Model

Elevation data from "Shuttle Radar Topographic Mission" (SRTM) with a spatial resolution at 30 m (1-arc second)was used to develop Digital Elevation Model (DEM). The data was obtained from USGS (http://www. Earthexplorer.usgs.gov.in) earth explorer online resources. The Digital Elevation Model for the study area is depicted in Fig. 2. The highest elevation and lowest elevations were observed with 1436 m at Western Ghats and 343 m located at study area outlet.

2.2.2 Land Use Land Cover data

Land Use and Land Cover (LULC) data for the study area was gathered from ISRO-National Remote Sensing Center (NRSC). This LULC data sets with resolution with 50 m were generated with LISS III imageries. Spatial map of LULC are depicted in Fig. 3. The extent of land use land cover along with SWAT codes and their per cent in total area are also tabulated in Table 1. Agriculture occupies major land use in the study area with 49.95 per cent (27.08 million ha). Total cropped area in the study area during *kharif*, *rabi*, summer and double/ triple crop of 2012-13 were recorded with 0.725, 0.341, 0.407and 1.23 million ha respectively. The major LULC after agriculture was current fallow class with 25.65 per cent (1.4million ha). The other LULC classes were other waste land & gullied (9.05%), forest-evergreen (4.12%), grass land & scrubland (6.36%), forest-deciduous (1.76), water bodies (2.55%) plantation/ orchard (0.33%), and settlement (0.23%).

Table 1 Land Use Land Cover classes and SWAT codes of the study area

Sl. No.	Land Use	Area (km^2)	Percentage	SWAT Code
1	Residential	123.8	0.23	URBN
2	Agriculture: Kharif only Rabi only Zaid Double/ Triple crop Total	 7250.1 3411.6 4070.1 12306.1 27087.8	49.95	AGRL
3	Current Fallow	13912.0	25.65	BARR
4	Plantation/ Orchard	177.4	0.33	ORCD
5	Forest-Evergreen	2231.9	4.12	FRSE
6	Forest-Deciduous	955.2	1.76	FRSD
7	Other waste land &Gullied	4909.5	9.05	RNGB
8	Grassland & Scrubland	3446.7	6.36	PAST
9	Water	1384.2	2.55	WATR

2.2.3 Soil data

Soil data sets were prepared from soil data sets of FAO by extracting the required data from data sets of FAO. many researchers 5km resolution of used FAO data set(Gosain *et al.*, 2006; ; Panda *et al.*, 2021). A lookup table was prepared with soil properties viz. texture, bulk density, albedo and erosion factor, Hydrological Group, various soil layer depth, Maximum depth of root zone(mm), and erosion factor. Clay loam soils and slay soils are predominant in the study area. The spatial dispersal of different soils of the study area is depicted in the Fig. 4. The information of taxonomy classification, soil mapping units, and their extent are presented in the Table 2.

2.2.4 Slope map

Digital Elevation model was used to prepare the slope map for the study area using ArcSWAT tool. The classification of study area was done with five slope classes. These slope classes were defined as 0-2 percent, 2-5; 5-10; 10-15 and >15%. An area of 44.43% was categorized in slope range of 2-5 % followed by 5-10% (20.59% area), 0-2% slope (20.53 % area), 10-15% (5.2 % area) and >15% slope (9.26 % area). The slope classification in detailed is depicted in Table 3 and the spatial distribution on slope classification is given in fig,5.

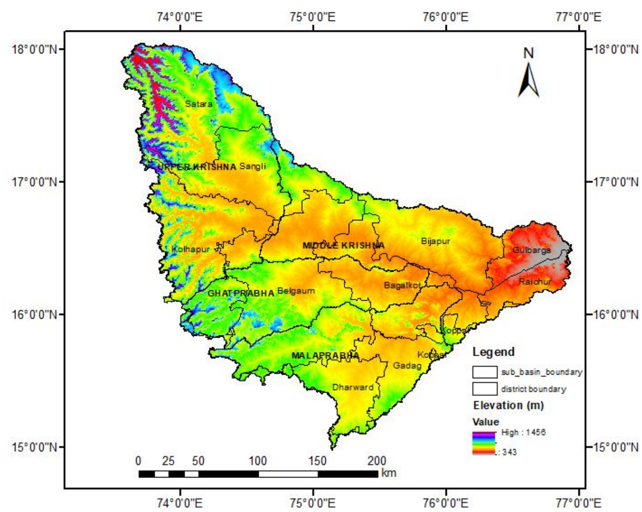


Fig. 2 Digital Elevation Model (DEM) of study

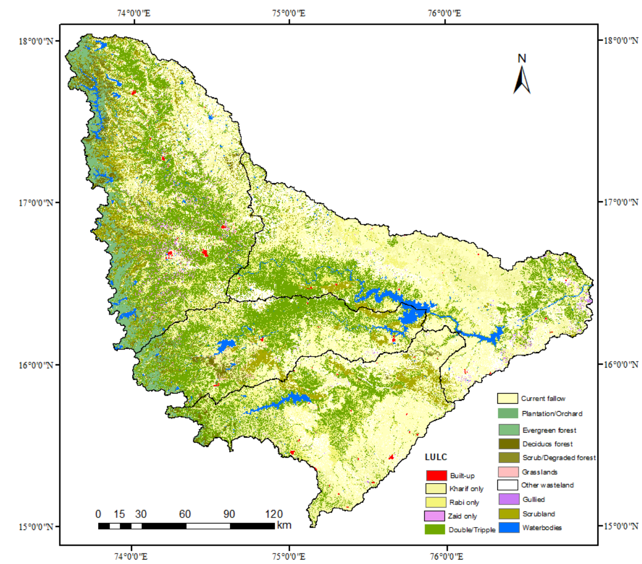


Fig. 3 Land Use Land Cover map of the study area

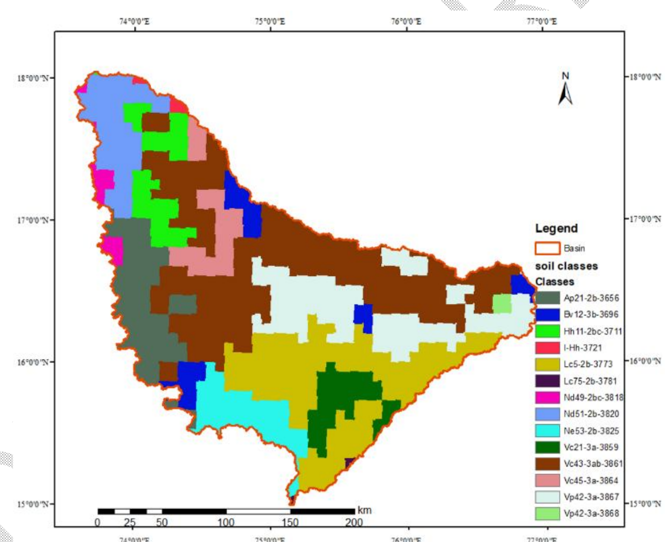


Fig. 4. Soil map of the study area

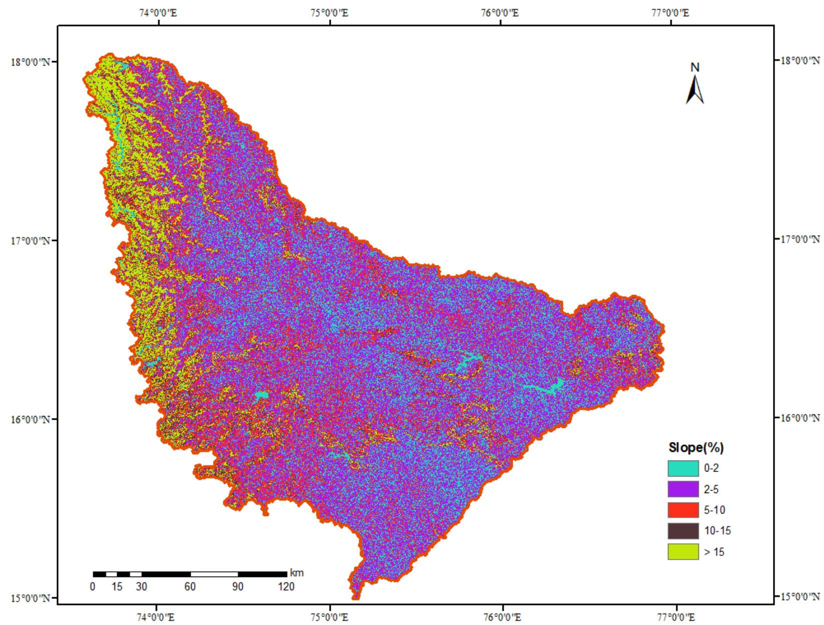


Fig. 5 Slope map of the study area

Table 2 Details of soil mapping units, taxonomy of soils in the study area

Sl. No.	Soil mapping unit and SWAT code	Taxonomy	Area (km^2)	Per cent area (%)
1	Ap21-2b-3656	Sandy Clay Loam	4662.81	8.6
2	Bv12-3b-3696	Clay Loam	2017.83	3.72
3	Hh11-2bc-3711	Clay Loam	2699.90	4.98
4	I-Hh-3721	Loam	178.19	0.33
5	Lc5-2b-3773	Clay Loam	9586.88	17.68
6	Lc75-2b-3781	Clay Loam	69.07	0.13
7	Nd49-2bc-3818	Loam	764.78	1.41
8	Nd51-2b-3820	Loam	3653.87	6.74
9	Ne53-2b-3825	Sandy Clay Loam	2964.27	5.47
10	Vc21-3a-3859	Clay	2302.27	4.25
11	Vc43-3ab-3861	Clay	15648.87	28.86
12	Vc45-3a-3864	Clay	2316.52	4.27
13	Vp42-3a-3867	Clay	7148.17	13.18
14	Vp42-3a-3868	Clay	215.04	0.4

Table 3 The details of slope classes in the study area

Sl. No.	Slope range (%)	Area (km^2)	Study area (%)
1	0-2	11130.61	20.53
2	2-5	24095.57	44.43
3	5-10	11164.14	20.59
4	10-15	2817.82	5.20
5	>15	5020.29	9.26

2.2.5 Streamflow data

The daily observed discharge data of various gauging stations located in the study area was obtained from India-Water Resources Information System (https://indiawris.gov.in/wris) and “Natural Disaster Monitoring Center of Karnataka State” (www.ksndmc.org). Six stream flow gauging stations were considered for the present study. These gauging stations namelyMalaprabha (Renukasagar), Narayanpur, Almatti, and Ghataprabha (Hidkal) dam in additions to the other two stream flow gauging stations namely Kurundwad and Huvenhedgi (Outlet). The Middle Krishna sub-basin gets inflow from other sub basins namely Upper Krishna ,Malaprabha and Ghataprabha . The gauging stations along with temporal flow characteristics are described in the Table 4 and the details of reservoirs/dams are presented in Table 5 and Fig. 6 also shows the gauging stations location and storage structures which were considered in present study.

