

Assessment of Stream Flow of Hidkal Dam Catchment Area in Krishna Basin of India Using SIMHYD Model

ABSTRACT

A study was conducted to predict the stream flow from a catchment area of Hidkal dam situated in Krishna basin of India. SimHYD model was selected to setup the stream flow model under limited data condition. Daily rainfall, potential evapotranspiration (PET) and observed discharges were used as input data to setup the model. Sensitivity analysis was carried out to identify the more sensitive parameter and fixed final parameter values. Genetic algorithm was used for calibration and validation of the model with object function of Nash -Sutcliffe Equation (NSE). 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 was found to be 0.77 and 0.93 during calibration period and 0.90 and 0.95 during validation period respectively. There was a very good agreement between monthly observed and simulated stream flows of catchment area of Hidkal Dam. The NSE value of model during calibration period with daily runoff was found to be satisfactory with 0.51. It was observed that good agreement between observed and simulated daily runoff (in mm) with correlation coefficient is 0.74. NSE and correlation coefficient during validation period using daily data is found to be 0.80 and 0.9 respectively. This study concluded that SimHYD model can be used for assessment of stream flow with limited data.

Key words: SIMHYD, stream flow, rainfall-runoff model, calibration and validation, sensitivity analysis.

1. INTRODUCTION

The stream flow can be simulated or modeled with help of hydrological models. These hydrological models require huge data to conduct the hydrological studies such as stream flows of given catchment. Rainfall characteristics influence the stream flow of a given area. These models are the tools that simulate the impact of various geomorphological, weather parameters 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. 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 China can also be used where limited data is available. Very limited studies on SIMHYD model was noticed in India. However, this model is widely used conceptual model in the world. SIMHYD model 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. The structure of SIMHYD model and model parameters and algorithms described in detail in the document are published by Zhang and Chiew (2009). Chiew and Siriwardena (2005) compared calibration of several models, investigated whether the calibrated parameter values could be related to catchment characteristics and compared the runoff model using parameter values estimated from the regionalisation relationships. The results indicated that SIMHYD could be calibrated satisfactorily to reproduce the monthly recorded runoffs. The use of the five-parameter version of SIMHYD was sufficient for most catchments, with Nash-Sutcliffe model efficiency values greater than 0.7 obtained in more than 90% of the catchments. Siriwardena (2005) used SIMHYD, a lumped conceptual daily rainfall-runoff model, on about 300 catchments across Australia and compared calibration results from several model types. The results indicated that SIMHYD can be calibrated satisfactorily to reproduce the monthly recorded runoffs. The SIMHYD model with five-parameter version was sufficient for most catchments, with Nash-Sutcliffe model efficiency values greater than 0.7 obtained in more than 90% of the catchments. The modelled monthly runoffs from both methods were reasonable in about three quarters of the catchments, where the Nash-Sutcliffe model efficiency was greater than 0.6 and the total modelled runoff was within 30% of the total recorded runoff. Srikanthan *et al.* (2003) compared the simulated runoff of historical (1901-1998) and 2021-2050 climate situations in the study area using SIMHYD. They found that decrease in mean annual rainfall and runoff in eastern and south-west Australia, but an increase in the extreme daily rainfall, in 2021-2050 relative to 1961-1990.

Yu and Zhu (2014) used conceptual models, AWBM and SIMHYD and simulated daily flows of two forest watersheds in France and USA. They evaluated their ability to model daily flows. They found that both models performed much better for the River Rimbaud watershed in France than for the Fernow W6 in the USA. They also found difference in model performance between AWBM and SIMHYD was small. Chiew *et al.* (2018) predicted different characteristics of streamflow in ungauged catchments and under climate change with three rainfall-runoff models using a large data set from 780 catchments across Australia. They concluded that medium and high flows were relatively easier to predict and suggested to use a single unique set of parameter values from model calibration. The low flow characteristics were considerably more difficult to predict and require careful modelling consideration to specifically target the low flow characteristic of interest. The modelling results also showed that different rainfall-runoff models and different calibration approaches could give significantly different predictions of climate change impact on streamflow characteristics, particularly for characteristics beyond the long-term averages. Li *et al.* (2018) evaluated the effect of length of calibration data on the performance of a hydrological model in data-limited catchments where data are non-continuous and fragmental. They used calibrated SIMHYD model with non-continuous calibration periods for more independent streamflow data. They found that longer calibration data series do not necessarily result in better model performance and results could be useful for the efficiency of using limited observation data for hydrological model

calibration in different climates. With the background, a study was conducted to assess the stream flow of Hidkal Dam catchment area in Krishna basin of India using SIMHYD model.

2. MATERIAL AND METHODS

2.1 STUDY AREA AND DATA SETS

The present study of catchment area of Hidkal dam is located situated in Ghatprabha subbasin of Krishna basin in India with a catchment area of 1370 km². 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 ranges from 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 m³ with irrigated area of 155559 ha. The rainfall, maximum & minimum temperatures were downloaded from the Indian Meteorological department website. Daily rainfall data at grid interval of 0.25° x 0.25° for 10 years from 2009-2019 (Pai et al.,2014) was used. Maximum and minimum temperatures at grid interval of 1° x 1° for the same years (Srivastava et al., 2009) was also used for this study. 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.

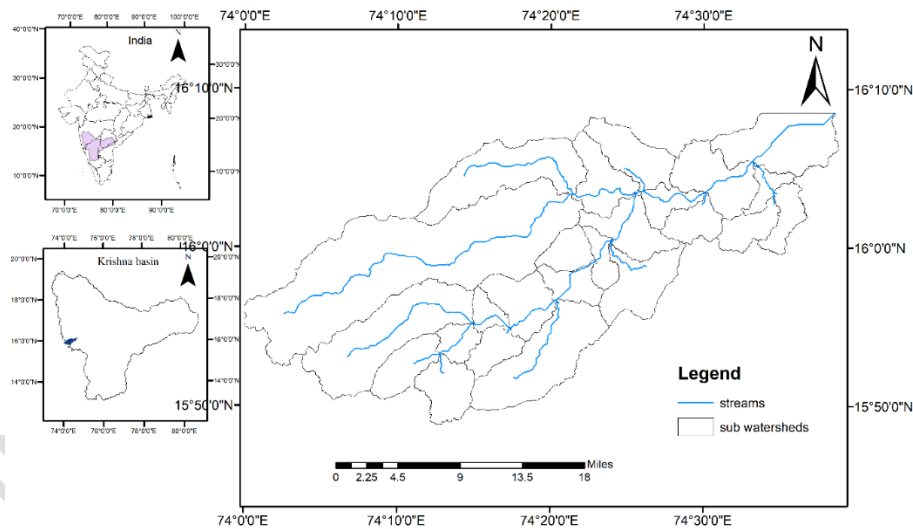


Fig. 1 Location of study area

2.2 SIMHYD MODEL

The process flow chart is presented in Fig. 2 . In this model, interception store is filled with daily rainfall, which is emptied each day by evaporation. The excess rainfall is then subjected to an infiltration function which estimates the infiltration capacity. The surplus rainfall that exceeds the infiltration capacity becomes infiltration excess runoff. The moisture that infiltrates is subjected to soil moisture function which diverts water to stream (interflow),

groundwater store (recharge) and soil moisture store. An interflow is first estimated as a linear function of the soil wetness (soil moisture level divided by soil moisture capacity). The groundwater recharge is then estimated as a linear function of the soil wetness and remaining moisture flows into the soil moisture store. An evapotranspiration from the soil moisture store is estimated as a linear function of the soil wetness. The soil moisture store has a finite capacity and overflows into the groundwater store. Base flow from the groundwater store is simulated as a linear recession from the store. The model therefore estimates runoff generation from three sources – infiltration excess runoff, interflow (and saturation excess runoff) and base flow.

