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Comparison of performance of SWAT and SIMHYD models in simulation of stream flow from Hidkal dam catchment area of India under present and future scenarios

I. Bhaskara Rao[1*], K.V. Rao[2], G.V. Srinivasa Reddy[3], M. Nemichandrappa[4], B.S. Polisgowdar[5] and M. Udaya Bhanu[6]

[1*]Agricultural Research Station (ANGRAU), Garikapadu 521 175, NTR District, Andhra Pradesh, India
[2]ICAR-CRIDA, Hyderabad 500 059, Telangana, India
[3]Department of Irrigation and Drainage, College of Agril. Engg., UAS, Raichur, Karnataka, India
[4]Agricultural Engineering, College of Agril. Engg., UAS, Raichur, Karnataka, India
[5]Department of Irrigation and Drainage, College of Agril. Engg., UAS, Raichur, Karnataka
[6]NIPHM, Rajendranagar, Hyderabad 500 030, Telangana, India

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ABSTRACT

A study was conducted to compare the performance of SWAT and SIMHYD models in prediction of stream flow from the catchment of Hidkal dam of Karnataka in India for present and future scenarios. SWAT and SIMHYD models were used for the present study and calibrated with SWAT-CUP and generic algorithm respectively. The performance of models were tested with Nash Sutcliffe Efficiency (NSE), RMSE-observations standard deviation ratio (RSR), Coefficient of Determination (R^2) and Per cent Bias (PBIAS). The SWAT model performed well and very good agreement between monthly observed and simulated stream flows with R^2, NSE, RSR and PBIAS as 0.84, 0.76, 0.49 and 23.8% respectively during calibration periods and 0.93, 0.83, 0.41 and 22.9 % respectively during validation period. SimHYD model also performed well and the NSE and correlation coefficient was found to be 0.77 and 0.93 during calibration period and 0.90 and 0.95 during validation period respectively. This study revealed that both models performed well in simulation of monthly stream flow during calibration and validation periods. The stream flows simulated with SimHYD were compared with stream flows simulated with SWAT model and found that very good agreement between two model outputs. This study concluded that SimHYD model could be used to simulate the stream flow when data limitation.

Key words : *SWAT model, SimHYD, SWAT-CUP, Stream flow*

Introduction

It is well known fact that the climate change alters the rainfall pattern and temperatures along with other weather parameters with respect to time and space. Rainfall characteristics influence the stream flow of a given area. The stream flow can be simulated or modeled with help of hydrological models. These models are the tools that simulate the impact of various geomorphological, weather parameters

([1*]Scientist, [2] Principal Scientist, [3]Associate Prof., [4]Dean, [5]Prof., [6] Scientific Officer)

on the hydrological processes in a watershed or basin. These models may be classified as data driven, conceptual, physical models and further classified as lumped, semi distributed and distributed models based on the spatial attribute data. Fully distributed models are data intensive and lumped models use averaged data of the catchment. Semi distributed models utilise both spatial data and averaged data of catchment.

Fully distributed models require more data and the catchment area with high resolution data can be modeled. Empirical models did not consider the physical processes in the watershed. Semi distributed models can be used in the areas data limitation (Mulligan, 2004). SWAT model is the most commonly used semi distributed, continues time scale hydrological model (Arnold *et al.*, 1998). SWAT model can be used for field scale to basin or regional scale. Hydrological process such as evaporation, infiltration, percolation, plant uptake, lateral and groundwater flows, snowfall and snowmelt are incorporated in the model (Neitsch *et al*., 2005). Simple Hydrology (SIMHYD), a lumped conceptual daily rainfall-runoff model, can be used to simulate runoff from the catchments successfully with limited data (Siriwardena, 2005). SIMHYD model which is frequently used in Australia and Chaina can also be used where limited data is available.

Many studies have been carried out on hydrological modeling of many catchments in India using SWAT model. Hydrological modelling on entire Krishna basin was also conducted by many researchers (Kulkarni *et al.,* 2014; Chanapathi and Thatikonda, 2020). Particularly, the sub-catchments of Krishna such as Tungabadhra (Singh *et al.*, 2013), Bhima (Patil *et al.*, 2014), Musi (Jothiprakash *et al.* 2017), Malaprabha and Netravati (Mudbhatkal *et al.,* 2017; Patil *et al.*, 2018), Very limited studies on SIMHYD model was noticed in India. However, this model is widely used conceptual model in the world. SIMHYD model is also one of the hydrological models to assess the stream flow. Impact of climate change on hydrologic components including evaporation and runoff can be assessed (Chiew *et al.*, 2018; Razaghian, *et al.*, 2018). Alamou *et al.* (2017) used regional climate models and evaluated future water availability in Mekrou catchment under climate change scenarios with the help of rainfall-runoff models including SimHyd.

