International SWAT Conference June 2023 - Aarhus, Denmark

Hydrological Modeling of Burhanpur Catchment in Tapi River Basin and its Calibration and Uncertainty analysis using sequential uncertainty fitting (SUFI2)

Vishal Chandole
Research Scholar

Dr. Geeta S. Joshi
Associate Professor

Faculty of Technology and Engineering (FTE), The Maharaja Sayajirao University of Baroda

Presentation Outline

- Introduction
- Objective
- Study area
- Hydrological Modeling
- Calibration, Uncertainty & Parameter Sensitivity
- Result
- Conclusion

Introduction

- Hydrological modeling is important for understanding how rainfall transforms into runoff within a catchment. Factors like the catchment's topography, soil type, and land use greatly influence this process.

- The main objective of hydrological modeling is to analyze the connections between rainfall, evapotranspiration, stream flow, and the overall water balance within the catchment, taking into account the varying spatial and temporal scales involved.

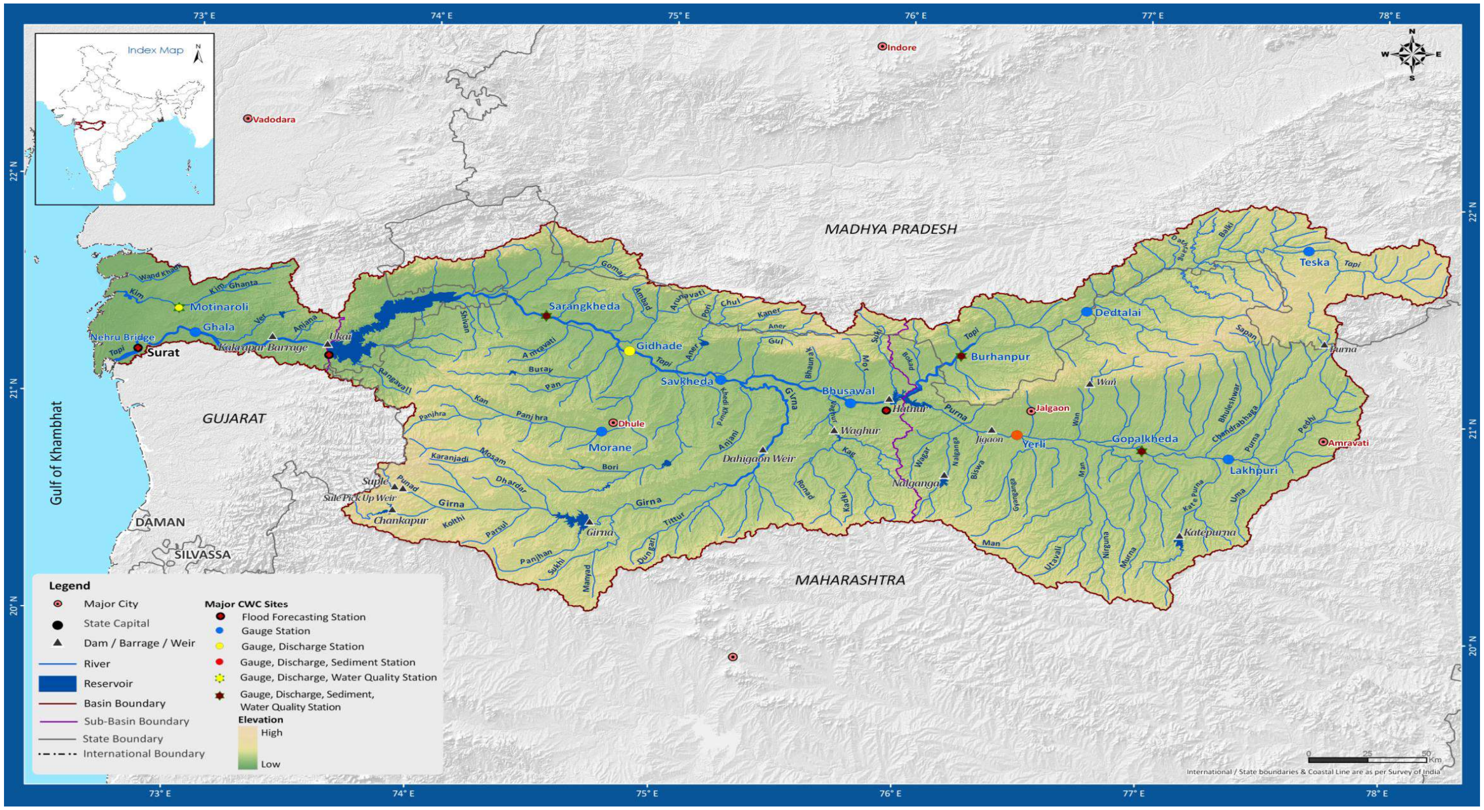
- Hydrological modeling is important because it helps manage water resources, forecast and mitigate floods, assess drought and water scarcity, evaluate environmental impacts, analyze climate change effects, and guide water infrastructure design and operation.