The fundamental equations of the model are:

$$\text{Impervious ET} = \min \left[\begin{array}{c} \text{PET,} \\ (1 - \text{Pervious fraction}) \times \text{Pervious threshold,} \\ \text{Impervious incident} \end{array} \right]$$

$$\text{Interception ET} = \min \left[\begin{array}{c} \text{Pervious incident,} \\ \text{PET,} \\ \text{[Rainfall interception storage capacity]} \end{array} \right]$$

$$\begin{aligned} \text{Infiltration Capacity} &= \\ &= \text{Pervious fraction} \times \text{Infiltration coefficient} \times \exp(-\text{Infiltration shape} \\ &\quad \times \text{Soil moisture fraction}) \end{aligned}$$

$$\text{Infiltration} = \min(\text{Throughfall}, \text{Infiltration capacity})$$

$$\text{Interflow Runoff} = \text{Interflow coefficient} \times \text{Soil moisture fraction} \times \text{Infiltration}$$

$$\text{Infiltration after Interflow} = \text{Infiltration} - \text{Interflow runoff}$$

$$\text{Recharge} = \text{Recharge coefficient} \times \text{Soil moisture fraction} \times \text{Infiltration after interflow}$$

$$\text{Soil input} = \text{Infiltration after interflow} - \text{Recharge}$$

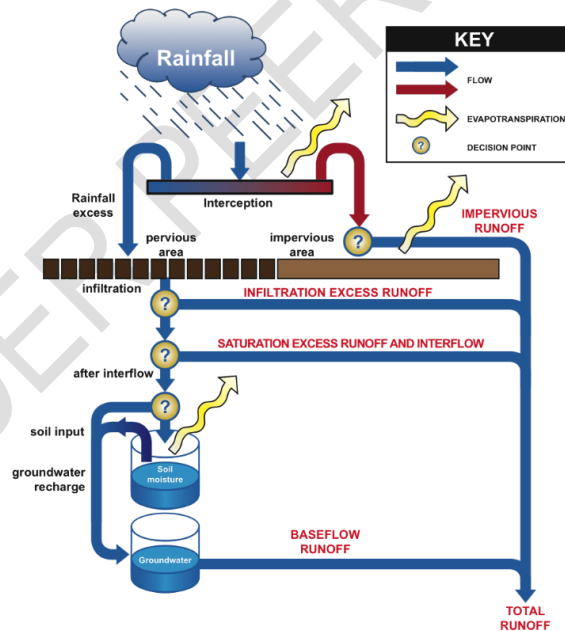


Fig. 2 Structure of SIMHYD model

2.3 INPUT DATA PREPARATION

The model utilizes daily time series data of average rainfall, average potential evapotranspiration (PET) and observed stream flow. The daily average rainfall of the catchment was calculated from IMD grid data. Hargreaves method was used to calculate the daily PET. The input files were saved in a desirable format that model can read the files. SWAT "pcp" format is also one of the readable formats of SIMHYD model. Daily time series data of average rainfall and PET were saved in. pcp (SWAT) format, mm/day. The daily time series

data of observed stream flow was also saved in .pcp (SWAT) format, m^3/s . The daily discharge data from 2013 to 2019 at the outlet point was used for the model set up. The general details of catchment and its area in km^2 was also required for the model.

2.4 MODEL SETUP

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 (Fig. 3) 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 (Fig. 4) was taken as warm period.

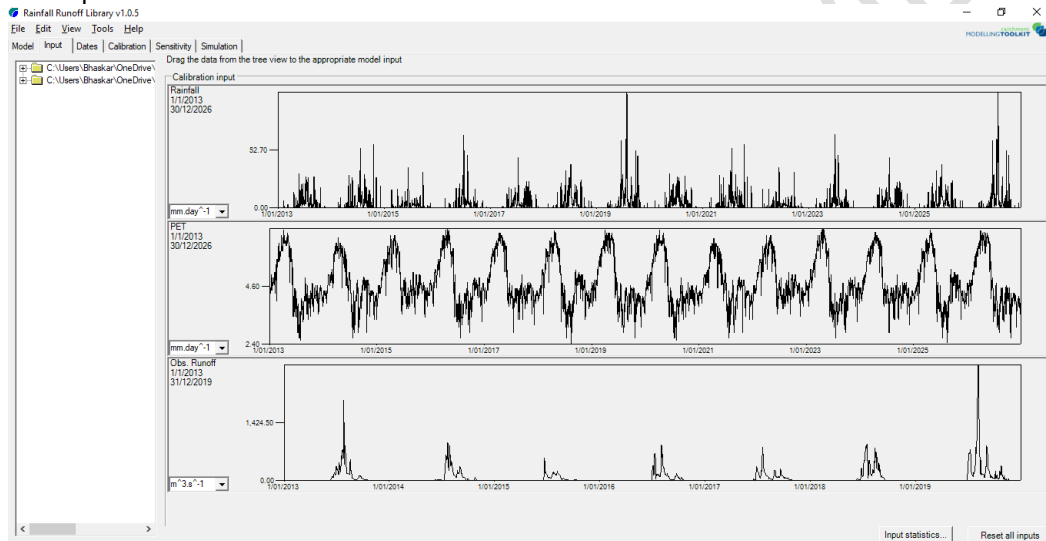


Fig. 3 Screenshot of model input data setup

2.5 CALIBRATION OF MODEL AND PARAMETER SENSITIVITY OF SIMHYD MODEL

Calibration of the model comprises with fixation of maximum and minimum values of parameters, selection of optimization method, selection of objective function, calculation and their criteria. SIMHYD model has nine parameters that depicts infiltration, storage, groundwater flow and recharge characteristics. The details of parameters and their ranges are given in the Table 1. RRL has three calibration procedures namely, manual, custom and auto calibration. SIMHYD supports auto calibration and manual calibration and does not support custom calibration. The present model was calibrated using auto calibration and manual calibration methods. Among the auto calibration methods, genetic algorithm technique was selected for calibration of the auto calibration method. The genetic algorithm is search procedure that uses principles of mechanics of natural selection and natural genetics. The genetic algorithm combines an artificial survival of the fittest with genetic operators abstracted from nature (Goldberg and Holland, 1975). Nash-Sutcliffe criterion was selected as objective function of the model. This can be applied on daily or monthly time step. The present model was calibrated on monthly time step.

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.

Table 1 SIMHYD Parameters and their ranges

Parameter	Description	Units	Min.	Max.
Baseflow coeff.	Base flow Coefficient	na	0	1
Impervious Threshold	Impervious Threshold	mm	0	5
Infiltration Coeff.	Infiltration Coefficient	na	0	400
Infiltration shape	Infiltration Shape	na	0	10
Interflow Coeff.	Interflow Coefficient	na	0	1
Perv. Fraction	Pervious Fraction	na	0	1
Recharge coefficient	Recharge Coefficient	na	0	1
RISC	Rainfall Interception Store Capacity	mm	0	5
SMSC	Soil Moisture Store Capacity	mm	1	500

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. The model results (graphs and time series data) were saved in the folder at daily and monthly time steps and the stream flow in mm/day and m³/s was also saved.

3. RESULTS AND DISCUSSION

SIMHYD model was set up for simulation of stream flow for catchment area of Hidkal comprises an area of 1370 km². The parameters sensitivity, range and model were calibrated 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 results are presented in below sections.