The climate change impact on stream flow can be modelled with help of climate projections of Global Circulation models (GCMs) of Regional Circulation Models (GCMs). The projected parameters of the different GCMs or RCMs are having some biasness and need to be corrected. The hydrological models which requires more parameters leads to more uncertainty in output and model that requires lees number of parameter leads to less uncertainty in the model output. A study was conducted to compare the predictability of stream flow from Hidkal dam catchment area of Krishna basin in India using semi distributed model (SWAT model) and conceptual model (SIMHYD) under present and future scenarios.An attempt was made in this study to compare the monthly stream flow simulation of SWAT and SIMHYD models for Ghataprabha (Hidkal) dam catchment area. This attempt suggested how best the conceptual lumped model (SIMHYD) can be used in place of SWAT model when resources are limited. SWAT model is a physically based semi distributed model representing hydrological process through physical laws of mass, momentum and conservation of energy. SWAT model considers the spatial variability in land use land cover, soil, slope and climate parameters and requires computational expertise to simulate the hydrological process in a given watershed. SIMHYD model is lumped hydrological model and conceptualize the system based on simplified mathematical equations with a set of interconnected variables used to represent different components of the hydrological process through recharge and depletion. The SIMHYD model is a lumped model that ignores the spatial variability of watershed characteristics. The SIMHYD model strongly depends on observed data, and the output of the model depends on the quality of input data.

Materials and Methods

Study area and data requirement

The present study was conducted in catchment area of Hidkal dam with an area of 1370 km^2situated in Ghatprabha subbasin of Krishna basin in India. It is situated between latitude of 15° 48′ to 16° 8′ N and longitude of 74° 0′ to 74° 40′ E. The elevations of study area ranges from 1049 m to 640 m which reveals that the catchment area is highly undulating and hilly terrain. The rainfall rangesfrom 6250 mm to about 1000 mm and most of the rainfall received during June to September. The annual mean temperature between 20 °C (Tmin) to 40.5 °C (Tmax). The location map of the study area is presented in Fig. 1. The gross storage capacity of Hidkal dam is 1443 M m^3 with irrigated area of 155559 ha.

The rainfall, maximum and minimum temperatures data was downloaded from the Indian Meteorological department website. Daily rainfall data at grid interval of 0.25° x0.25° for 10 years from 2009-2019 (Pai *et al*., 2013) was used. Maximum and minimum temperatures at grid interval of 1 °x1 °for the same years (Srivastava *et al*., 2009) was also used for this study. Digital elevation map of 30 m resolution for the study area was downloaded from United States Geological Survey" (USGS) website; https://earthexplorer.usgs.gov/. Land use land cover data at resolution of 1: 50000 was obtained from National Remote Sensing Centre, India. The soil map of study area was clipped from global soil map from Food and Agriculture Organization(FAO) data sets at a scale of 1:5000000. The major land use in the study area is agriculture and accounted 59.4% of the total study area. The slope map of the study area classified into five classes, i.e. 0-2, 2-5, 5-8, 8-15 and >15% with an occupied area of 8.22, 24.23, 22.94, 29.17 and 15.44 %.The major classes of land use are agriculture, forest and pasture with 59.4, 22 and 10% of the study area (Fig. 2). Stream flow data on daily time step was downloaded from Indian water resource information system website (www.indiawirs.gov.in) from the year (2009-2019). This daily stream flow data was used to calibrate and validate the model outputs.

Hydrological modelling of catchment area of Hidkal dam

In the present study, SWAT and SIMHYD hydrological models were compared to simulate the stream flow from the catchment area of Hidkal Dam from the year 2009 to 2019. These two models have capable of simulate daily inflows from any study area. Initially the models were setup for historical data from 2013-2019 through calibration and validation process, then the models were used to predict the stream flow for future scenarios using projections of climate parameters such as rainfall, maximum and minimum temperatures and keeping the other parameters constant. The simulated stream flow of the two models for future scenarios were

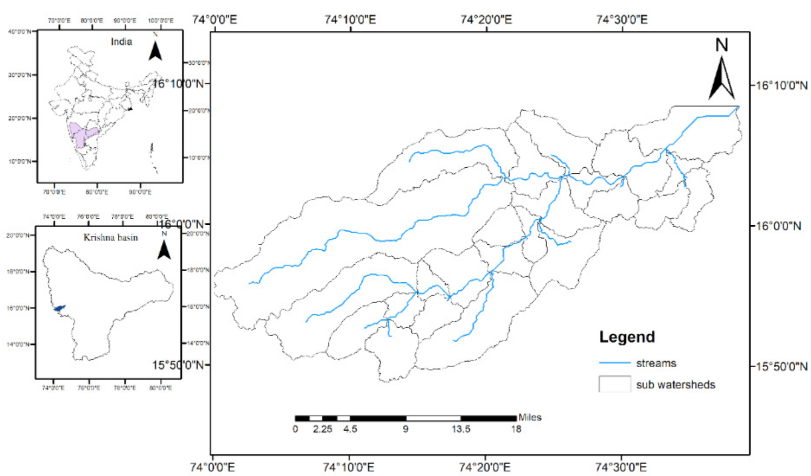

Fig. 1. Location map of study area

Table 1. Input data for SWAT and SIMHYD models

S. No	SWAT model	SIMHYD model	Source
1	Daily Climate data (rainfall, Tmax and Tmin)	Rainfall and temperature data	IMD
2	Daily stream gauging data	Daily stream gauging data	CWC
3	DEM	NA	Earth explorer
4	Soil data	NA	FAO soil base
5	Land use land cover	NA	NRSA
6	Future climate projections from climate models	Future climate projections from climate models	CCCR, IITM

compared with help of statistical parameters to understand the these models behaviors and use of SIMHYD model in data limited conditions.