Mean monthly stream flow at main outlet(Huvinhedgi gauging station) of the study area was found to be 379.72 m^3/s. The maximum flow scaled atHuvinhedgi station was found to be 5721.3 m^3/s. Mean monthly flow at Kurundwad gauging station, Ghataprabha (Hidkal) dam and Malaprabha (Renukasagar) dam, Almatti dam, Narayanpur dam, were 363, 66 28.8315, and 433, m^3/s respectively. The maximum flow at these sites were 5060, 796, 585, 5568, and7365, m^3/s respectively.

2.2.6 Weather data

Daily rainfall at a grid interval with resolution of $0.25^{\circ} \times 0.25^{\circ}$, maximum, and minimum temperature with $1^{\circ} \times 1^{\circ}$ resolution of were used for the present study. The data prepared by Pai, *et al*. (2014) & Srivastava, *et al.* (2009) was obtained from Indian Meteorological Department (IMD) website. A total of 74 grid stations ($0.25^{\circ} \times 0.25^{\circ}$) of rainfall & 5 grid stations ($1^{\circ} \times 1^{\circ}$) of Maximum & minimum temperature covering the entire study area were consumed in the present study and shown in the Fig.7. Weather generator (WXGEN) was used to generate RH, wind speed and radiation available with SWAT database for India condition. Neitsch*et al*, (2011) explained the step by step procedure for simulation of weather parameters in the SWAT input output document. SWAT admits users to select the input file or mimic the input parameters using mean monthly data over several years. Other weather parameters like maximum& minimum temperature, solar radiation and relative humidity is then created based on the rain for that given day.

Table 4 Details of the gauging stations and stream flow characteristics

Sl. No.	Gauging station name	Length of data	Contributing area, km^2	Monthly discharge (m^3/s)			
				Minimum	Maximum	Average	Standard deviation
1	Kurnudwad	2003-2018	15530	0	5060.69	363.84	547.59
2	Hidkal Dam	2011-2019	1370	0	796.47	65.97	134.67
3	Malaprabha Dam	2011-2019	2229	0	585.81	28.79	68.34
4	Almatti Dam	2011-2019	33720	0	5568.97	315.23	932.92
5	Narayanpur Dam	2011-2019	47630	0	7365.44	433.50	1005.60
6	Huvenhegdi	2003-2018	54230	0	5721.31	379.72	825.19

Table 5 Details of the storage structures considered in the study area

Sl. No.	Name of the Dam/ reservoir	Reservoir became operational in the year	Live storage (10^4 m^3)	Water Surface area (ha)	Dead storage (10^4 m^3).
1	Almatti	2002	348500	24230	35300
2	Dhom	1977	38227	2205	5117
3	Dhudhsagar	1989	71912	3933	4010
4	Ghataprabha	1977	144869	17100	5945
5	Koyana	1961	298068	11969	14514
6	Malaprabha	1973	106841	13578	9139
7	Naraynpur	1982	107208	13206	20817
8	Urmodi	2001	28214	1450	887

2.3 Sensitivity & uncertainty analysis

Determination of high sensitive parameters is a primary step in the SWAT model calibration & validation process (Abbaspour *et al.*, 2011). This provides the model behaviour with various input parameters along with their magnitude. Sensitivity analysis facilitates in recognizing parameters that impact simulations of the model. SWAT Calibration & Uncertainty Program (SWAT-CUP) that is companionable with output files of SWAT model. SWAT-CUP has various calibration methods like SUFI2, GLUE, PSO, ParaSol and MCMC. SUFI2 programme was used by several researchers as it's a faster, robust, versatile nature towards sensitivity and calibration of models (Chanapathi*et al*., 2020 and Singh *et al*, 2013; Phinyoyang, A. and Ongsomwang, S., 2021, Zhao *et al* 2024). In the present study, SUFI2 method was utilized with global sensitivity method to find out model sensitivity and calibration. Global sensitivity analysis do sensitivity of one parameter and the values of remaining parameters also keep changing. This sensitivity analysis was done to identify the more sensitive parameters and the selection of parameter was done based on study area characteristics and targeted stream flow (output) . Statistical tools such as t-test and p-values were used to do parameter sensitivity. Parameter ranking was done with t-stat or p-values that gives the similar ranking. Global sensitivity procedure for model was done after first iteration by choosing simulations around 500 (Abbaspour, *et al*, 2015). Among the parameters, stream flow was found to be more sensitive to catchment physical factors viz watershed characteristics, LULC, groundwater characteristics and characteristics of soil. Sensitivity analysis process becomes more difficult and computationally complex when all the parameters were under considered. Researchers used the SWAT model sensitivity analysis in Krishna basin and considered major fifteen parameters for sensitivity analysis(Chanapathi*et al*., 2018; Dashavant, 2018; Singh *et al.*, 2013). The selected parameters and their details are presented in Table 6.

The procedure followed in SUFI-2 uncertainty analysis of SWAT-CUP was used to conduct the uncertainty analysis of the SWAT model. In SUFI-2, the model output uncertainty measures at 95 % Prediction of Uncertainty (PPU) and input parameters' uncertainty is illustrated as uniform distribution. The parameters are updated until the best simulation is achieved (Abbaspour*et al*., 2007). The desirable quantities of p-factor & r-factor, 1.0 and less than 1.5, respectively and match simulated data with observed data.

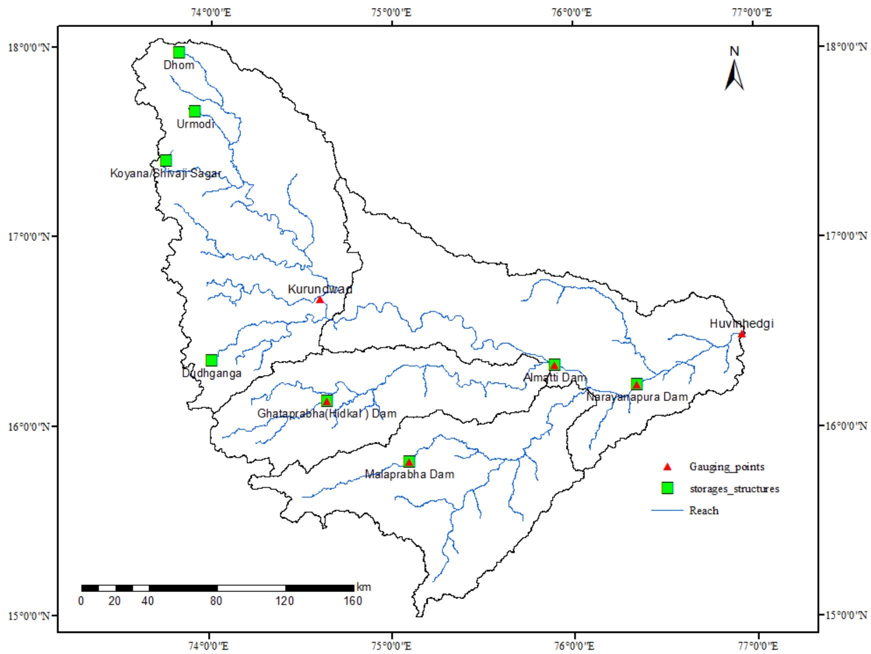


Fig. 6 Location of gauging stations and storage structures in the study area

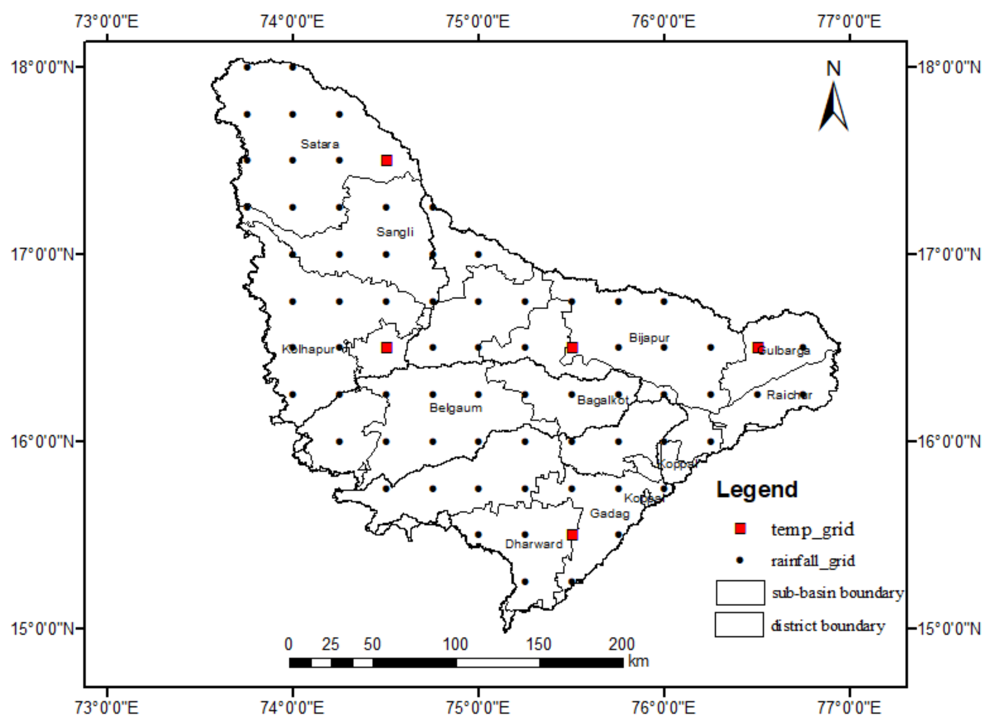


Fig. 7 Location of grid points of rainfall and temperatures

2.4 Calibration & Validation of Model

SUFI2 programme of SWAT-CUP was employed to SWAT calibration and validation using measured stream flow. Model calibration is done by suitable selection of values of model input parameter by relating the model simulations (output) against measured data (Arnold *et al*., 2012). Model validation is the procedure of demonstrating a model calibration and is capable enough to predict the output at given accuracy. The procedure of model calibration and validation was done according to the procedure given in manual of SWAT-CUP (Abbaspour *et al.*, 2015). The model calibration and validation was carried outfor six gauging sites, viz., Huvenhedgi (2003-2017), Kurnunwad (2003-2018), Ghataprabha (Hidkal) (2014-2019), Malaprabha (Renukasagar) (2014-2019), Narayanpur (2014-2019) and Almatti Dam (2014-2019) .The model calibrated and validated with monthly stream flow. The model warmup period was taken as 3 years. Gauging station wise stream flow for calibration period & validation periods are given in the Table 7. SWAT model calibration and validation was carryout based on the data availability .