3.1 PARAMETER SENSITIVITY

Sensitivity analysis was carried out using genetic algorithm of auto calibration model. The sensitivity graphs between parameter values against the objective function values are presented Fig.5 to Fig. 13. 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. The sensitivity graphs for all nine parameters are presented below.

3.1.1 SENSITIVITY OF BASEFLOW COEFFICIENT

The default range of parameter is in between 0 to 1. The sensitivity of baseflow coefficient is depicted in Fig. 5. It was observed that the parameter was highly sensitive and highest NSE

is found when value is fixed at 0.1. The NSE value was monotonically decreasing with increasing of parameter value.

3.1.2 SENSITIVITY OF IMPERVIOUS THRESHOLD

The default range of impervious threshold is 0 to 5. The sensitivity of impervious threshold is presented in Fig. 6. It was observed that the parameter is not sensitive and highest NSE was found when value was fixed at 4.5. The NSE value didn't follow certain trend with increase in parameter value.

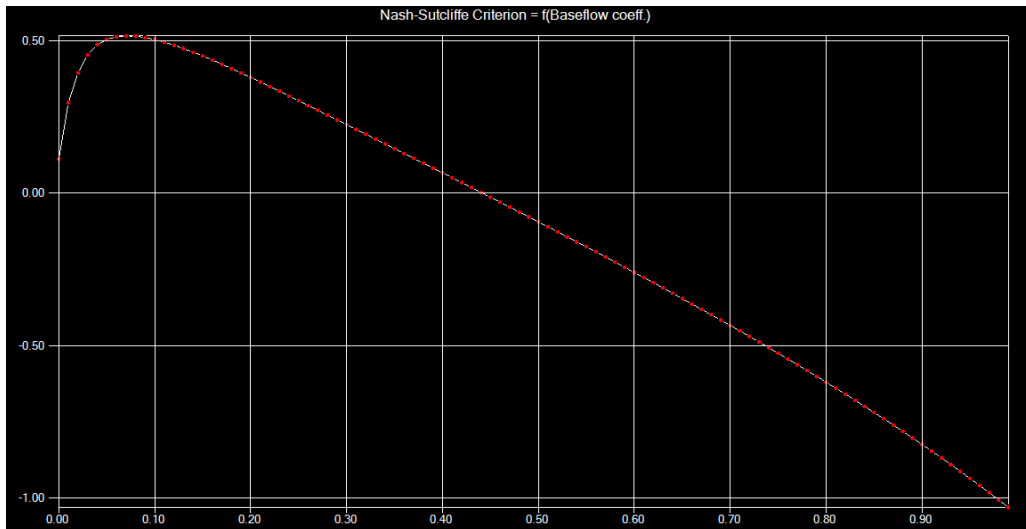


Fig. 5 Sensitivity of baseflow coefficient (x axis – parameter value; y axis – NSE value)

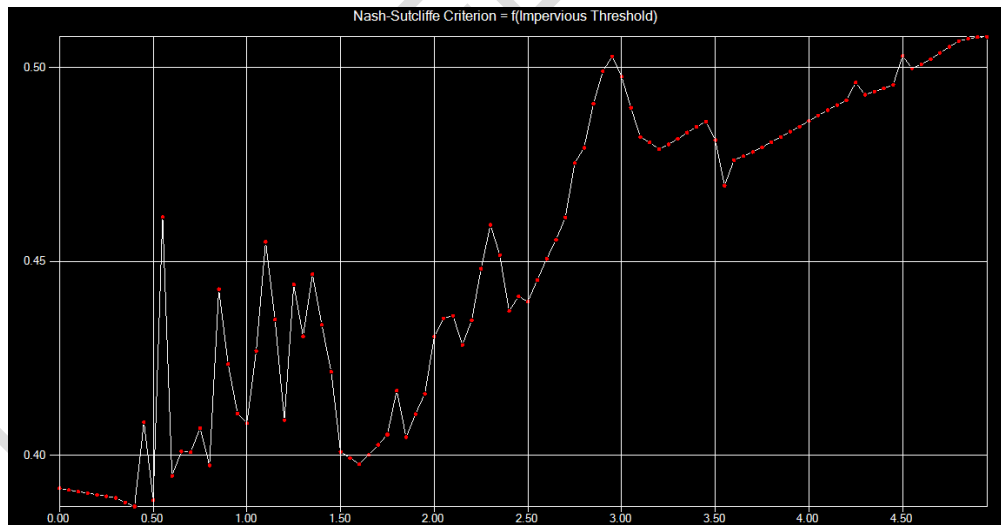


Fig. 6 Sensitivity of impervious threshold (x axis – parameter value; y axis – NSE value)

3.1.3 SENSITIVITY OF INFILTRATION COEFFICIENT

The default range of infiltration capacity is 0 to 400. The sensitivity of infiltration coefficient is presented in Fig. 7. It was observed from the graph that the highest NSE is found when impervious value is fixed at 190. The NSE value increased with increasing value of infiltration coefficient upto 190 and later it decreased with increasing value beyond 190.

3.1.4 SENSITIVITY OF INFILTRATION SHAPE

The default range of infiltration shape is 0 to 10. The sensitivity of infiltration shape is presented in Fig. 8. It was observed from the graph that infiltration shape parameter was not sensitive. The value of this factor was taken as 1.096.

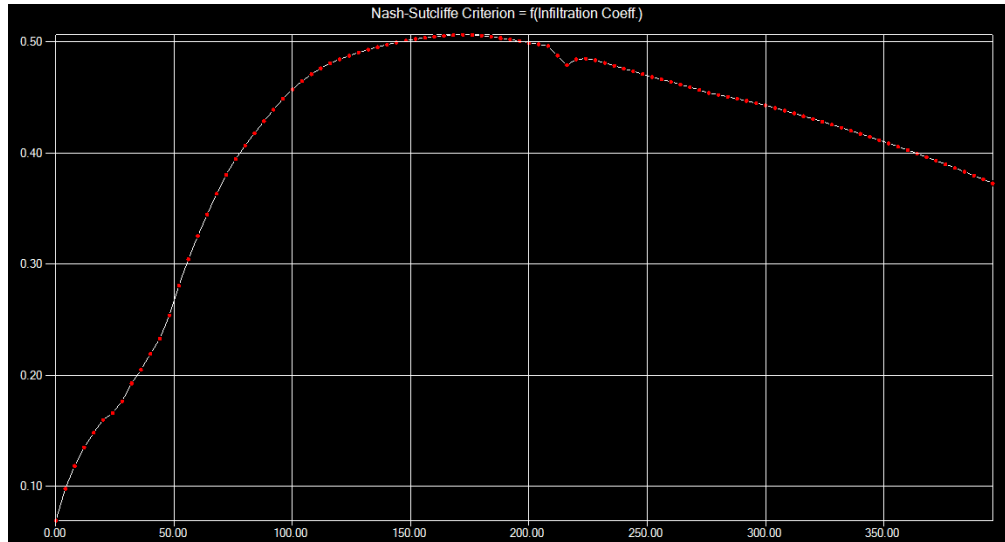


Fig. 7 Sensitivity of infiltration coefficient (x axis – parameter value; y axis – NSE value)