Model description

SWAT model

SWAT model is a semi-distributed physically based watershed scale continuous model that simulates the effect of land management practices on water, sediment and agricultural chemical yields in un-gauged basins that works on a daily time step (Arnold *et al*., 1998). This model can simulate surface and subsurface flows, pesticide, nutrient and sediment movement in the hydrologic cycle of watershed system. This model was developed to simulate the long-term impact of land management practices on water, sediment movement, pesticide and nutrient yields for un-gauged agricultural watersheds with varying soils and land cover. Various hydrological process, evaporation, infiltration, percolation, plant uptake, lateral and groundwater flows, snowfall and snowmelt are incorporated in the model (Neitsch *et al*., 2005). All these hydrological processes are simulated in surface, soil, and intermediate (vadose) zone, shallow and deep aquifers. Surface runoff volume is estimated by Soil Conservation Society (SCS) Curve Number method. Modified rational method is used to estimate the peak runoff rate from the hydrological unit. Muskingum method is used to calculate the channel flow. The return flow is estimated by kinematic storage model (Arnold *et al*., 1998). Penman Monteith method is used to estimate the potential evapotranspiration. Actual evapotranspiration (AET) is calculated from potential evapotranspiration. The simulation of hydrological process in SWAT model is based on the water balance equation mentioned below.

$$SW_t = SW_0 + \sum_{i=1}^{t} R_{day} - Q_{Surf} - E_a - W_{seep} - Q_{gw}$$

Where,

SW_t is the final soil water content (mm);

SW_0 is the initial soil water content on day i (mm);

R_{day} is the amount of precipitation on day i (mm);

Q_{surf} is the amount of surface runoff on day i (mm);

E_a is the amount of evapotranspiration (ET) on day i (mm);

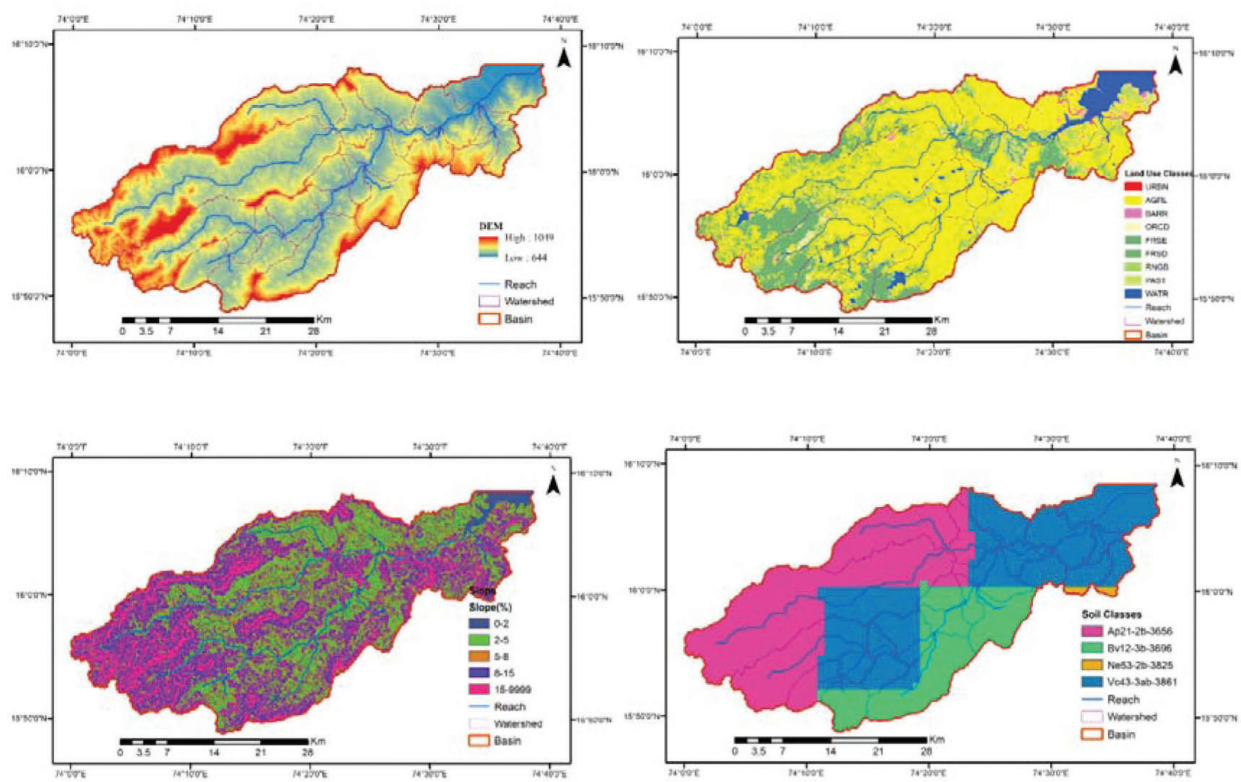

Fig. 2. Study area (a) dem (b) land use land cover (c) soil and (d) slope map

W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm);

Q_{gw} is the amount of return flow on day i (mm).