The model parameters were determined based on the analysis of model sensitivity and the same fifteen parameters were chosen for model calibration and validation for the gauging stations of the study area . These model parameters were selected based on the soil, stream and groundwater characteristics, characteristics of basin and management practices. Primarily, the outlets of upstream study area(Kurnundwad, Ghataprabha dam and Malaprabha dam were calibrated to get suitable objective functions. The values of parameter were finalized for the outlets and the SWAT model was reorganized with new parameter values. Further, the other three stream flow outlets (Almatti Dam, Huvenhedgi and Naranpur dam) were calibrated subsequently and further parameters were updated in similar sequential manner. first iteration with 500 simulations was run after setting up of the programme. The programmes were executed by SWAT executable files (SUFI2_pre.bat; SUFI2_post.bat; SUFI2_run.bat; Sufi2_extract.bat files). During 1st iteration, the parameters range found in the 1st was used in the subsequence iteration. The vales of parameter were changed at required level and acceptable range till it matches the values of objective function. New parameters range along with fitting values were found during the calibration period and the same parameter range was utilized and tested for model validation period. The above followed procedure was repeated for the validation period of various gauging stations (Table 7).

Table 6 List of parameters considered for sensitivity analysis

S. No	Name of the parameter	Description	Unit	Default Range
1	r_CN2.mgt	SCS runoff curve number for AMC II	na	-0.20 - 0.2
2	r__SOL_AWC(1).sol	Available water content in the soil layer	mm/mm	0 - 1
3	r__SOL_BD(1).sol	Soil bulk density	g/cc	0.9 - 2.5

4	r__SOL_K(1).sol	Soil hydraulic conductivity	mm/h	0 - 2000
5	v__ALPHA_BF.gw	Base flow alfa factor	days	0.01 - 1.0
6	v__ALPHA_BNK.rte	Baseflow alpha factor for bank storage	na	0.01 - 1.0
7	v__CH_K2.rte	Effective hydraulic conductivity in main channel	mm/h	0.01 - 500
8	v__CH_N2.rte	Mannings coefficient for channel	na	0.01 -0.3
9	v__ESCO.hru	Soil evaporation compensation factor	na	0.01 - 1.0
10	v__GW_DELAY.gw	Groundwater delay	days	0 - 500
11	v__GW_REVAP.gw	Available water content of the layer	na	0.02 - 0.2
12	v__GWQMN.gw	Threshold dept of water in the shallow aquifer for return flow to occur	mm	0 - 5000
13	v__RCHRG_DP.gw	Deep aquifer percolation factor	na	0 - 1
14	v__REVAPMN.gw	Threshold depth of water in the shallow aquifer for "revap" to occur	mm	0 - 500
15	v__SURLAG.bsn	Surface runoff lag time	na	0.05 - 24

Note: v_ existing parameter value is to be replaced by the given value
a_ given value is added to the existing parameter value
r_ existing parameter value is multiplied by (1+ a given value)

2.5 Model Performance Evaluation

The model performance was scrutinized during calibration and validation with performance indices viz. Nash Sutcliffe Efficiency (NSE), , Coefficient of Determination (R^2), RMSE observations standard deviation ratio (RSR)and Per cent Bias (PBIAS). The range of acceptance of the above performance indices are depicted in the Table 8. The model performance indices detailed are given below.

2.5.1 Nash Sutcliffe Efficiency (NSE)

SWAT model, prediction ability was tested with Nash Sutcliffe Efficiency. It ranges from one to infinity. It is used to determine the scale of variance in comparison to measured data variance (Nash and Sutcliffe, 1970). This performance index betterunderstanding how the observed & simulated values seamlessly fit linearly. The NSE was worked out with following equation.

$$\text{Nash} - \text{Sutcliffe Ef iciencies(NSE)} = 1 - \frac{\sum_{i=1}^{n}((Q_i)_{obs} - (Q_i)_{sim})^2}{\sum_{i=1}^{n}((Q_i)_{obs} - (\bar{Q})_{obs})^2}$$

Where,

$(Q_i)_{obs} -$ observed discharge at time i, m^3s^{-1}

$(Q_i)_{sim} -$ simulated discharge at time i, m^3s^{-1} -

$(\bar{Q})_{obs} -$ mean observed discharge at time i, m^3s^{-1}

2.5.2 RSR : RMSE - observations standard deviation (SD) ratio

RSR is the ratio between the RMSE to standard deviation (SD). The lower values of RSR shows enhanced model performance. The formula used to compute RSR is given below.

$$RSR = \frac{RMSE}{SD_{obs}} = \frac{\sqrt{\sum_{i=1}^{n}((Q_i)_{obs} - (Q_i)_{sim})^2}}{\sqrt{\sum_{i=1}^{n}((Q_i)_{obs} - (\bar{Q})_{obs})^2}}$$

Where,

$(SD)_{obs} -$ standard deviation of observed values

$(Q_i)_{obs} -$ observed discharge at time i, m^3s^{-1}

$(Q_i)_{sim} -$ simulated discharge at time i, m^3s^{-1} -

$(\bar{Q})_{obs} -$ mean observed discharge at time i, m^3s^{-1}

2.5.3 Coefficient of Determination (R^2)

This parameter is applied to verify the "goodness of fit" among the observed & simulated data sets. The range of R^2 between 0 to 1, good agreement between observed and simulated values when the Coefficient of Determination reaches to 1. The following formula is employed to calculate R^2.

$$R^2 = \frac{\left[\sum_{i=1}^{n}((Q_i)_{obs} - (\bar{Q})_{obs})((Q_i)_{sim} - (\bar{Q})_{sim})\right]^2}{\sum_{i=1}^{n}((Q_i)_{obs} - (\bar{Q})_{obs})^2 \sum_{i=1}^{n}((Q_i)_{sim} - (\bar{Q})_{sim})^2}$$

Where,

$(Q_i)_{obs}$ and $(Q_i)_{sim}$ observed and simulated discharges respectively, in m^3s^{-1}

$(\bar{Q})_{obs}$ and $(\bar{Q})_{sim}$ $mean$ observed and mean simulated discharges respectively, in m^3s^{-1}

2.5.4 Per cent Bias (PBIAS)

The Percent Bias determines the tendency of predicted data as larger or smaller when compared to measured data. The optimal value of PBIAS is zero that shows more precise simulation. Positive value of PBIAS shows under assessment and negative value shows over assessment by model (Moriasi, *et al*., 2007). PBIAS evidently indicates under performance of model (Gupta *et al*., 1999).

$$PBIAS = 100 * \frac{\sum_{i=1}^{n}((Q_i)_{obs} - (Q_i)_{sim})}{\sum_{i=1}^{n}(Q_i)_{obs}}$$

Where,
$(Q_i)_{obs}$ and $(Q_i)_{sim}$ – observed & $simulated\ discharges, respectively, in$ m^3s^{-1}

Table 7 Calibration and validation periods of gauging stations

Sl. No.	Gauging station name	Warmup period	Calibration period	Validation period
1	Kurnudwad	2000-2002	2003-2011	2012-2018
2	Hidkal Dam	2011-2013	2014-2016	2017-2019
3	Malaprabha Dam	2011-2013	2014-2016	2017-2019
4	Almatti Dam	2011-2013	2014-2016	2017-2019
5	Narayanpur Dam	2011-2013	2014-2016	2017-2019
6	Huvenhegdi	2000-2002	2003-2011	2013-2017

Table 8 Performance rating of hydrological models with different indices

Sl. No.	Performance of model	NSE	RSR	R^2	PBIAS
1	Very good	0.75 to 1.0	0.00 to 0.50	0.7 to 1.0	≤ ± 10
2	Good	0.65 to 0.75	0.50 to 0.60	0.6 to 0.7	± 10 to ± 15
3	Satisfactory	0.50 to 0.65	0.60 to 0.70	0.5 to 0.6	±15 to ± 25
4	Unsatisfactory	≤ 0.50	> 0.70	<0.5	≥ ± 25

(Source:Moriasi*et al.*, 2007)

3. RESULTS AND DISCUSSION

Sensitivity analysis

Initially, each parameter behaviour was studied by using "one-at-a time" sensitivity analysis. The global sensitivity analysis was run to know parameters which are more sensitive among the parameters under consideration. . The parameter sensitivity ranking was caried out with t-stat and p-values which gives the same ranking. The sensitivity analysis was done with default range of parameter published in SWAT_CUP. The most sensitive parameters were found to be groundwater delay (GW_DELAY), curve number (CN), hydraulic conductivity of soil (SOL_K);, evaporation soil compensation factor (ESCO) followed by bank storage baseflow alpha factor (ALPHA_BNK), Main channel manning's n value(CH_N2), percolation factor of deep aquifer (Recharge_DP), shallow aquifer's threshold depth of water for "revap" to occur (REVAPMN), alpha factor of base flow (ALPHA_BF), effective hydraulic conductivity of main channel (CH_K2), surface (runoff) lag time (SURLAG), groundwater revap coefficient (GW_REVAP), Threshold depth of water in the shallow aquifer for return flow to occur (GWQMN), soil characteristics such as Bulk density (SOL_BD) and Hydraulic conductivity (SOIL_K). The output of the sensitivity analysis is given in Fig. 8. Sensitivity rankings of Parameters were allotted based on P-value and t-test and are given in the Table 9. Similar outcomes were observed in various studies conducted on river basin of Krishna and same parameters were identified to be sensitive to stream flow (Mudbhatkal*et al.,* 2017; Chanapathi and Thatikonda, 2020). The model response in terms of objective function with several values in the default range of individual parameter was also tested. The above analysis was done with help of dotty plot between parameter values and objective function. Similar kind of analysis was done for all other model parameters which were under consideration. The dotty plots were obtained model calibration with SUFI2 programme and NSE was considered as an objective function (Fig.9). The dotty plots which were achieved in model calibration process with threshold value of NSE with 0.5. The parameter which is ensitive shows a sharp peak to objective values in dotty plots whereas, insensitive parameter indicates scattered distribution of dots.

SWAT Model calibration & validation

SWAT model calibration & validation was executed using mean monthly stream flow. The sensitive parameters which were found in the model sensitivity analysis process were utilized to model calibration process . Initially, the values of selected parameters with default range given in the SUFI2 programme were utilized for model calibration withanr objective function of NSE (Threshold value of 0.5). SWAT-CUP was executed with 500 simulations during the calibration period as given in Table 7. SWAT-CUP recommended parameters with new range that were employed in subsequent iteration again, SWAT-CUP was run with 500 simulations. This procedure was repeated until the model performance was improved and reached predefined threshold values of model performance indices. New parameter range for individual gauging station, viz. Kurnudwad, Hidkal (Ghataprabha) dam, Renukasagar (Malaprabha) dam, Alamatti dam, Narayanpur dam and Huvenhedgi were attained. The parameters with new range which were attained in calibration period were utilized to validate the model for all the above mentioned gauging stations for validation period (Table 6). Gauging station wise parameters fitted values finally are presented in Table 10.