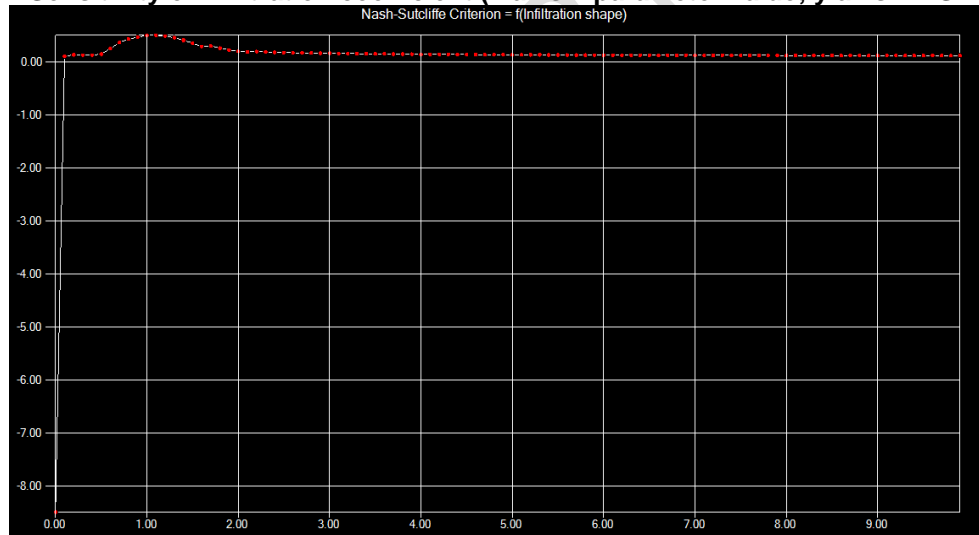


Fig. 8 Sensitivity of infiltration shape (x axis – parameter value; y axis – NSE value)

3.1.5 SENSITIVITY OF INTERFLOW COEFFICIENT

The default range of interflow coefficient is 0 to 1. The sensitivity of interflow coefficient is presented in Fig. 9. It was observed from the graph that the highest NSE is found when impervious value is fixed at 0.076. The NSE value increased with decreasing value of interflow coefficient.

3.1.6 SENSITIVITY OF PERVIOUS FRACTION

The default range of pervious fraction is 0 to 1. The sensitivity of pervious fraction is presented in Fig. 10. It was observed from the graph that the highest NSE was found when pervious

fraction value was fixed at 0.7. The NSE value increased with increasing value of pervious fraction.

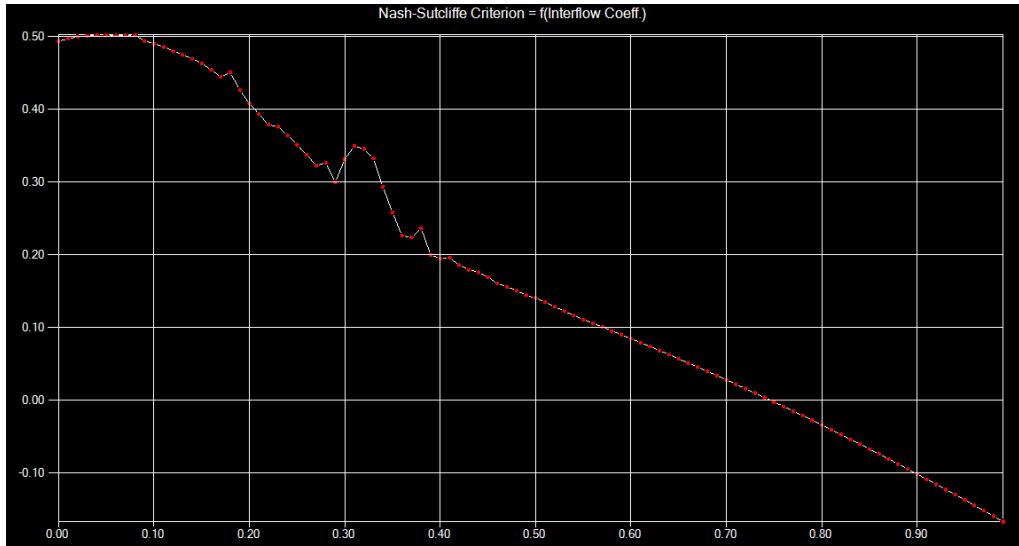


Fig. 9 Sensitivity of Interflow coefficient (x axis – parameter value; y axis – NSE value)

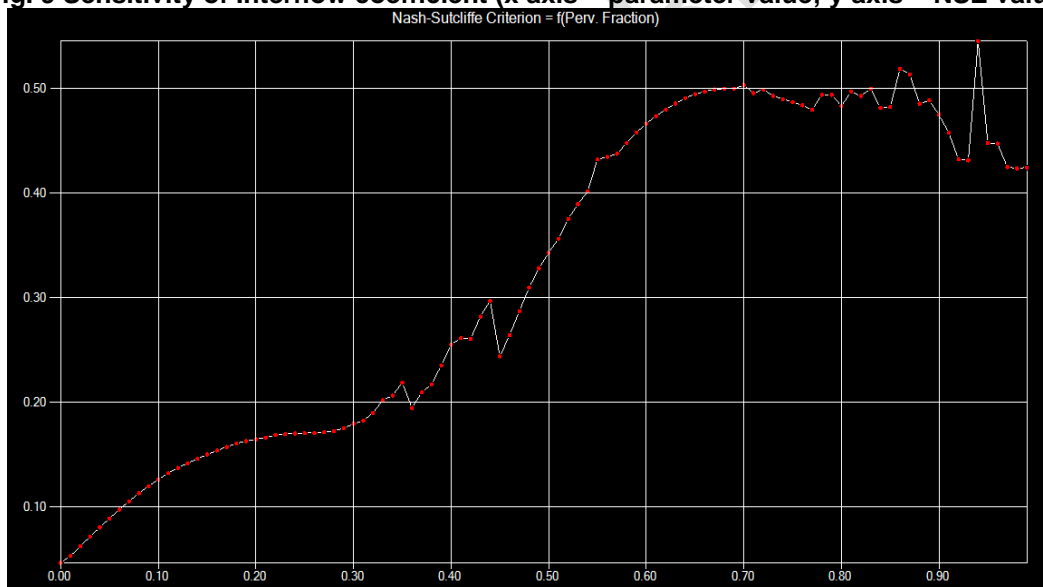


Fig. 10 Sensitivity of Interflow coefficient (x axis – parameter value; y axis – N

3.1.7 SENSITIVITY OF RAINFALL INTERCEPTION STORE CAPACITY (RISC)

The default range of rainfall interception store capacity is 0 to 5. The sensitivity of rainfall interception store capacity is presented in Fig. 11. It is observed from the graph that the highest NSE is found when impervious value is fixed at 3.43.

3.1.8 SENSITIVITY OF RECHARGE COEFFICIENT

The default range of recharge coefficient is 0 to 1. The sensitivity of interflow coefficient is presented in Fig. 12. It was observed from the graph that recharge coefficient was one of the sensitive parameters and the highest NSE is found when recharge coefficient value is fixed at 0.92. The NSE value increased with increasing value of recharge coefficient.