Digital Elevation Model prepared from SRTM data with 30 m (1 arc second) resolution was used to generate the stream network and delineate sub watersheds of the study area. Land soil data, land use land cover data were reclassified after slope of topography was defined as five classes (0-2, 2-5, 5-10, 10-15 and >15%) and the slope map was reclassified. Hydrological Response Units (HRUs) definition option was used to reduce the number of HRUs with threshold values of land use percentage (10%) soil class percentage (10%) and soil slope percentage (10%). The study area was divided in to 25 sub watersheds and248 HRUs. Weather parameters such as rainfall, maximum and minimum temperatures were written from the data base and other weather parameters were simulated using weather generator in SWAT model. The SWAT model was run from the year 2010 to 2019 with three years of warm up period to simulate the stream flow. The simulations were saved in the data base. The output of the simulations was examined with Run SWAT check point to ascertain the simulation results.

Calibration and validation of SWAT model

SUFI2 programme of SWAT-CUP was used to calibrate and validate the SWAT model using observed stream flow discharge. The SWAT model was calibrated with monthly stream flow from the year 2013-2015 carried out from the year 2013 to 2016 with warmup period of three years (2010-2012) by appropriate selection of input parameter valuesfor model by comparing model predictions (output) with observed data (Arnold *et al*., 2012). The calibrated model was validated for the period of 2017-2019. The parameters were selected based on the sensitivity analysis and the same 15 parameters used for calibration and validation of model. The performance of the model was analyzed during calibration and validation with statistical indices such as Nash Sutcliffe Efficiency (NSE), RMSE-observations standard deviation ratio (RSR), Coefficient of Determination (R^2) and Per cent Bias (PBIAS).

SIMHYD model

SIMHYD is a daily conceptual rainfall-runoff model that uses daily rainfall and potential evapotranspiration data which estimates daily stream flow.It is one of the programmes embedded with Rainfall Runoff Library (RRL), in eWater tool kit developed by University of Canberra, Australia. RRL tool kit is being widely used in Australia and China for rainfall - runoff modelling. The structure of SIMHYDmodel and model parameters and algorithms described in detail in the document are published by Zhang and Chiew (2009).

The model setup was done with the help of the procedure mentioned in the Rainfall Runoff Library user manual (Podger, 2004). SIMHYD model was selected from the list of models given in the Rainfall Runoff Library software of eWater tool kit. The model setup was started with general description of study area and catchment area in km^2. The selected catchment area of Ghataprabha (Hidkal) dam was 1370 km^2 and the same is entered as input to the model. The time series data of daily rainfall (mm/day), daily PET (mm/day) and observed discharge data (m^3/s) from the years 2013-2019 were uploaded in the model. Warmup period for the model was adjusted from 1/1/2013 to 31/12/2013, calibration period was taken from 1/1/2014 to 31/12/2016 and Performance verification (validation) period was adjusted from 1/1/2017 to 31/12/2019 in which 1/1/2017 to 31/12/2017 period was taken as warm period.

SIMHYD model calibration and validation

Initially, the model was auto calibrated with default ranges of all the parameters using genetic algorithm optimizer. As a result of auto calibration, a set of parameter values were found. While running the auto calibration, dynamic update option was selected. This option is very useful to investigate the model behaviour against different parameters values. It also gives an idea of how sensitive the model is against change of each parameter values. Further, the calibration of model was improved with the help of manual calibration until it attains desirable threshold values of objective function. Sensitivity analysis of the model parameters was also done. It is important to understand how sensitive a model is to certain parameters. This is very important to identify the most influential parameters that influence the model output. If the model is significantly affected by a particular parameter, then the focus of calibration should be on that parameter. The sensitivity of parameters against different values of their assigned range were also plotted and analysed. Simulation was run after setting up of model input, calibration, validation, and sensitivity analysis.

Simulation of stream flows under different climate change scenarios

The calibrated and validated SWAT and SIMHYD models were run for future periods to study the expected changes in stream flows. Future climate change scenarios with six models CanESM2 (CCMA), GFDL-ESM2M (NOAA), CNRM-CM5 (CNRM), MPI-ESM-MR (MPI), MPI-ESM-MR, IPSL-CM5A-LR (IPSL), CSIRO-Mk3.6 (CSIRO) were downloaded from ESGF data node http://cccr.tropmet.res.in/home/esgf_node.jsp. The RCM models were filtered based on the statistical indices between observed and simulated historical data. Bias correction of future climate change was done using CMHyd tool. Future climate change scenarios of six RCMs of CORDEX-SA were compared with historical data of observed rainfall, minimum and maximum temperatures of baseline period of 1961-90. After statistical performance climate models with historical data, two climate models viz. NCRM-CM5(CNRM) and GFDL-CM5A-LR (NOAA) projected climate data were used to project the stream flows in future. The climate projections of these models such as rainfall, maximum and minimum temperatures from the year 2020 to 2099 were used to predict the stream flows of both the models.