The SWAT model performance at calibration & validation were evaluated with statistical indicators such as NSE, RSR, Coefficient of Determination (R^2) and Percent Bias (PBIAS) as suggested by Moriasi*et al.* (2007). NSE portrays better idea about, how the observed & simulated values seamlessly fit linearly. The coefficient of Determination gives the goodness-of-fit between the observed and simulated data. The PBIAS quantify the tendency

of predicted data as smaller and larger when compared to the observed data. Several researchers used these performance indices &evaluated SWAT model performance (Perrin *et al*. 2012, Singh *et al*., 2013, Kulkarni *et al*., 2014, Mudbhatkal, *et al*, 2017, Chanapathi and Thatikonda 2020).
The model performance indices during calibration & validation are given in Table 11. It was detected from the outcome that the model could able to simulate stream flows at various gauging stations. In calibration and validation process, model estimated runoff flows within acceptable range of performance indices which were mentioned above.

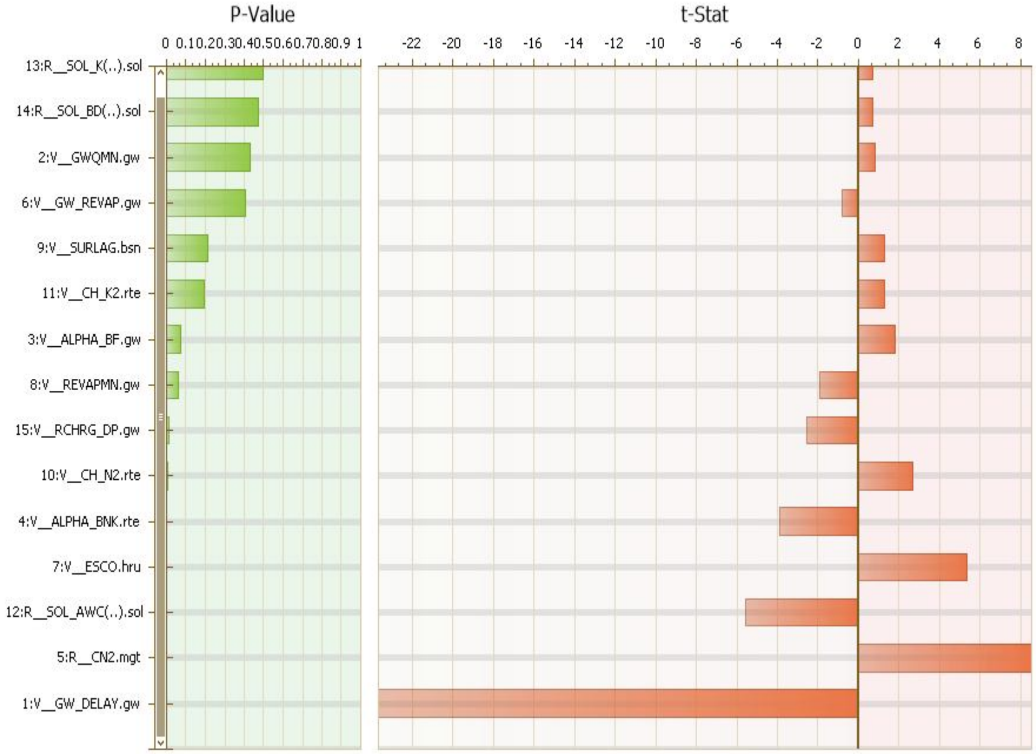


Fig. 8 Sensitivity analysis of model parameters

Table 9 P-value and t-test of sensitivity analysis for model parameters

Sl. No.	Parameter Name	P-Value	t-Stat	Ranking
1	1:V__GW_DELAY.gw	0.00	-23.67	1
2	5: R__CN2.mgt	0.00	8.53	2
3	12: R__SOL_AWC.sol	0.00	-5.55	3
4	7: V__ESCO.hru	0.00	5.37	4
5	4: V__ALPHA_BNK.rte	0.00	-3.91	5
6	10: V__CH_N2.rte	0.01	2.67	6
7	15: V__RCHRG_DP.gw	0.01	-2.54	7
8	8: V__REVAPMN.gw	0.06	-1.90	8
9	3: V__ALPHA_BF.gw	0.07	1.80	9
10	11: V__CH_K2.rte	0.20	1.30	10
11	9: V__SURLAG.bsn	0.21	1.26	11

12	6: V__GW_REVAP.gw	0.41	-0.83	12
13	2: V__GWQMN.gw	0.43	0.79	13
14	14: R__SOL_BD.sol	0.47	0.72	14
15	13: R__SOL_K.sol	0.50	0.68	15

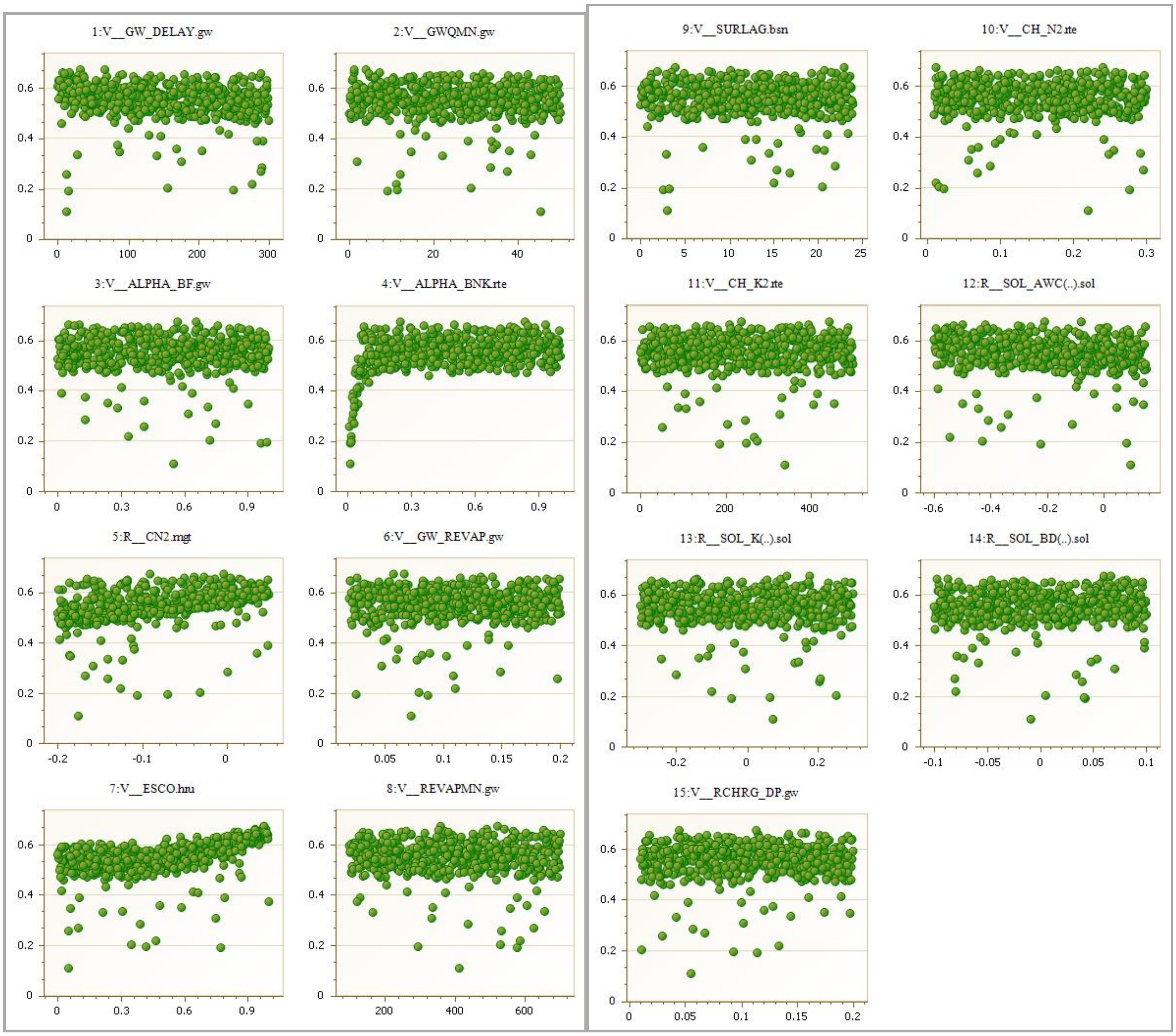


Fig. 9 Dotty plots of SWAT parameters range against the objective function of NSE

Table 10 Sensitive parameters absolute SWAT values range and final fitted values of six gauging stations

Sl. No.	Parameters	Default range	Parameters fitted values					
			Kurundwad	Ghataprabha	Malaprabha	Almatti	Narayanpur	Huvenhedgi
1	v__GW_DELAY.gw	0-500	131.250	34.168	67.500	270.000	54.500	106.412
2	v__GWQMN.gw	0-5000	1.289	41.658	1.050	0.500	2.975	8.992
3	v__ALPHA_BF.gw	0.01-1	0.052	0.492	0.657	0.048	0.756	0.395
4	v__ALPHA_BNK.rte	0.01-1	0.248	0.813	0.249	0.588	0.249	0.165
5	r__CN2.mgt	-0.2-0.2	0.035	-0.005	-0.004	-0.135	-0.111	-0.020
6	v__GW_REVAP.gw	0.02-0.2	0.194	0.158	0.067	0.189	0.064	0.209
7	v__ESCO.hru	0-1	0.851	1.009	0.979	0.624	0.842	0.336
8	v__REVAPMN.gw	0-500	281.856	302.918	359.800	270.000	337.500	314.638
9	v__SURLAG.bsn	0.05-24	6.791	3.492	23.016	7.840	6.122	5.308
10	v__CH_N2.rte	0.01-0.3	0.044	0.035	0.012	0.039	0.275	0.224
11	v__CH_K2.rte	0.01-500	118.559	236.472	443.501	24.000	154.000	457.896
12	r__SOL_AWC(1).sol	0-1	-0.203	-0.472	-0.210	-0.240	-0.006	-0.201
13	r__SOL_K(1).sol	0-2000(a)	-0.217	0.044	0.178	-0.080	-0.175	-0.227
14	r__SOL_BD(1).sol	0.9-2.5(a)	-0.007	-0.012	0.067	-0.080	-0.085	-0.100
15	v__RCHRG_DP.gw	0-1	0.067	0.025	0.113	0.191	0.079	0.093

Note: r = existing value of parameter is multiplied by (1 + given value)
v = existing value of parameter to be replaced by the given value.

Kurundwad Gauging station:

During the calibration period, performance of the model was good at Kurundwad station during calibration period. It was found that NS, RSR and R^2, with 0.68, 0.56 and 0.84 respectively. The results were satisfactory in terms of PBIAS (24%) and results were within the acceptable range. It was comprehended that that runoff was underestimated by this model with 24%. Subsequently, the model enhanced the results during validation period and found to be decreased PBIAS from 24.0% to 11.5% which shown that the model was good at PBIAS. The model performance indices such as NS, RSR and R^2 also showed that the performance of the model was good during validation period.