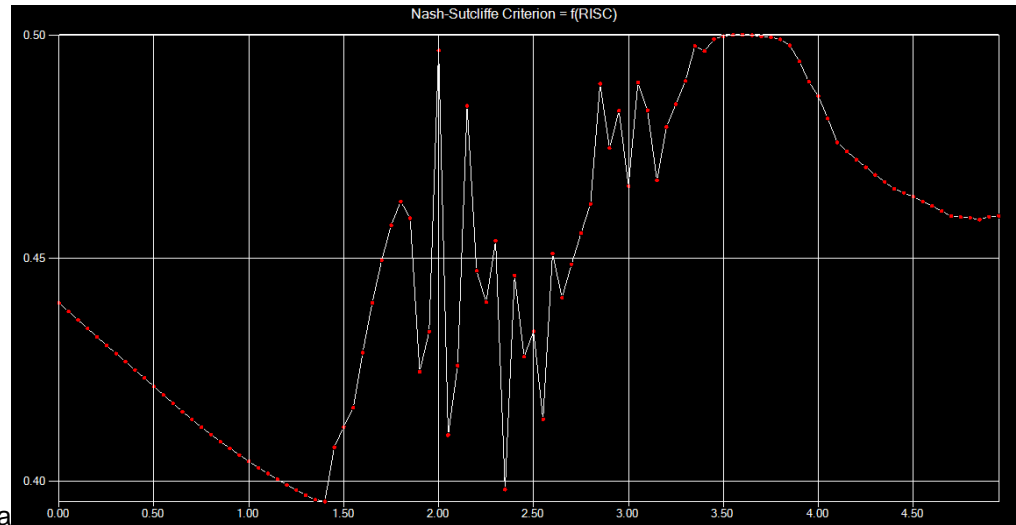


Fig. 11 Sensitivity of rainfall interception store capacity (x axis – parameter value; y axis – NSE value)

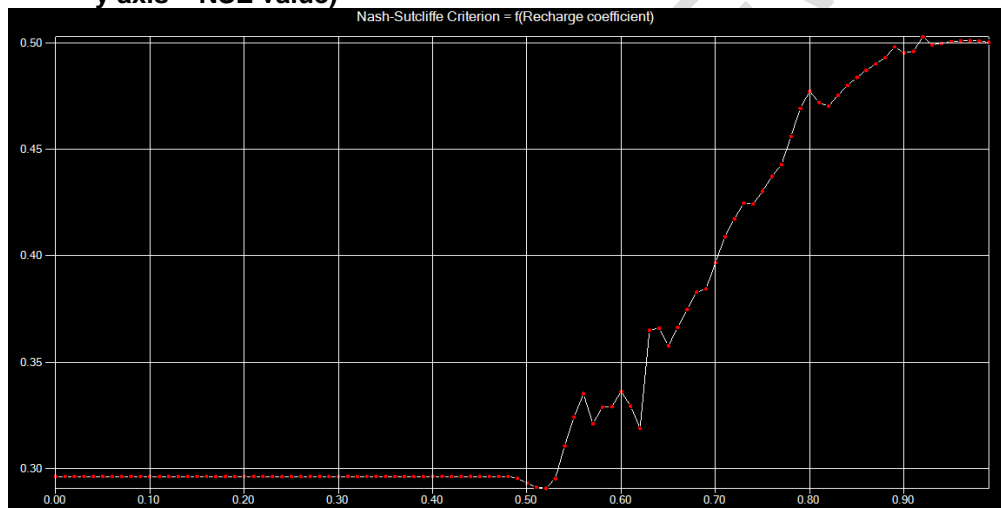


Fig. 12 Sensitivity of rainfall storage (x axis – parameter value; y axis – NSE value)

3.1.9 SENSITIVITY OF SOIL MOISTURE STORE CAPACITY

The default range of soil moisture storage capacity is 1 to 500. The sensitivity of soil moisture store capacity interflow is presented in Fig. 13. It was observed from the graph that soil moisture storage capacity was one of the sensitive parameters and the highest NSE is found when soil moisture storage capacity value is fixed at 1. The NSE value increased with decreasing value of soil moisture storage capacity.

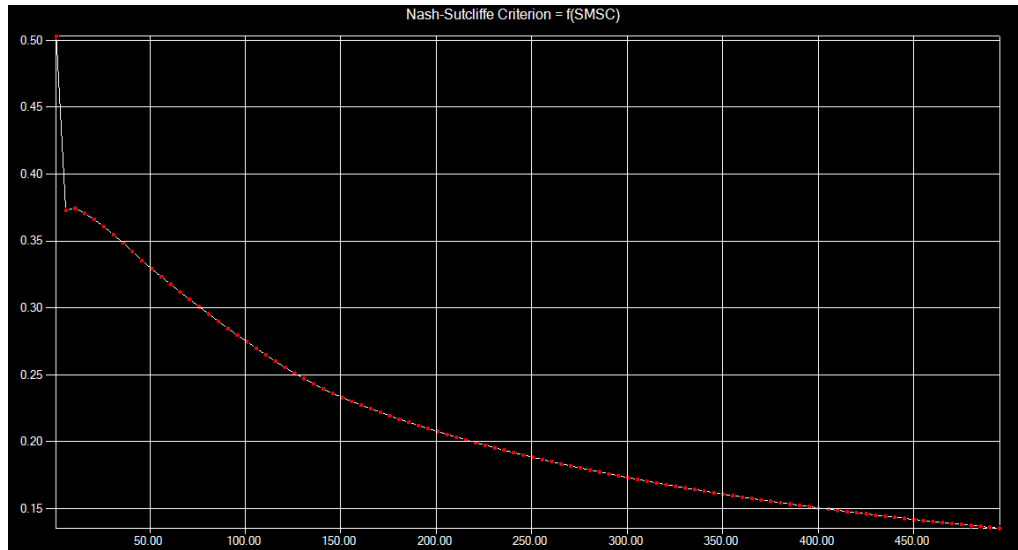


Fig. 13 Sensitivity of soil moisture storage capacity (x axis – parameter value; y axis – NSE value)

3.2 CALIBRATION AND VALIDATION OF SIMHYD MODEL

The model calibration and validation setup were done for Ghataprabha (Hidkal) dam with a catchment area of 1370 km² for the years 2014-2019. Warm up 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 2), the NSE was selected as primary objective function for both calibration and validation period. The first step in applying a genetic algorithm is defining an objective function NSE. This function is used to evaluate the performance of a particular set of parameters. The next step in applying the genetic algorithm to the SIMHYD model is defining the range of values that each respective parameter can take. This is done to ensure that the parameters stay within physically plausible limits. Once the range of each parameter is defined, the next step of the genetic algorithm is the initialization. The initialization assigns random values to each of the parameters (within its limits) to each of the individuals of the population. After the initialization, the initial population passes through the general loop of the genetic algorithm.

Table 2 Parameters fitted values of SIMHYD

Parameter	Units	Min.	Max.	Fitted values
Baseflow coeff.	na	0	1	0.1
Impervious Threshold	mm	0	5	4.5
Infiltration Coeff.	na	0	400	190
Infiltration shape	na	0	10	0.0196
Interflow Coeff.	na	0	1	0.0762
Perv. Fraction	na	0	1	0.7
Recharge coefficient	na	0	1	3.431
RISC	mm	0	5	0.92

SMSC	mm	1	500	1.0
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The model provided a scatter graph between daily observed and simulated runoff of the study area for both calibrated and validated periods (Fig. 14). The scatter plot between monthly observed and simulated runoff are also presented in Fig. 15. During the calibration and validation process of model, it compared the daily and monthly simulated data with comparative statistics and univariate statistics.