Evaluation of Model Performance

The performance of the model was analyzed during calibration and validation with statistical indices such as Nash Sutcliffe Efficiency (NSE), RMSE-observations standard deviation ratio (RSR), Coefficient of Determination (R^2) and Per cent Bias (PBIAS). The details of the model performance indices are given below.

Nash Sutcliffe Efficiency (NSE)

Nash Sutcliffe Efficiency (NSE) was used to evaluate the prediction ability of hydrological models. It is the normalized statistic and ranges from one to infinity. It is used to estimate the magnitude of variance in comparison to observed data variance (Nash and Sutcliffe, 1970). This parameter depicts better idea of how the observed and simulated values perfectly fit linearly. The NSE was calculated with following equation.

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

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

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

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

RMSE-observations standard deviation ratio (RSR)

It is the ratio of Root Mean Square Error (RMSE) to standard deviation. Lower value of RSR indicates better model performance. The following formula was used to calculate RSR.

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

Where,

SD_{obs} standard deviation of observed values

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

$(\bar{Q})_{obs}$ mean observed and discharge in$m^3 s^{-1}$

Coefficient of Determination (R^2)

This parameter is used to check the goodness of fit between observed and simulated data. The R^2 ranges from 0 to 1, better agreement between simulated values with observed values when the R^2 approaches to 1. The R^2 was calculated using the following formula.

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

Where,

and observed and simulated discharges respectively, in$m^3 s^{-1}$

and mean observed and mean simulated discharges respectively, in$m^3 s^{-1}$

Per cent Bias (PBIAS)

PBIAS measures the tendency of simulated data as larger or smaller than the observed data. The optimum value of PBIAS is zero that indicates more accurate simulation. Positive value of PBIAS indicates under estimation and negative value indicates overe stimation by model (Moriasi *et al*., 2007). PBIAS clearly indicates poor performance of model (Gupta *et al*., 1999).

Where, and observed and simulated discharges respectively, in $m^3 s^{-1}$

Results and Discussion

Calibration and validation of SWAT model

The SWAT model was calibrated with monthly observed stream flow data i.e inflow to the Hidkal dam. The calibration was done using the monthly stream flow data from the year 2013 to 2015 and validation of the same model was done using the monthly stream flow data from the year 2016 to 2019. The monthly observed stream flow and simulated stream flowfor both the calibration and validation periods is depicted in Fig. 3. The model parameters were selected based on the sensitivity analysis of the model using SWAT-CUP. Fifteen parameters were selected based on the sensitivity analysis of the SWAT-CUP. The default range and the final fitted values are given in the Table 2. The SWAT model performance was assessed based on the statistical parameters such as, R^2, NSE, RSR and PBIAS. It was observed that very good agreement between monthly observed and simulated stream flows with R^2, NSE, RSR and PBIASobserved as 0.84, 0.76, 0.49

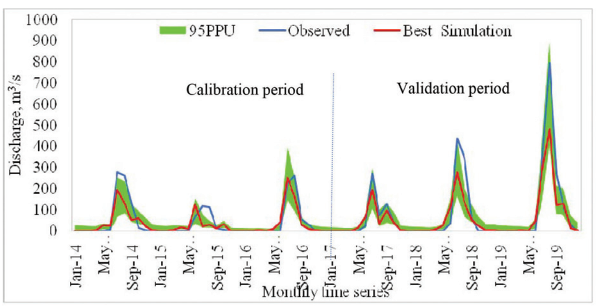

Fig. 3. Observed, simulated stream flow and 95PPU during calibration and validation period at Ghataprabha (Hidkal) dam gauging station

Table 2. Details of the parameters and their final fitted values during calibration of the SWAT model

Sl. No.	Parameters	Default range	Final fitted values
1	v__GW_DELAY.gw	0-500	34.168
2	v__GWQMN.gw	0-5000	41.658
3	v__ALPHA_BF.gw	0.01-1	0.492
4	v__ALPHA_BNK.rte	0.01-1	0.813
5	r__CN2.mgt	-0.2-0.2	-0.005
6	v__GW_REVAP.gw	0.02-0.2	0.158
7	v__ESCO.hru	0-1	1.009
8	v__REVAPMN.gw	0-500	302.918
9	v__SURLAG.bsn	0.05-24	3.492
10	v__CH_N2.rte	0.01-0.3	0.035
11	v__CH_K2.rte	0.01-500	236.472
12	r__SOL_AWC(1).sol	0-1	-0.472
13	r__SOL_K(1).sol	0-2000(a)	0.044
14	r__SOL_BD(1).sol	0.9-2.5(a)	-0.012
15	v__RCHRG_DP.gw	0-1	0.025

and 23.8% respectively during calibration periods and 0.93, 0.83, 0.41 and 22.9 % respectively during validation period (Table 4).