Ghataprabha (Hidkal Dam)

The model was found to be performed very-good during the periods of calibration and validation. During validation period -, the model also enhanced its capability to simulate the stream flow . However, during calibration & validation period, the model outcomes were slightly under estimated. when compared to observed stream flow. The performance indices during model calibration period viz., NS, RSR, R^2 andPBIAS were observed as 0.76, 0.49 0.84, and 23.80 respectively. The values of NS, RSR, R^2 and PBIAS in validation period were found to be 0.83, 0.41 0.93 and 22.90 respectively.

Malaprabha Dam

During calibration and validation period, the model capability at Malaprabha dam was found to be good. Ub terms of PBIA, model performed very good. The values of NS, RSR, R^2 andPBIAS were 0.67, 0.57, 0.78 and 3.2 respectively, during calibration period. The model improved its avility particularly in terms of NS, RSR and R^2 values with 0.73, 0.52, 0.85 and 10.40.

Almatti Dam

The model fpund to be performed well during calibration further, improved its capability during validation period. Simulated stream flow was slightly overestimated during model calibration period and underestimated during model validation period. The performance indices such as NS, RSR, R^2, and PBIAS during model calibration period were calculated as 0.67, 0.57, 0.70 and -12.6 respectively. T The values of NS, RSR, R^2 and PBIAS were 0.79, 0.45, 0.85 and 12.00 respectively, during model validation period.

Narayanpur Dam

During calibration & validation periods of the model, performance indices such as NS, RSR, R^2 and PBIAS were found to be 0.72, 0.53, 0.74, and -11.7 respectively. and 0.75, 0.69, 0.55 and 8.5 respectively. The performance indicators discovered that the model was performed good in both calibration &validation periods with reference to , R^2 and RSR. The model performed was found to be very good with reference to PBIAS during both calibration & validation periods.

Huvengedgi gauging station

Huvengedgi stream flow gauging station is located at the main outlet. Area under study. The model performance was satisfactory in both calibration & validation period. The performance indices such as NS, RSR, R^2 and PBIAS were 0.56, 0.66 0.64 and -3.70 respectively, during calibration and 0.58, 0.60, 0.60and 23.30 respectively, during validation period.

Many researchers reported similar results in their study carryout on Krishna basin and certain parts of Krishna basin of India. Kulkarni *et al*. (2014) stated that performance of SWAT model in terms of statistical indices for Krishna basin such as NS and R^2 were 0.82 and 0.72 for model calibration period and 0.79 and 0.69 for model validation period. Patil *et al.* (2018) established SWAT model for Malaprabha sub catchment and found that NS and R^2 values were 0.69 and 0.67 during calibration 0.60 and 0.67 during validation. In another study, Mudbhatkal*et al.*, (2017) SWAT model was set up for Malaprabha sub-basin and found that NSE and R^2 of 0.82 and 0.83 respectively, during calibration and 0.85 and 0.83 respectively, during for validation periods of model. Chanapathi and Thatikonda (2020) also conducted a study in Krishna basin and found that the model performance indicators NSE and R^2 for Krishna Basin were 0.61 and 0.63 during SWAT model calibration period and 0.56 0.61 during validated period shown satisfactory results in agreement with Moriasi*et al.* (2007).

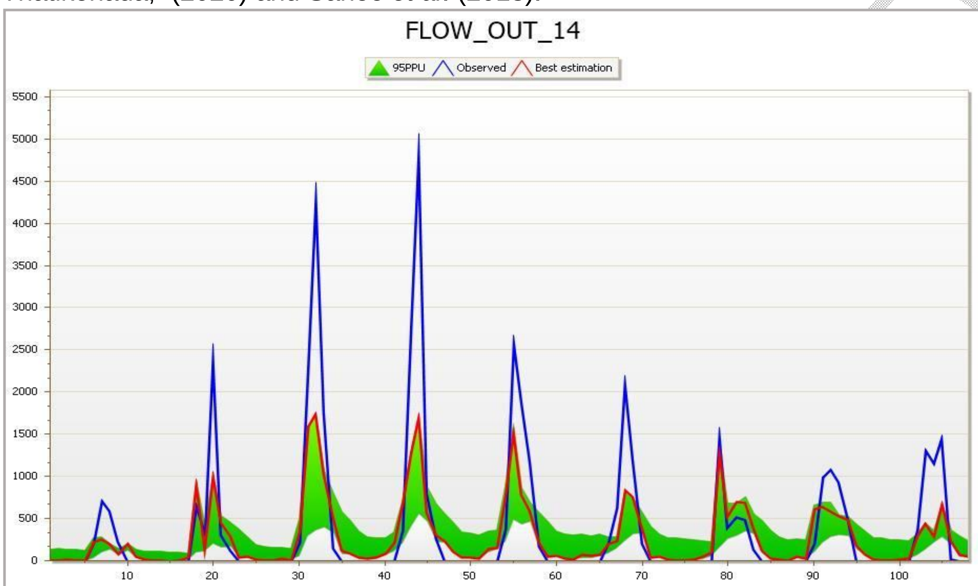
Its was also observed that the SWAT model was performed well for the gauging station viz. Kurundwad and Ghataprabha gauging station which are located at up stream side of the study area. While calibrating thedown stream side gauging stations such as Narayanpur and Huvengedgi gauging station, uncertainty in performance has increased as the uncertainty presented in the parameters of upstream side cathment area added to the uncertainty presented in the down stream side catchment areas.

Table 11 Performance indices of the model during calibration and validation period

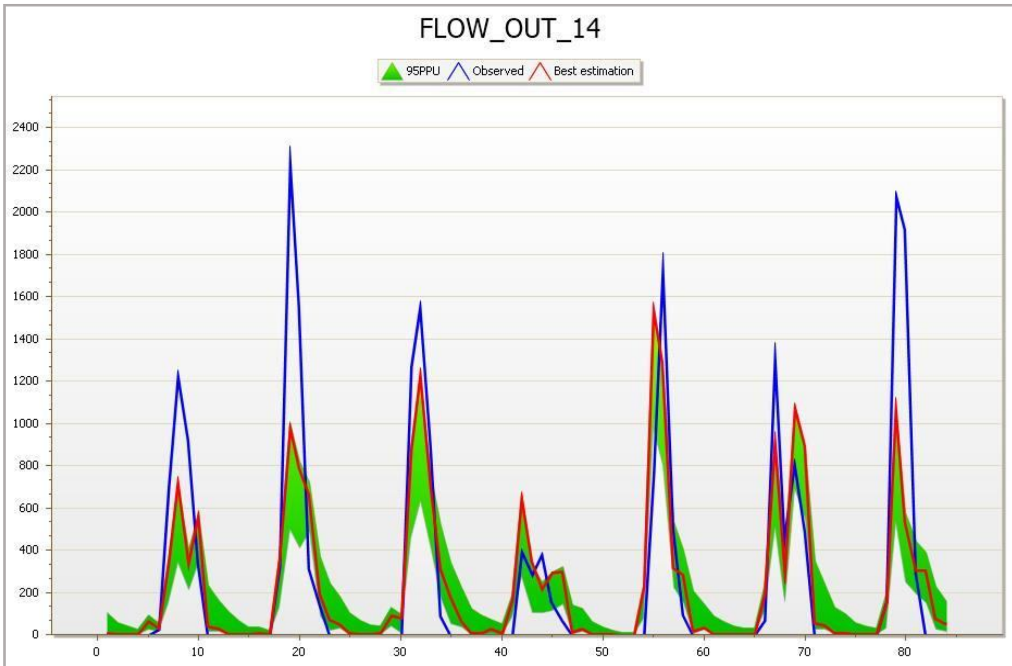
Station Name	Period	p-factor	r-factor	R^2	NS	RSR	PBIAS
Kurundwad							
Calibration	2003-2011	0.35	0.39	0.84	0.68	0.56	24
Validation	2012-2018	0.34	0.33	0.7	0.67	0.58	11.5
Ghataprabha (Hidkal dam)							
Calibration	2014-2016	0.43	0.23	0.84	0.76	0.49	23.8
Validation	2017-2019	0.39	0.14	0.93	0.83	0.41	22.9
Malaprabha Dam							
Calibration	2014-2016	0.44	0.29	0.78	0.67	0.57	3.2
Validation	2017-2019	0.47	0.34	0.85	0.73	0.52	10.4
Almatti Dam							
Calibration	2014-2016	0.39	0.71	0.70	0.67	0.57	-12.6
Validation	2017-2019	0.31	0.10	0.85	0.79	0.45	12
Narayanpur Dam							
Calibration	2014-2016	0.45	0.48	0.74	0.72	0.53	-11.7
Validation	2017-2019	0.37	0.33	0.75	0.69	0.55	8.5
Huvengedgi							
Calibration	2003-2011	0.36	0.20	0.64	0.56	0.66	-3.7
Validation	2013-2017	0.35	0.38	0.60	0.58	0.60	-23.3

The graphs between measured stream flow, simulated stream flow with 95 Percent Prediction Uncertainty (PPU) for the both calibration & validation periods which are depicted in Fig. 10 & Fig. 11 for the stream gauging stations located at Kurundwad&Huvenhedgi respectively. The above plots indicated that the model was incapable to predict the peak flows. The stream flow with low and medium magnitude were well simulated using the model, however, peak flows were found to be underestimated in most of the instants. Similar results were reported in a study and reported that SWAT model was inability to predict extreme events further underestimates the peak runoff flows as it involves uncertainty in several parameters (Tolson and Shoemaker, 2004).

The model uncertainty analysis during calibration &validation were measured with "p-factor and r-factor" (Abbaspour *et al*. 2007). The r-factor with uncertainty range was calculated between 0.31 to 0.49, and p– factor was calculated in between 0.10 to 0.71. Uncertainty analysis for observed & simulated monthly flows (95 PPU) are presented in Fig. 12 to Fig. 15. The deviation in the model performance and uncertainty might be because of uncertainty in grided (0.25° x 0.25°) rainfall data and gridded temperature data (1° x 1°) that were calculated from meteorological stations and uncertainty presented in spatial data such as soil characteristics and land use & land cover. Further, the present study based on only 4 major storage reservoirs and dams for setting up of SWAT model that resulted additional uncertainty in the model output. Water storage structures in the study area substantially impact the model output and model performance as reported by Chanapathi and Thatikonada, (2020) and Sahoo *et al*. (2018).