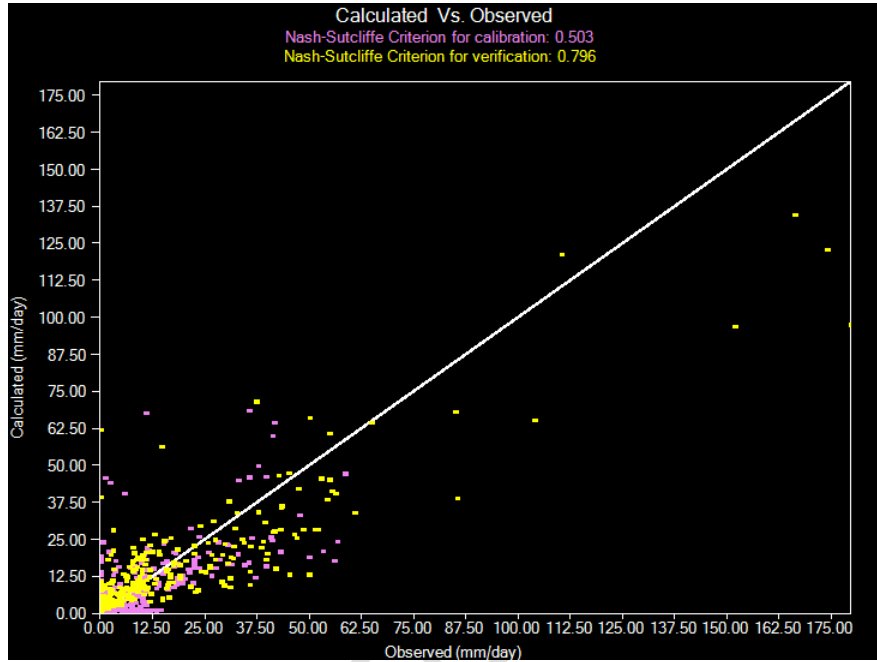


Fig. 14 Scatter plot between daily observed and simulated runoff – Ghataprabha (Hidkal) dam during calibration and verification period

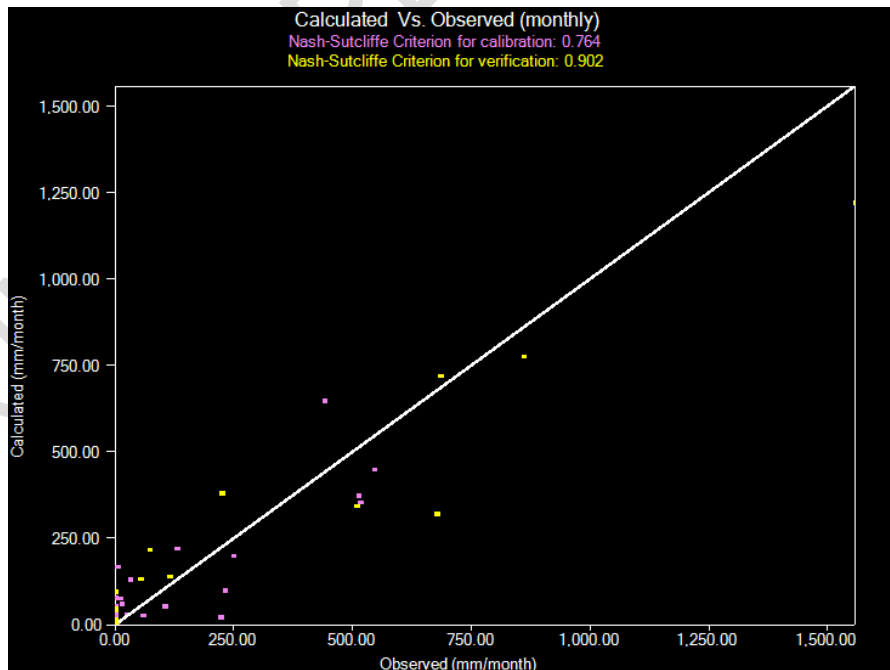


Fig. 15 Scatter plot between monthly observed and simulated runoff – Ghataprabha (Hidkal) dam during calibration and verification period

The statistical performance of monthly calibration and validation of model were calculated. The result of daily and monthly calibration and validation of model are presented in Table 3. Daily calibration and validations are done with runoff (mm). Monthly calibration and validation of the model is done using monthly stream flow data (m^3/s). The Nash Sutcliffe value of model during calibration period with daily runoff is found to be satisfactory with 0.51. It is observed that good agreement between observed and simulated daily runoff (in mm) with correlation coefficient is 0.74. NSE and correlation coefficient during validation period using daily data is found to be 0.80 and 0.9 respectively. The comparative statistics of model validation period with daily runoff improved than the calibration period. The warmup period of the model is restricted to one year due to data limitations. If the warmup period of model is for three years or more, then the model would have given good results in calibration period also. The performance of model during calibration and validation with monthly stream flow (m^3/s) is 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 3). The coefficient of correlation during calibration and validation period indicated that there is a very good agreement between monthly observed and simulated stream flows of Ghataprabha (Hidkal) Dam. The model generated graphs between daily observed and calculated runoff during calibration period and validation period are presented in Fig. 16 and Fig. 17 respectively.

Table 3 Results of model performance indices during calibration and validation periods

Sl. No.	Parameter	Calibration		Validation	
		Daily	Monthly	Daily	Monthly
1	NSE	0.51	0.77	0.80	0.90
2	Coefficient of correlation	0.74	0.93	0.90	0.95
3	Coefficient of determination	0.56	0.86	0.81	0.91

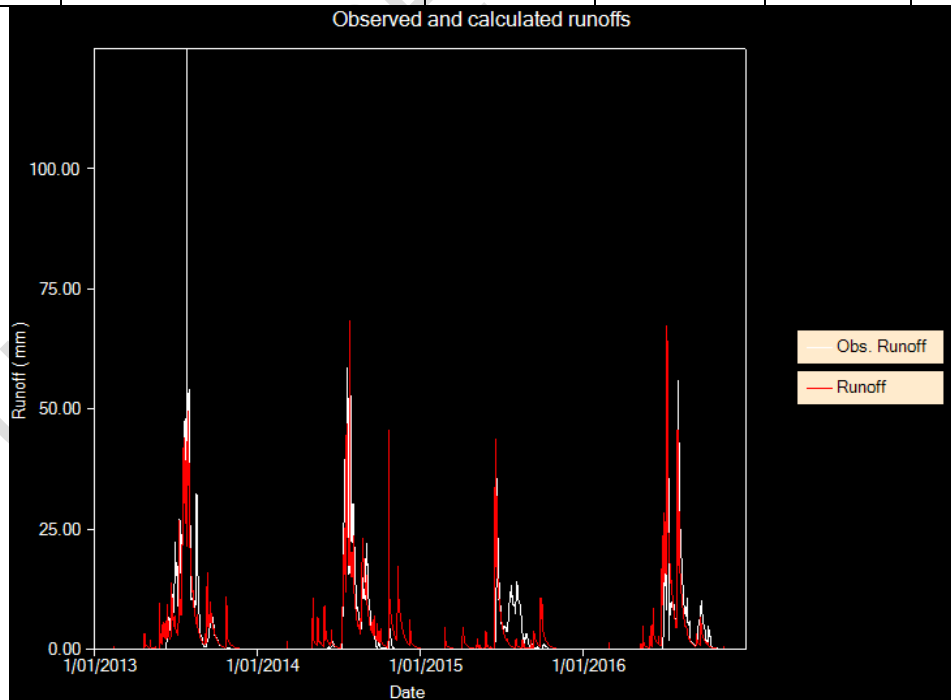


Fig. 16 Comparison between simulated and observed runoff for calibration period from 2013 to 2016