Calibration and validation of SIMHYD model

The parameters sensitivity, was done with genetic algorithm using auto calibration option. The objective function of model was fine-tuned with manual adjustment of parameter ranges based on the sensitivity graphs. The parameter values against the maximum values of objective function were selected as fitted value of the model. The new set of minimum and maximum values were selected as new range of model parameters. Warmup period for the model was adjusted from 1/1/2013 to 31/12/2013, calibration period was taken from 1/1/2014 to 31/12/2016 and performance verification (validation) period was adjusted from 1/1/2017 to 31/12/2019 in which 1/1/2017 to 31/12/2017 period was taken as warm period. The model was calibrated with observed stream flow and was run with genetic optimizer. The fitted parameters which were obtained in parameter sensitivity process were used for calibration of model (Table 3), the NSE was selected as primary objective function for both calibration and validation period. The simulated stream flow with the model during calibration and validation periods and observed stream flow is shown in Fig. 4.

The performance of model during calibration and validation with monthly stream flow (m^3/s) was found to be very good in terms of NSE, R^2. The NSE and correlation coefficient is found to be 0.77 and 0.93 during calibration period and 0.90 and 0.95 during validation period respectively (Table 4). The coefficient of correlation during calibration and validation period indicated that there is a very good

Table 3. Details of the parameters and their final fitted values during calibration of the SimHYD model

S. No.	Parameter	Default range	Final fitted value
1	Baseflow coeff	0-1	0.1
2	Impervious Threshold	0-5	4.5
3	Infiltration Coeff	0-400	190
4	Infiltration shape	0-10	1.0196
5	Interflow Coeff	0-1	0.0762
6	Perv. Fraction	0-1	0.7
7	RISC	0-5	3.431
8	Recharge coefficient	0-1	0.92
9	SMSC	1-500	1

Table 4. Performance indicators of models during calibration and validation periods

Model	Period	R^2	NS	RSR	PBIAS
SWAT	Calibration (2013-2015)	0.84	0.76	0.49	23.8
	Validation (2016-2019)	0.93	0.83	0.41	22.9
SIMHYD	Calibration (2013-2015)	0.93	0.77	-	10.6
	Validation (2016-2019)	0.95	0.90	-	8.1

agreement between monthly observed and simulated stream flows of Ghataprabha (Hidkal) Dam.

Scatter plot between monthly observed flow and simulated flows of SimHYD and SWAT models from the year 2013 to 2018 is presented in Fig. 5. Observed and simulated stream flows are well distributed and close to 1: 1 line when the flows with lower magnitude say 70 m^3/s for both models. When the magnitude of flows is more than 100 m^3/s than, both the model under estimated the stream flows. Deviation of scatter dots from the 1:1 line represents the models strengths and weaknesses. However, the results are satisfied in case of higher magnitude also. SimHYD model is better performed when compared to SWAT model in case of higher magnitude flows.

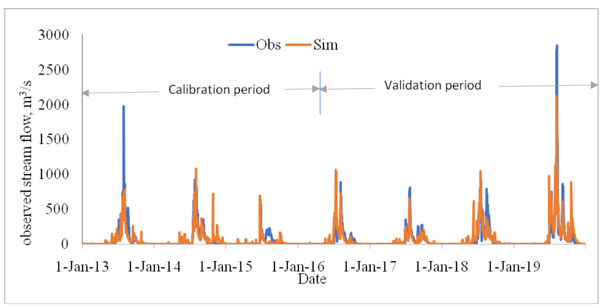

Fig. 4. Comparison of observed and simulated daily stream flow discharge from 2013-2019

Comparison of simulated monthly stream flows of SWAT and SIMHYD models

The observed monthly inflows to Ghataprabha (Hidkal) dam were compared with monthly simulated stream flow using SWAT model and SIMHYD model and presented in Fig.6 During the initial period of models, both the models unable to capture the peak flows during the year 2013 and 2014 and SIMHYD model followed the SWAT model output trend. SIMHYD model performed better than SWAT model during the years 2016 to 2018 and capture the high flows when compared with SWAT model. It was observed that the SIMHYD model performed better than the SWAT model in terms of high flows. A scatter plot between simulated monthly flows using SWAT and SIMHYD models in Fig. 7. It was observed that a very good agreement between simulated monthly flows of SWAT model and SIMHYD model with R^2 of 0.945.