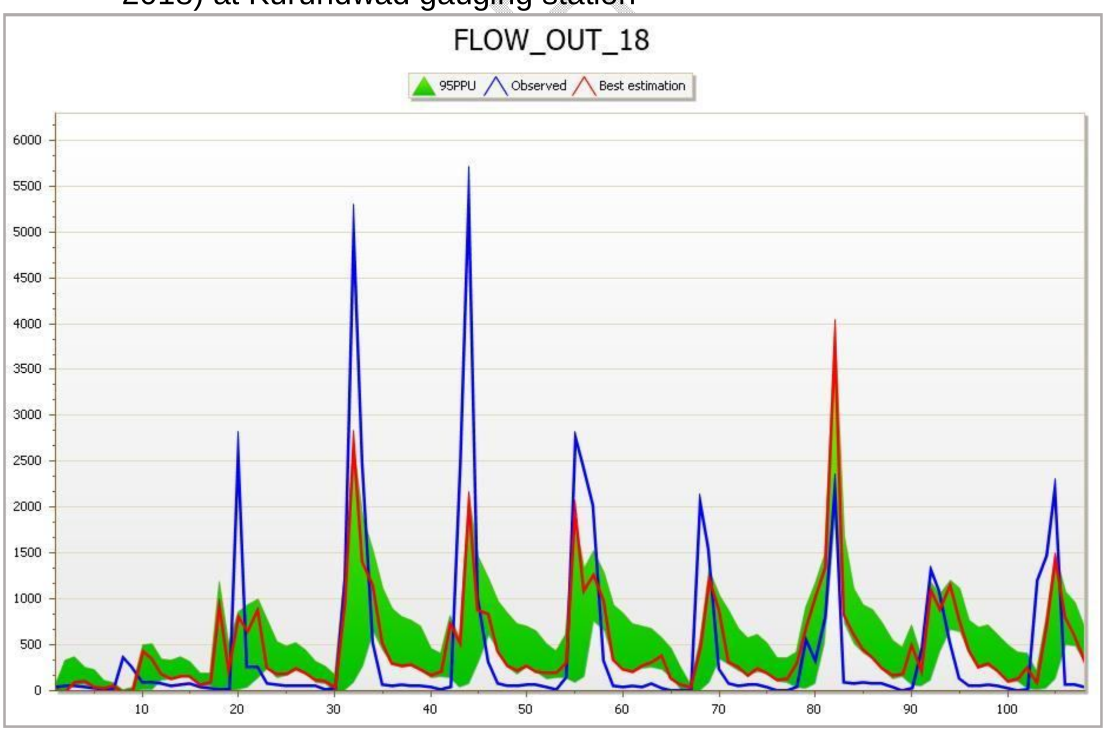


(a)

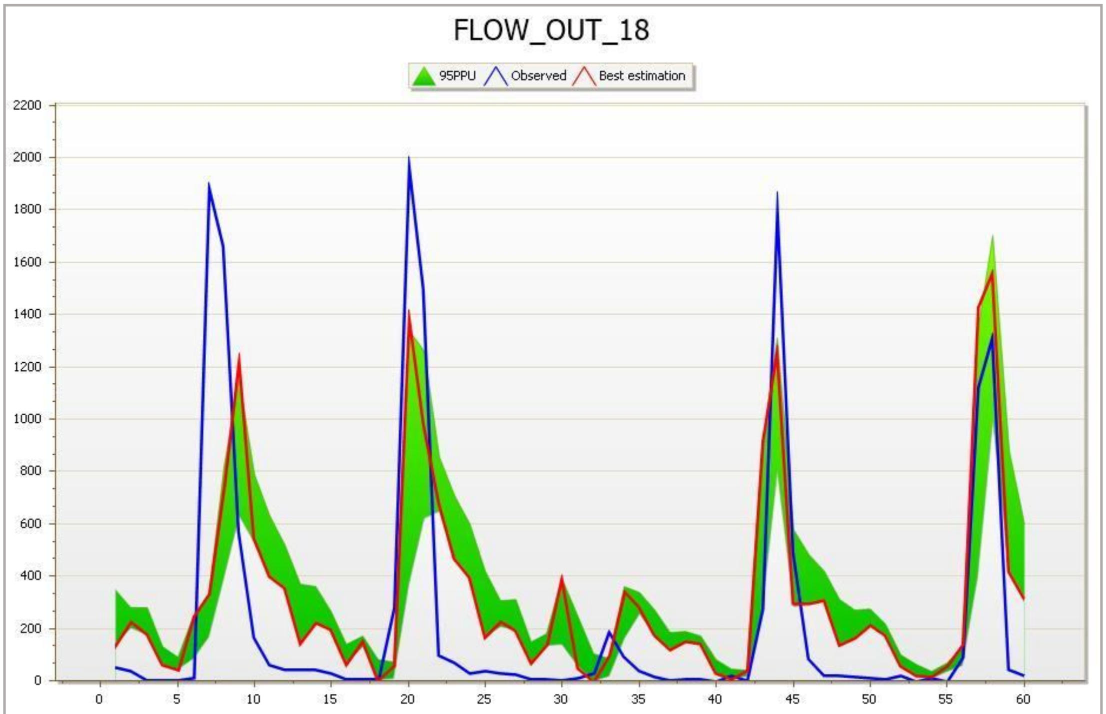


(b)

Fig. 10 Observed, simulated stream flow and 95 % probability uncertainty plot during (a) calibration (2003–2011) and (b) validation (2012–2018) at Kurundwad gauging station



(a)



(b)

Fig. 11 Observed, simulated stream flow and 95 % probability uncertainty plot during (a) calibration (2003–2011) and (b) validation (2013–2017) at Huvenhedgi gauging station.

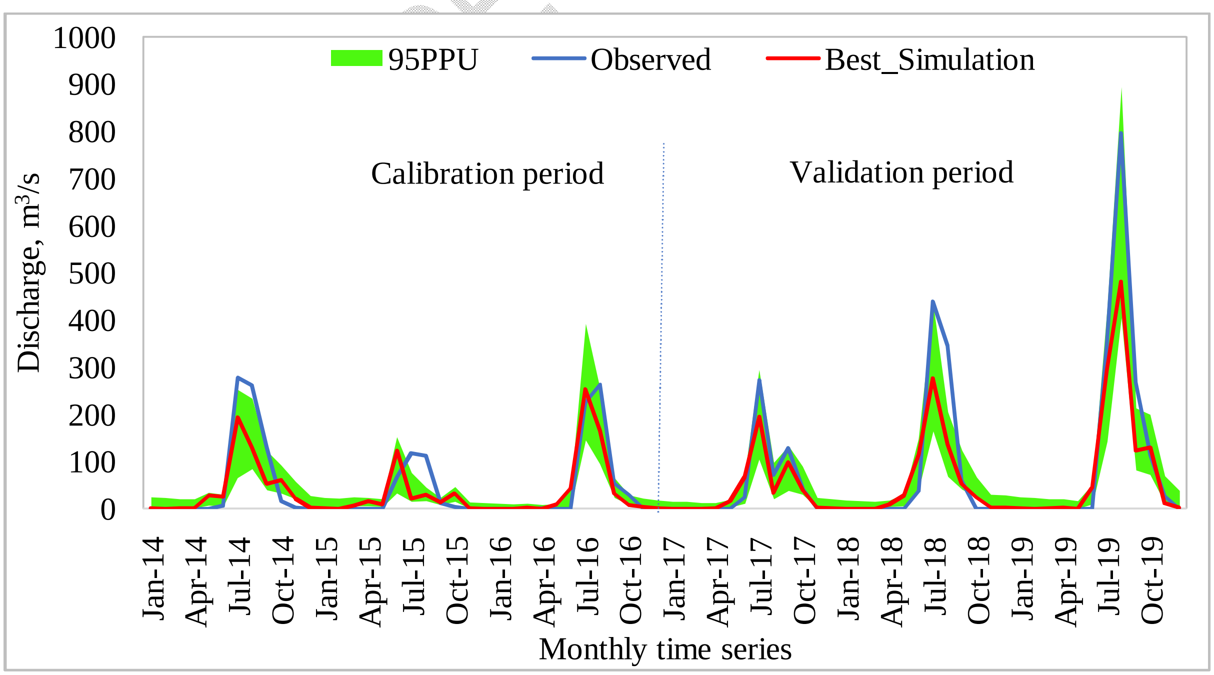


Fig. 12 Observed, simulated stream flow and 95PPU during calibration and validation period at Ghataprabha (Hidkal) dam gauging station

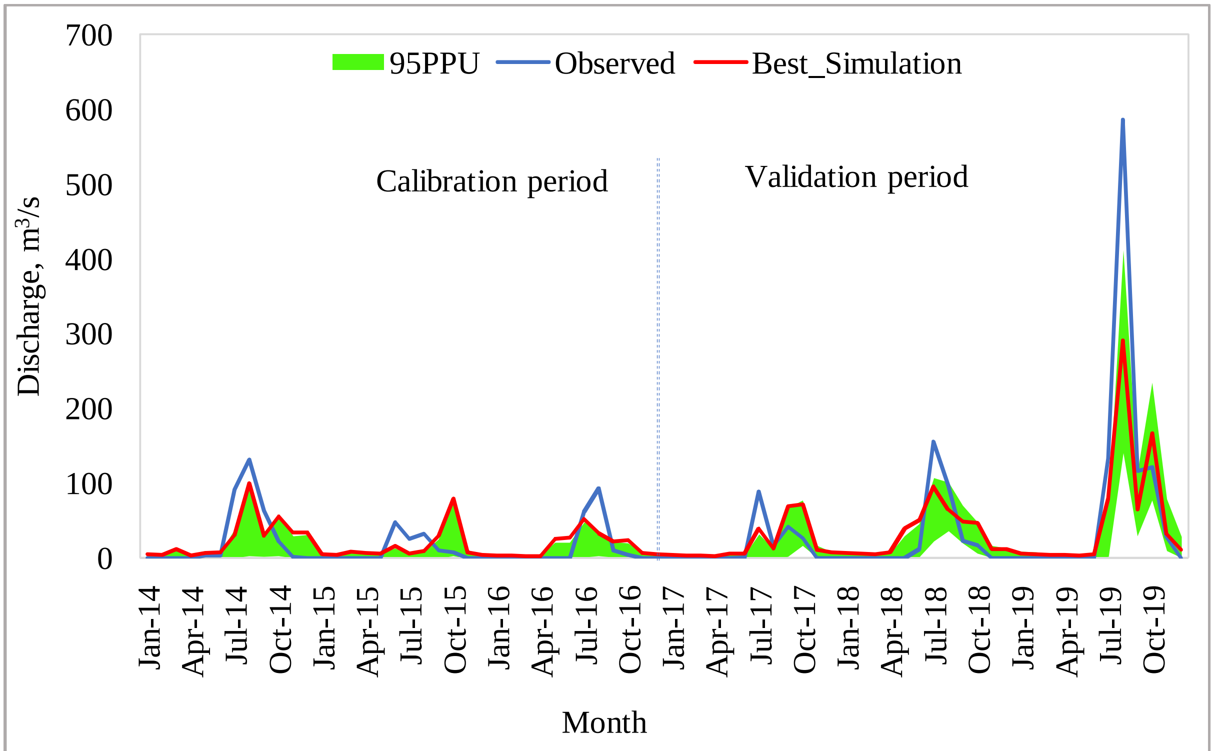


Fig. 13 Observed, simulated stream flow and 95PPU during calibration and validation period at Malaprabha (Renukasagar) dam gauging station