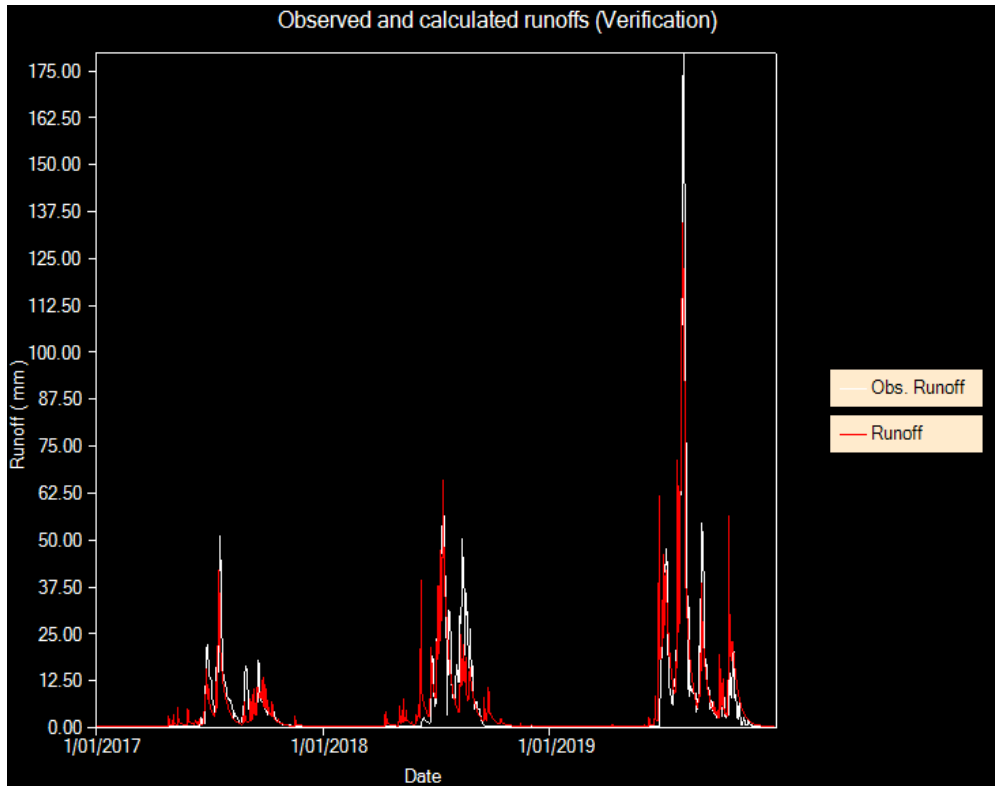


Fig. 17 Comparison between simulated and observed runoff for validation period from 2017 to 2019

3.3 PREDICTION OF STREAM FLOW

The model was run for the entire period (2013 to 2019) that included calibration and validation period at daily basis and monthly basis. It can be seen from the daily simulated and observed graph (Fig. 18) that the model successfully simulated low and medium flow. Though the model was unable to capture the extreme events that occurred in 2019, a good agreement between observed and simulated stream flow was observed with R^2 values of 0.72. A scatter plot between simulated and observed monthly discharge is presented in Fig. 19. A good agreement was observed between observed and simulated discharges with R^2 value of 0.73. Further, it was also observed that the high flow events for more than 1000 m^3/s were underestimated by the model. The observed and simulated monthly stream flow from the year 2013 to 2019 followed similar path when plotted (Fig. 20). The scatter plot between observed and simulated monthly stream flow (Fig. 21) revealed a good agreement between observed and simulated monthly stream flow with R^2 value of 0.89.

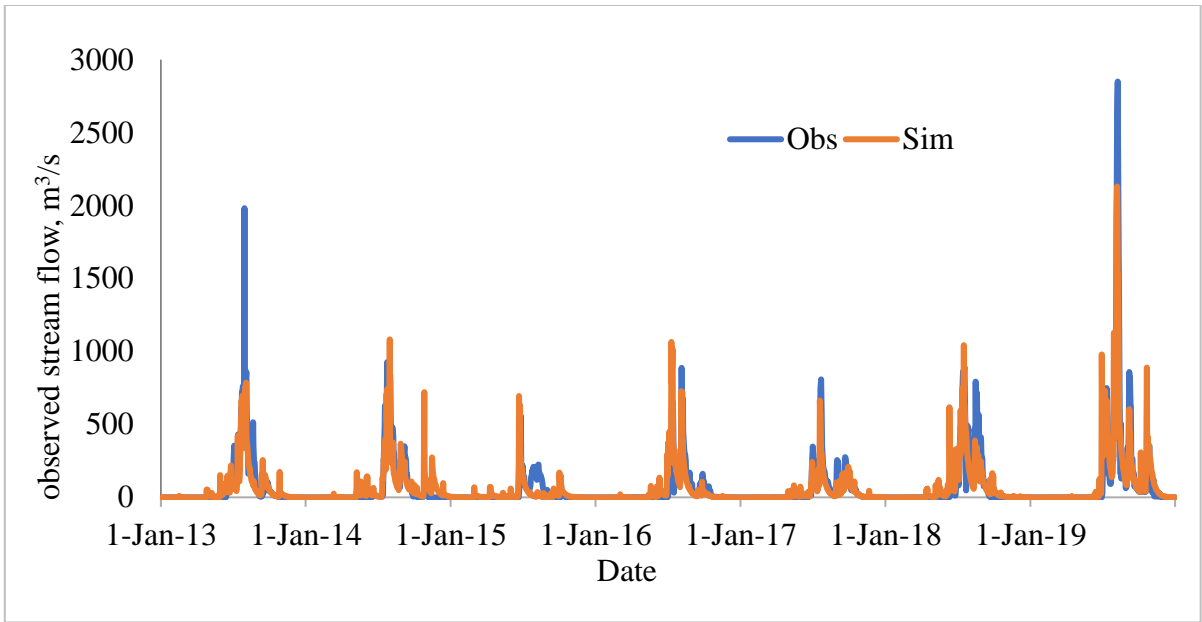


Fig. 18 Comparison of observed and simulated daily stream flow discharge from 2013-2019