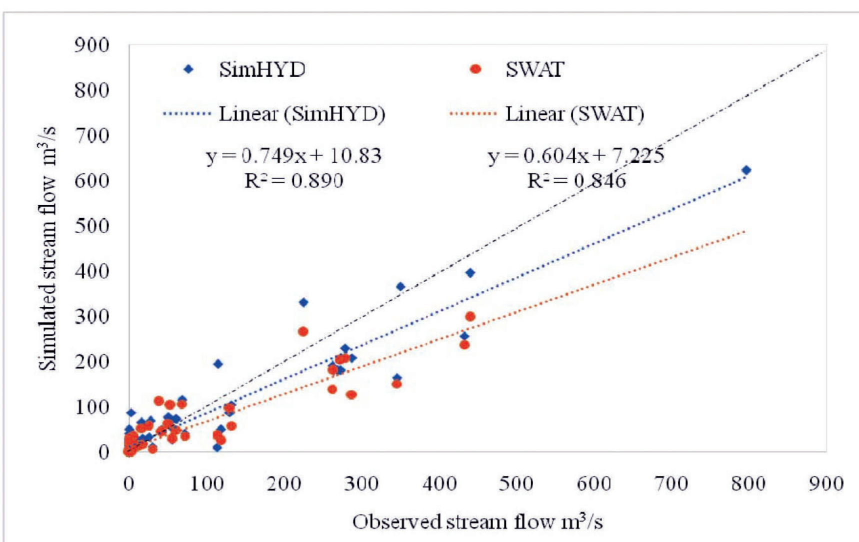

Fig. 5. Scatter plot between monthly observed and simulated stream flows of SWAT and SIMHYD models

Comparison of simulated stream flows using SWAT and SIMHYD for future scenarios

The monthly stream flows simulated using SWAT model and SIMHYD models were compared to examine the ability of SIMHYD in simulation to stream flows for future scenarios. The calibrated and validated models were used to simulate the monthly stream flow for future periods. Time series data between simulated monthly stream flows of SWAT and SIMHYD models under both climate models (CNRM and NOAA) with RCP 4.5 and RCP 8.5 scenarios were analyzed. The time series data of monthly stream flow of both the models revealed that both models projected the stream flow in similar trend and followed similar hydrological responses except few high flows. For both models and RCP scenarios the response of both models was found to be similar. Scatter plots between the projected monthly flows of both the models also revealed a good agreement between projected monthly flow of both models (Fig. 8 and 9) with R^2 values of 0.89, 0.77, 0.77, 0.91 for CNRM RCP 4.5, CNRM RCP 8.5 and NOAA RCP 4.5 and NOAA RCP 8.5 respectively.

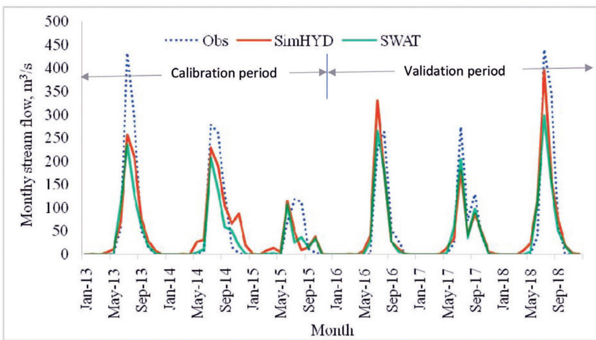

Fig. 6. Comparison of monthly stream flows of SWAT and SIMHYD models with Observed stream flow

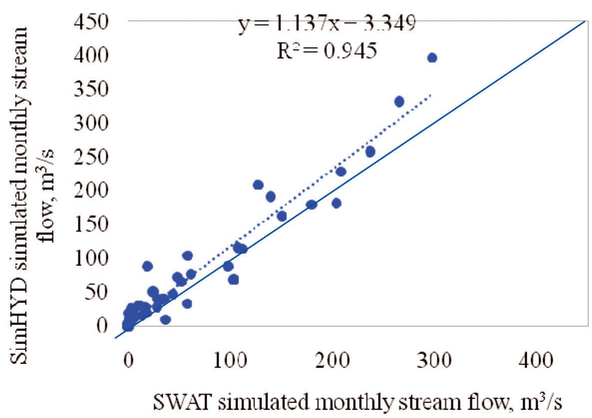

Fig. 7. Correlation between simulated flows from SWAT and SimHYD models

The performance of the SIMHYD model was assessed with reference to SWAT model using some statistical parameters such as Nash-Sutcliffe Efficiency (NSE), percent bias (PBIAS), coefficient of determination (R^2), coefficient of correlation (r), root mean square error (RMSE) and RMSE-observations standard deviation ratio (RSR). The results of these statistical indies are presented in Table 4.21. The projected monthly stream flows with SIMHYD are found to be very close to that of SWAT projected monthly stream flow and the NSE, PBIAS and RSR found to be very good and ranged from 0.71 to 0.91%, -5.55 to 4.17% and 0.30 to 0.54% respectively for both models and both the RCPs. The other statistical indicators such as Mean error, RMSE, Coefficient of correlation were also found to be very good and ranged from -0.78 to 1.70, 39.52 to 68.39 and 0.83 to 0.95 respectively for both the models and both RCP 4.5 and RCP 8.5. This attempt revealed that SimHYD model can be used to simulate the stream flows for future scenarios using projections of climate models. When SWAT model is unable to use due to datalimited condition, Sim HYD model can be used to simulate the stream flow foe given area.