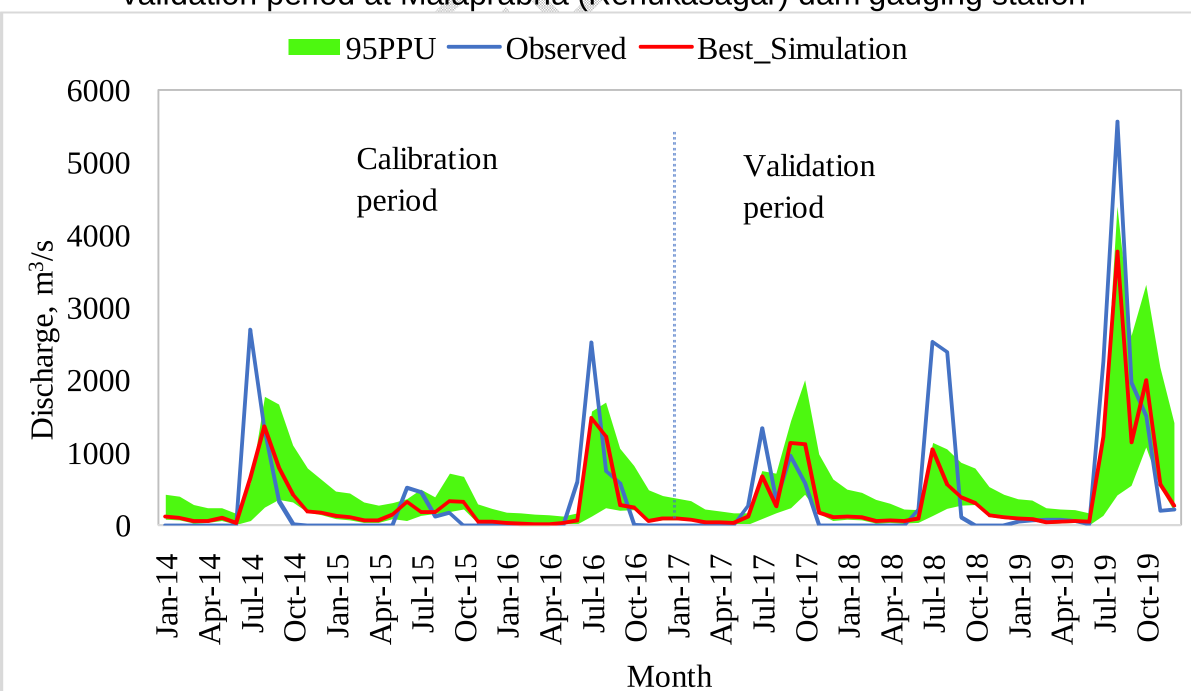


Fig. 14 Observed, simulated stream flow and 95PPU during calibration and validation period at Almatti dam gauging station

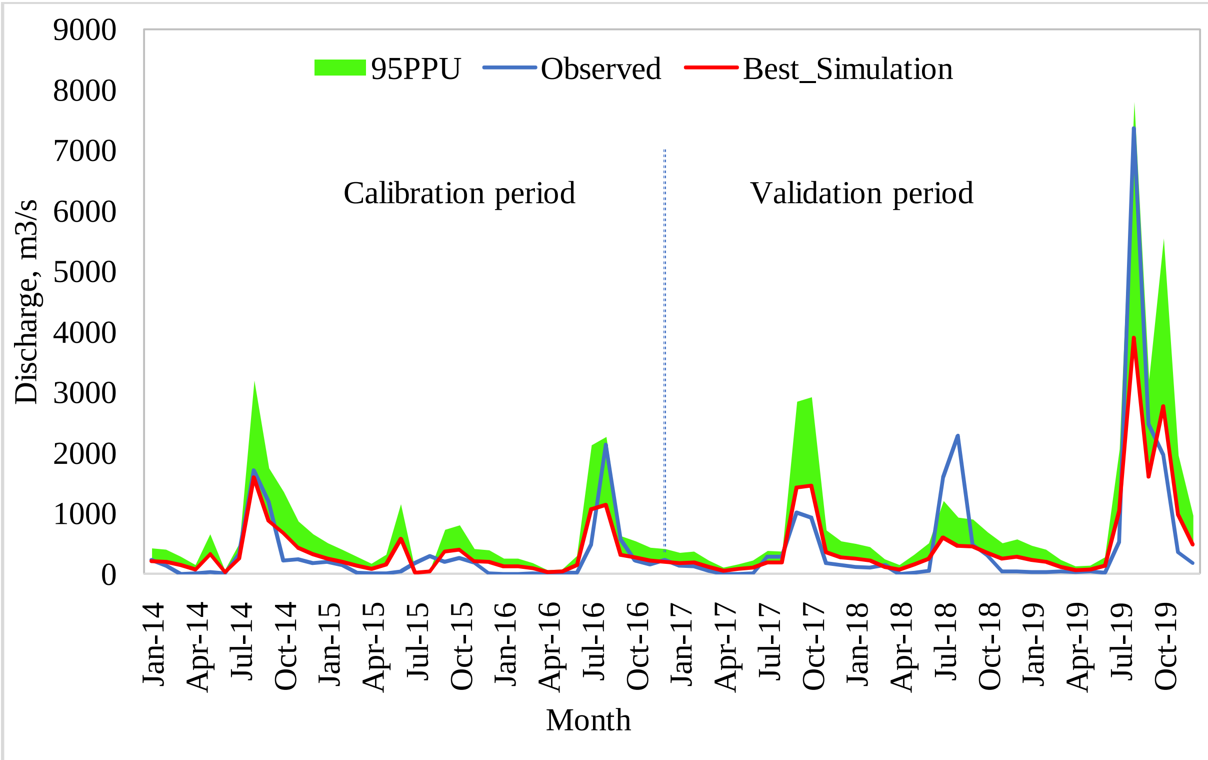


Fig. 15 Observed, simulated stream flow and 95PPU during calibration and validation period at Narayanpur dam gauging station

4.3 Water balance with SWAT model

After calibrated and validated of SWAT model, the model was utilized for the period of year 1991 to 2019 on daily time step and the results were aggregated to monthly basis. The water balance components viz. such as rainfall, surface flow, subsurface flow (later flow), evapotranspiration, and groundwater flow were averaged at whole study area level also. The estimated monthly water budgeting (components) were plotted the period from 1991 to 2019. (Fig. 16). The monthly rainfall received on August, 2019 and was maximum with 299 mm. Out of which, surface runoff & groundwater flow were 165 & 47 mm respectively. Water yield during above period was found to be 207 mm. During April 2018, monthly evapotranspiration was estimated as 72 mm which was observed to be maximum during period 1991 to 2019.

The average monthly & seasonal water balance components for the study area was also estimated for the period 1991 to 2019. The mean monthly rainfall received in the month of July was found to be maximum with 152 mm. The mean monthly surface runoff in July with 46 mm found to be maximum. During September, water yield was found to be maximum with 65 mm against mean rainfall of 112 mm. It was found that contribution of groundwater flow to water yield was maximum in the month of September with 25 mm. It was also observed that contribution of lateral flow was negligible which ranged from 0-2.7 mm. Average potential evapotranspiration (PET) was found to be maximum in the month of May with magnitude of 199 mm followed by March and April. During month of August, mean monthly PET was found to be low with 96 mm.

The mean rainfall in monsoon season was 537 mm. Surface runoff; groundwater flow and evapotranspiration were found to be 144, 50 and 190 mm respectively. The mean PET in pre-monsoon season was observed as 588 mm. The seasonal mean average actual evapotranspiration was found to be highest during monsoon season with 190 mm and followed by pre-monsoon period with 97 mm.

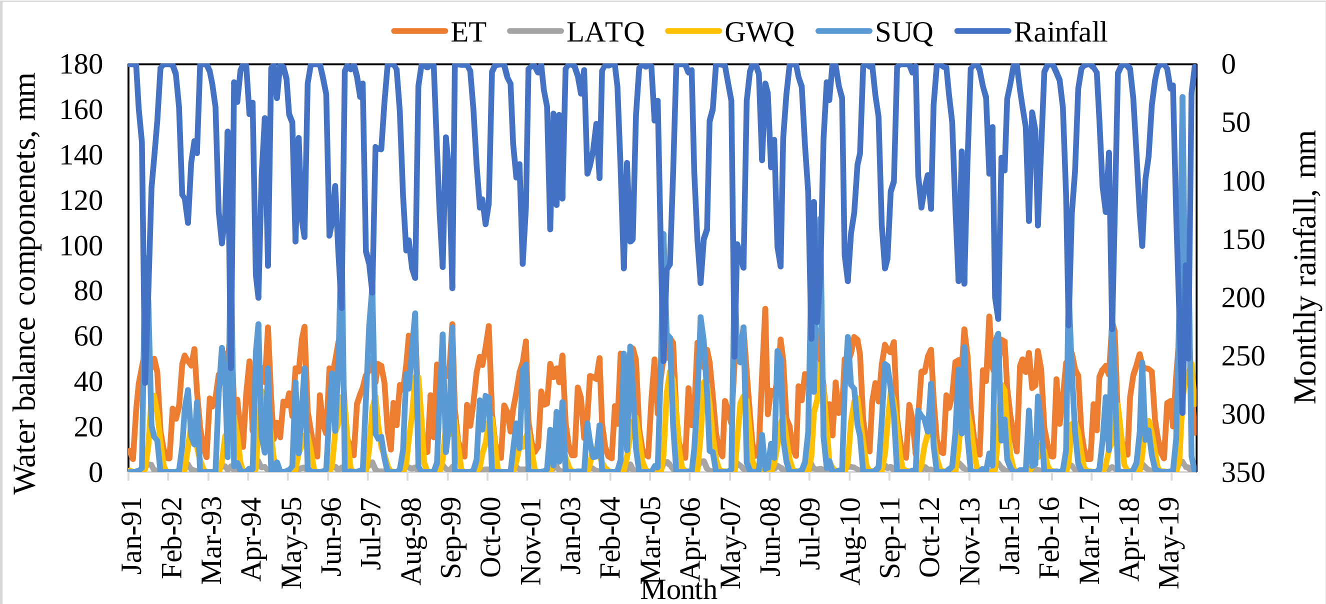


Fig. 16 Monthly water balance components (in mm) of study area from the year 1991-2019

4. CONCLUSION

SWAT-CUP was used to simulate historical streamflow on a monthly basis for multi-site calibration and validation of the SWAT model. SUFI-2 algorithm embedded in the SWAT-CUP was applied for sensitivity and uncertainty analysis, and calibration and validation of SWAT model. It was concluded that SWAT model can be employed to simulate the water availability and other components of water balance in study area further this model can be utilized to evaluate the spatial variability in various components of water balance within the study area.