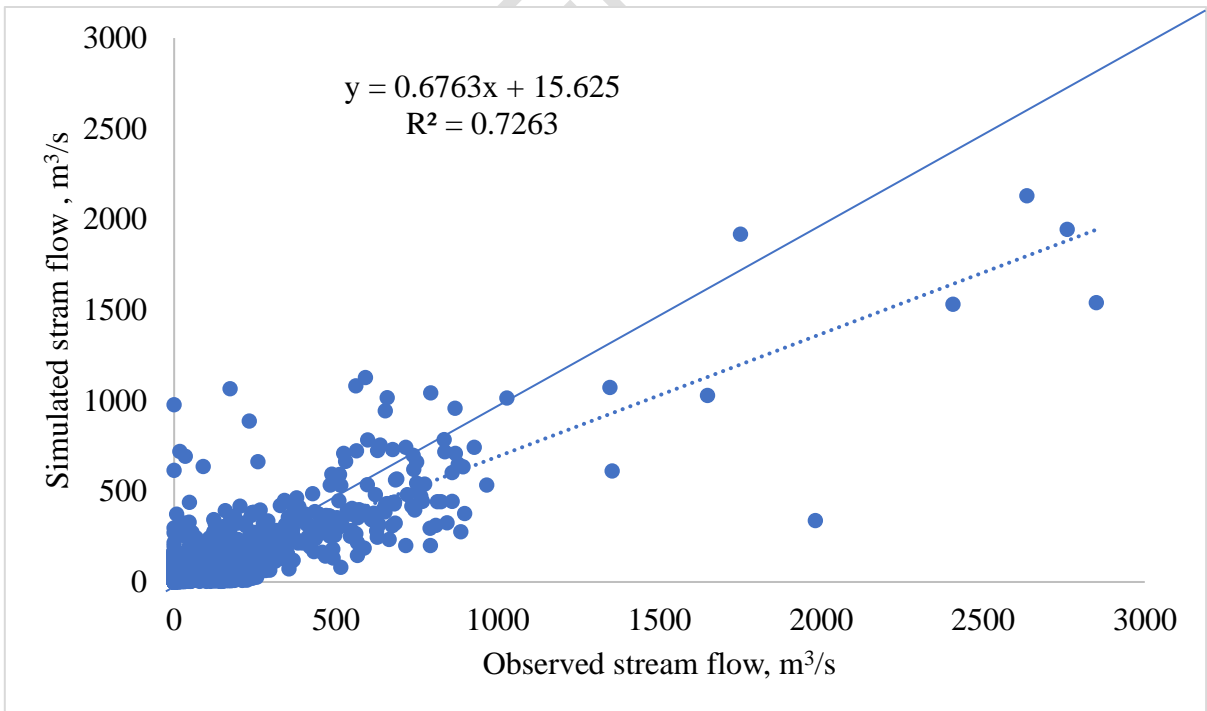


Fig. 19 Scatter plot between observed and simulated daily stream flow from 2013-2019

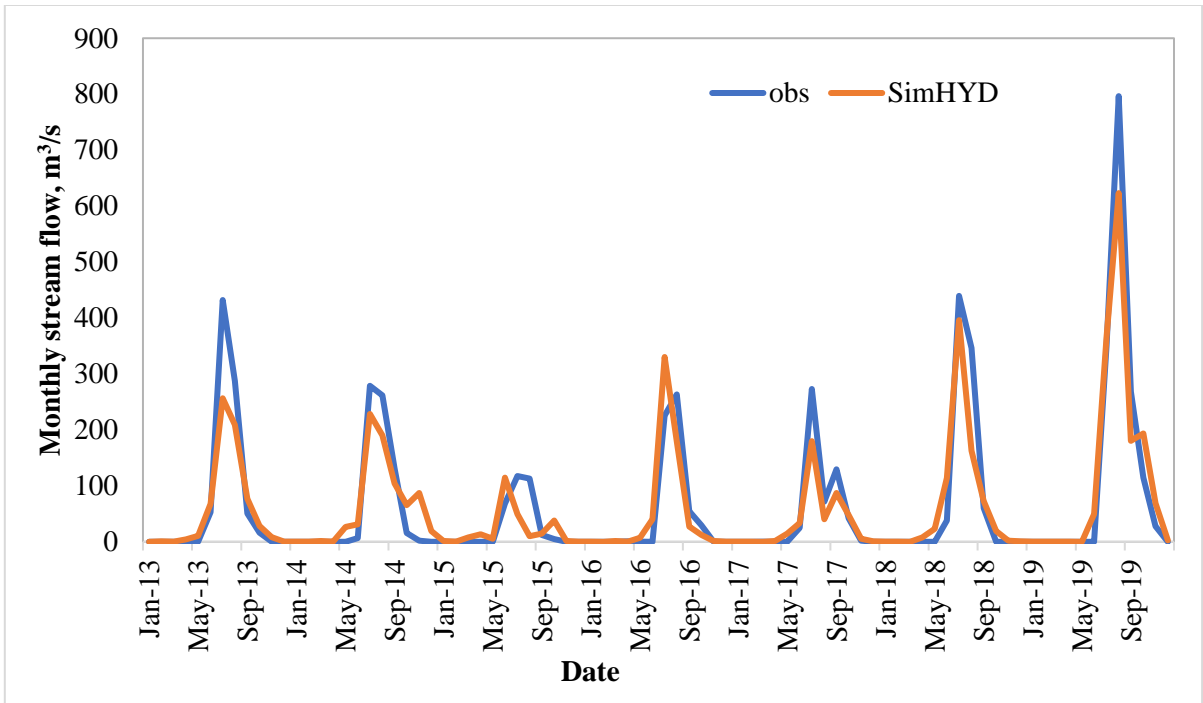


Fig. 20 Comparison of observed and simulated monthly stream flow discharge from 2013-2019

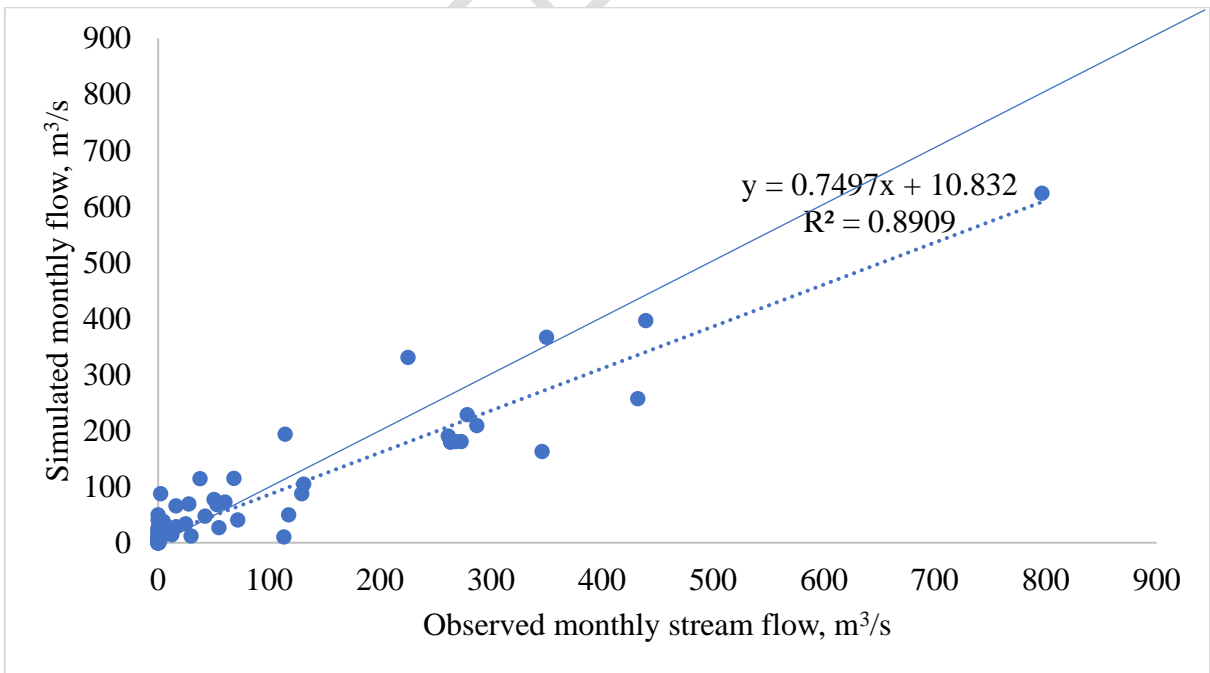


Fig. 21 Scatter plot between observed and simulated monthly stream flow discharge from 2013-2019

4. CONCLUSION

The conceptual lumped model, SIMHYD is calibrated and validated using genetic algorithm of autocalibration for catchment area of Hidkal dam in Krishna Basin of India Karnataka in India. This model could able to simulate the daily stream and monthly stream flow which are close to the observed stream flows. The performance of model measured with statistical indices such as NSE and R^2 for daily and monthly stream flows for both calibration and validation period. It was found that a very good agreement is between observed and monthly stream flows of catchment area of Hidkal dam. The study was concluded that SIMHYD model also could be used to simulate stream flows under limited data conditions.

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