Table 5. Performance of SWAT and SIMHYD models under CNRM and NOAA under both RCPs

Statistical Indices	Symbol	CNRM		NOAA	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Nash-Sutcliff efficiency	NSE	0.89	0.71	0.77	0.91
Mean Error	ME	1.70	-0.78	0.34	0.29
Percent Bias	PBIAS	4.17	-5.55	-2.88	1.31
Root means square error	RMSE	41.78	68.69	63.25	39.56
Coefficient of correlation	r	0.95	0.83	0.88	0.96
Coefficient of determination	R^2	0.89	0.77	0.77	0.91
RMSE-observations standard deviation ratio	RSR	0.33	0.54	0.48	0.30

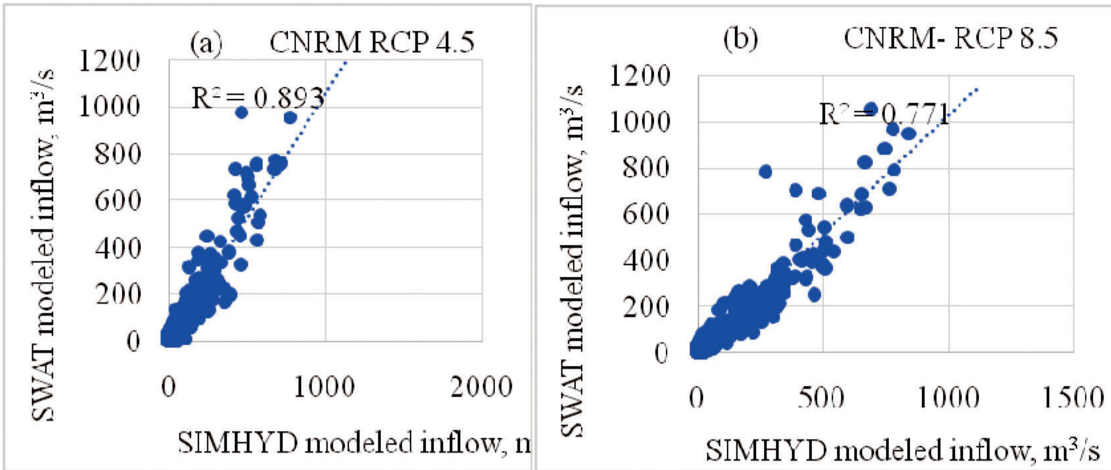

Fig. 9. Scatter plot between projected monthly inflows in future periods with SIMHYD and SWAT models using NOAA climate model under (a) RCP4.5 and (b) RCP8.5 scenarios

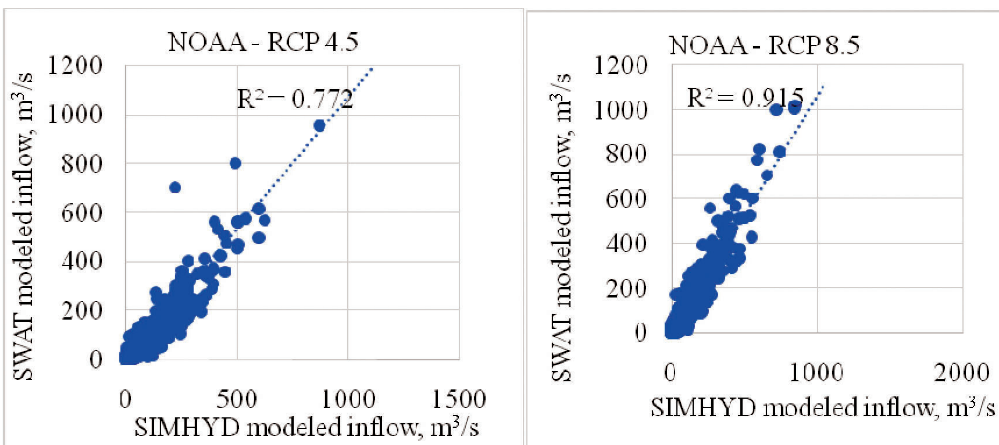

Fig. 8. Scatter plot between projected monthly inflows in future periods with SIMHYD and SWAT models using CNRM climate model under (a) RCP 4.5 and (b) RCP 8.5 scenarios

Conclusion

The present study compared the simulated monthly stream flow using SWAT model and SIMHYD models to examine the ability of SIMHYD model in simulation of stream flows for future scenarios. The study concluded that there was very good agreement between simulated data of SWAT and SIMHYD during calibration and validation periods. The calibrated model was used to simulate the stream flow for future scenarios with climate projections of climate models. The performance of SimHYD model was compared with SWAT model in simulation of monthly stream flow with help of statistical parameters for future scenarios. These parameters also indicated that there was very good agreement between two model out put for future as well. This study concluded that Under data limitation conditions, SIMHYD model can be used to simulate the stream flows in place of SWAT model and can be used to simulate the impact of climate change on stream flows.

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Conflict of interest

No conflict of interests that are directly or indirectly related to the work submitted for publication.

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