SWAT model performed well with refence to the performance indices for all the stream gauging stations. The performance indices viz NSE, RSR, $R^2$and PBIAS were ranged from 0.67 to 0.76, 0.49 to 0.57, 0.70 to 0.84and -11.7 to 24.0% respectively, during the calibration period and 0.67 to 0.83, 0.41 to 0.58, 0.70 to 0.93, and 8.5 to 22.9% respectively, during validation period. After calibration and validation of SWAT model, the same model was used to simulate inflows to the reservoirs/dams in the study area which were under consideration. It was concluded that good agreement between observed and simulated flows for all the gauging stations. Uncertainty in parameters values which influence the model performance can be reduced through multisite calibration and improve the hydrological model performance

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1.

2.

3.

REFERENCES

Abbaspour, K. C., Rouholahnejad, E., Vaghefi, S., Srinivasan, R., Yang, H., and Kløve, B., 2015, A continental-scale hydrology and water quality model for Europe: Calibration and uncertainty of a high-resolution large-scale SWAT model. *Journal of Hydrology,* 524:733-752. doi:10.1016/j.jhydrol.2015.03.027.

Abbaspour, K. C., Yang, J., Maximov, I., Siber, R., Bogner, K., Mieleitner, J., Zobrist, J. and Srinivasan, R., 2007, Spatially distributed modelling of hydrology and water quality in the Pre-Alpine/Alpine Thur watershed using SWAT. *Journal of Hydrology*, 333(2): 413-430.

Anand, J., Gosain, A. K. and Khosa, R., 2018, Prediction of land use changes based on Land Change Modeler and attribution of changes in the water balance of Ganga basin to land use change using the SWAT model. *Science of Total Environmental*, 644: 503-519.

Arnold, J. G., Srinivasan, R., Muttiah, R. S. and Williams, J. R., 1998, Large area hydrologic modeling and assessment part i: model development. *Journal of American Water Resources Association,* 34(1):73–89. doi:10.1111/j.1752-1688.1998.tb05961.x.

Ayivi., F. and Jha, M. K., 2018, Estimation of water balance and water yield in the Reedy Fork-Buffalo Creek Watershed in North Carolina using SWAT. *International Soil and Water Conservation Research,* 6:203-213.

Biggs, T., Gaur, A., Scott, C., Thenkabail, P., Gangadhara Rao, P., Gumma, M. K., Acharya, S. and Turral, H., 2007, *Closing of the Krishna Basin: Irrigation, streamflow depletion and macroscale hydrology* (Vol. 111). IWMI.

Central Water Commission (CWC), 2021, Water resources at glance 2021, Central Water Commission, Ministry of water resources, Govt. of India, accessed on 19th August, 2021, http://www.cwc.gov.in/sites/default/files/registered-water-resources-glance-2021.pdf.

Chanapathi, T., Thatikonda, S. and Srinivasan, R., 2018, Analysis of rainfall extremes and water yield of Krishna River basin under future climate scenarios. *Journal of Hydrology*, 19: 287-306.

Chanapathi, T. and Thatikonda, S., 2020. Investigating the impact of climate and land-use land cover changes on hydrological predictions over the Krishna river basin under present and future scenarios. *Science of the Total Environment*, *721*, p.137736.

Chiew, F., Zheng, H., and Potter, N., 2018, Rainfall-Runoff modelling considerations to predict streamflow characteristics in ungauged catchments and under climate change. *Water,* 10(10): 1319. doi:10.3390/w10101319.

Food and Agriculture Organization, 2021, W*orld water resources by country,* accessed on 19th of August 2021, http://www.fao.org/3/y4473e/y4473e08.htm

Gosain, A. K., Rao, S. and Basuray, D, 2006, Climate change impact assessment on hydrology of Indian river basins, *Current Science*, 90(3): 346-353.

Gupta, H.V., Sorooshian, S. and Yapo, P.O., 1999. Status of automatic calibration for hydrologic models: Comparison with multilevel expert calibration. *Journal of hydrologic engineering*, *4*(2), pp.135-143.

Halwatura, D. and Najim, M. M. M., 2013, Application of the HEC-HMS model for runoff simulation in a tropical catchment. *Environmental Modelling & Software*, 46: 155-162.

Jain, S.K., 2019, Water resource management in India–challenges and the way forward. *Current Science*, 117(4): 569-576.

Jain, S.K., 2021, A perspective on water security in India, *Current Science*, 120(1): 7-8.

Jang, S., Cho, M., Yoon, J., Yoon, Y., Kim, S., Kim, G., Kim, L. and Aksoy, H., 2007, Using SWMM as a tool for hydrologic impact assessment. *Desalination*, 212(1-3): 344-356.

Jimeno-Sáez, P., Senent-Aparicio, J., Pérez-Sánchez , J. and Pulido-Velazquez, P., 2018, A comparison of SWAT and ANN models for daily runoff simulation in different climatic zones of peninsular Spain. *Water,* 10(192): 1-19.

Jothiprakash, V., Praveenkumar, C. and Manasa, M., 2017, Daily runoff estimation in Musi river basin, India, from gridded rainfall using SWAT model. *European Water*, 57: 63-69.

Kulkarni, B. D., Deshpande, N. R., Patwardhan, S. K. and Bansod, S. D., 2014, Assessing hydrological response to changing climate in the Krishna basin of India. *Journal of Earth Science & Climate Change,* 5(7):211, Doi:10.4172/2157-7617.1000211.

Kumar, R., Singh, R, D. and Sharma K. D., 2005, Water resource of India. *Current Science,* 89(5):794-811.

Maliehe, M. and Mulungu, D. M. M., 2017, Assessment of water availability for competing uses using SWAT and WEAP in South Phuthiatsana catchment, Lesotho. *Physics and Chemistry of the Earth*,100: 305-316.

Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L., Harmel, R.D. and Veith, T.L., 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transactions of the ASABE*, *50*(3), pp.885-900.

Mudbhatkal, A., Raikar, R.V., Venkatesh, B. and Mahesha, A., 2017. Impacts of climate change on varied river-flow regimes of southern India. *Journal of Hydrologic Engineering*, *22*(9), p.05017017.

Nash, J.E. and Sutcliffe, J.V., 1970. River flow forecasting through conceptual models part I—A discussion of principles. *Journal of hydrology*, *10*(3), pp.282-290.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R. and Williams, J.R., 2011. *Soil and water assessment tool theoretical documentation version 2009*. Texas Water Resources Institute.

Pai, D. S., Sridhar, L., Rajeevan, M., Sreejith, O. P., Satbhai, N. S. and Mukhopadyay, B., 2013, Development of a new high spatial resolution (0.25° × 0.25°) Long Period (1901-2010) daily gridded rainfall data set over India and its comparison with existing data sets over the region. *Mausam*, 65(1):1-18.

Panda, Ch., Das, D. M., Sahii, B.C., Phanigrahi, B. and Singh, K. K., 2021, Spatio-temporal modeling of surface runoff in ungauged sub-catchments of Subarnarekha river basin using SWAT. *Mausam*, 72 (3): 597-606.

Patil, N. S., Nataraja, M. and Omprakash, T, 2018, Evaluation of hydrological components using hydrological model SWAT for Malaprabha subbasin. *Journal of Geological Society of India.*, 92:195-200.

Perrin, J., Ferrant, S., Massuel, S., Dewandel, B., Maréchal, J. C., Aulong, S. and Ahmed, S., 2012, Assessing water availability in a semi-arid watershed of southern India using a semi-distributed model. *Journal of Hydrology*, 460-461: 143-155.

Phinyoyang, A. and Ongsomwang, S., 2021. Optimizing Land Use and Land Cover Allocation for Flood Mitigation Using Land Use Change and Hydrological Models with Goal Programming, Chaiyaphum, Thailand. *Land*, *10*(12), p.1317.

Rao, I.B., Nemichandrappa, M., Rao, K.V., Polisgowdar, B.S., Reddy, G.V., Sreenivas, A.G. and Ajayakumar, M.Y., 2021. Effect of climate change on water requirements of crops and adaptative water strategies in Krishna upper Basin. *Indian Journal of Dryland Agricultural Research and Development*, *36*(1), pp.43-57.

Rao, I. B., Nemichandrappa, M., Rao, K.V., Polisgowdar, B.S., Reddy, G.S., Sreenivas, A.G. and Kumar, M.A., 2022. Long term trend analysis of rainfall, maximum and minimum temperature in Krishna upper basin region of India. *The Journal of Research ANGRAU*, *50*(2), pp.60-73.

Rao, I.B., Nemichandrappa, M., Rao, K.V., Polisgowdar, B.S., Reddy, G.V., Sreenivas, A.G. and Ajayakumar, M.Y., 2024. Assessment of Stream Flow of Hidkal Dam Catchment Area in Krishna Basin of India Using SIMHYD Model. *Journal of Geography, Environment and Earth Science International*, *28*(2), pp.11-26.

Sahoo, S., Dhar, A., Debsarkar, A. and Kar, A., 2018, Impact of water demand on hydrological regime under climate and LULC change scenarios. *Environmental Earth Sciences*, 77(9): 1-19.

Shinde, S., Aher, S., Pawar, A. and Kantamaneni, K., 2020, Spatio-temporal variability of discharge over the past 40 Years in Krishna and Koyna Rivers, India. *Iranian Journal of Science and Technology, Transaction of Civil Engineering*, 44(1): 395-407. https://doi.org/10.1007/s40996-020-00375-z

Singh, R. K., Panda, R. K., Satapathy, K. K. and Ngachan, S. V., 2011, Simulation of runoff and sediment yield from a hilly watershed in the eastern Himalaya, India using the WEPP model. *Journal of Hydrology*, 405(3-4): 261-276.

Singh, V., Bankar, N., Salunkhe, S.S., Bera, A. K. and Sharma, J. R., 2013, Hydrological stream flow modelling on Tungabhadra catchment: parameterization and uncertainty analysis using SWAT CUP. *Current Science*, 104(9): 1187-1199.

Srivastava, A. K., Rajeevan, M and Kshirsagar, S. R., 2009, Development of high resolution daily gridded temperature data set (1969-2005) for the Indian Region. *Atmospheric Science Letters*, 10(4): 249-254. DOI: 10.1002/asl.232.

Tolson, B. A. and Shoemaker, C. A. 2007, Dynamically dimensioned search algorithm for computationally efficient watershed model calibration. *Water Resource Research* 43(W01413): 1-13. doi: 10.1029/2005WR004723.

Yazdi, M. N., Ketabchy, M., Sample, D. J., Scott, D. and Liao, H., 2019, An evaluation of HSPF and SWMM for simulating streamflow regimes in an urban watershed. *Environmental Modelling & Software*, 118: 211-225.

Yu, B. and Zhu, Z., 2014, A comparative assessment of AWBM and SimHyd for forested watershed. *Hydrological Science Journal*, Special issues: Modelling Temporally variable Catchment. 60(7-8): 1200-1212. DOI: 10.1080/02626667.2014.961924.

Zhao, J., Zhang, N., Liu, Z., Zhang, Q. and Shang, C., 2024. SWAT model applications: From hydrological processes to ecosystem services. *Science of The Total Environment*, p.172605.