Introduction

- The Burhanpur gauging station is located upstream of the Hathnur dam, which is situated at the confluence of the Purna and Tapi rivers. The Hathnur dam has a live storage capacity of 255 MCM and irrigates 3,78,384 hectares of land. Therefore, it is important to develop a hydrological model to effectively manage the dam and assess the impact of climate change on water resources in the catchment area.

- The Tapi river basin has experienced floods in the past, and Surat, located in the lower Tapi basin, has faced devastating floods. Districts in Maharashtra situated in the Tapi basin, such as Nandurbar, Dhule, and Jalgaon, are prone to drought. Thus, the development of a hydrological model is crucial for implementing effective water management practices in the Tapi river basin.

Introduction



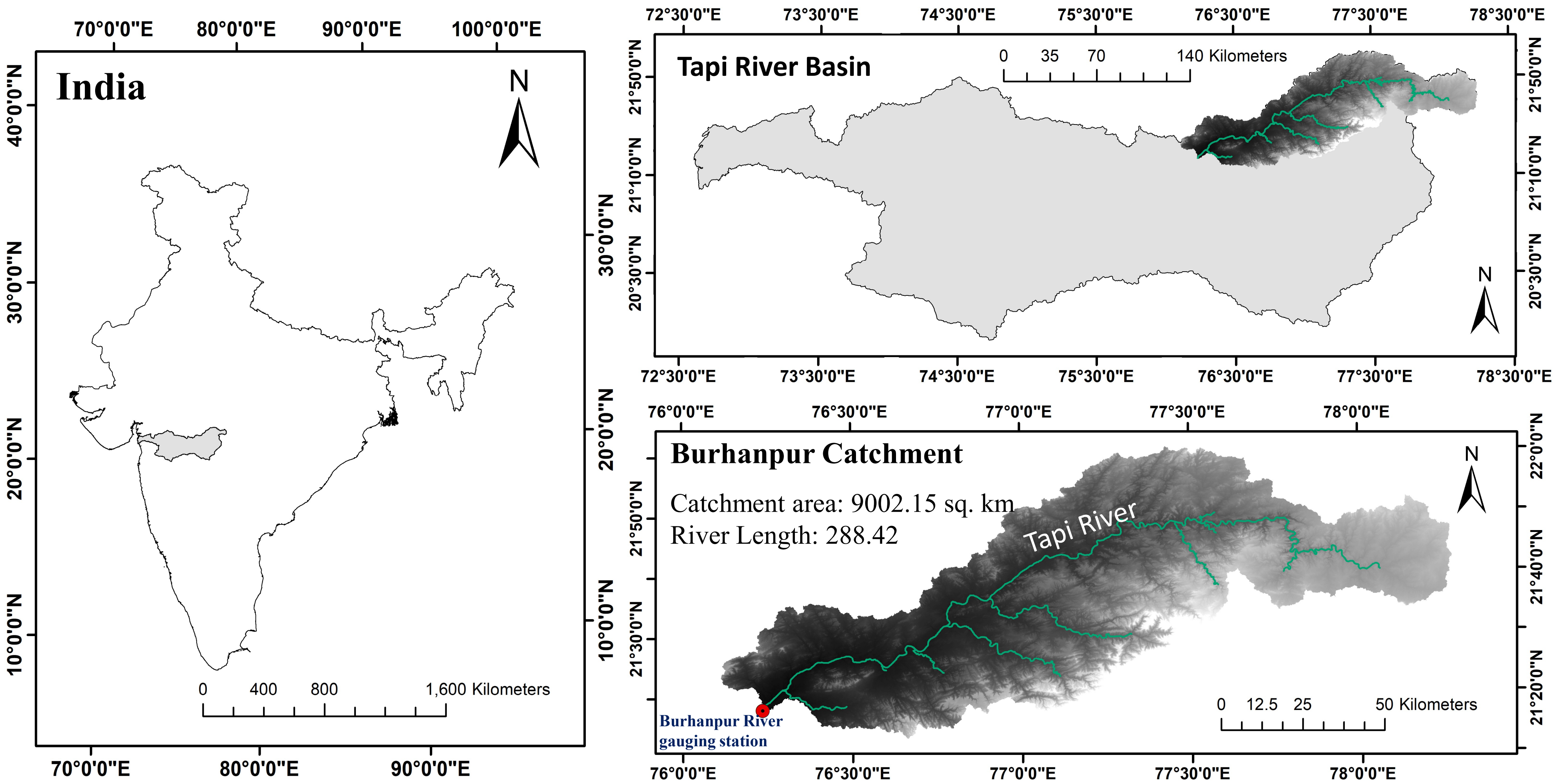
Source: https://indiawris.gov.in/downloads/Tapi%20Basin.pdf

Objective

- Development of Hydrological model using SWAT

- Model Calibration, Uncertainty, Parameter Sensitivity Analysis and Validation of model.

Study area

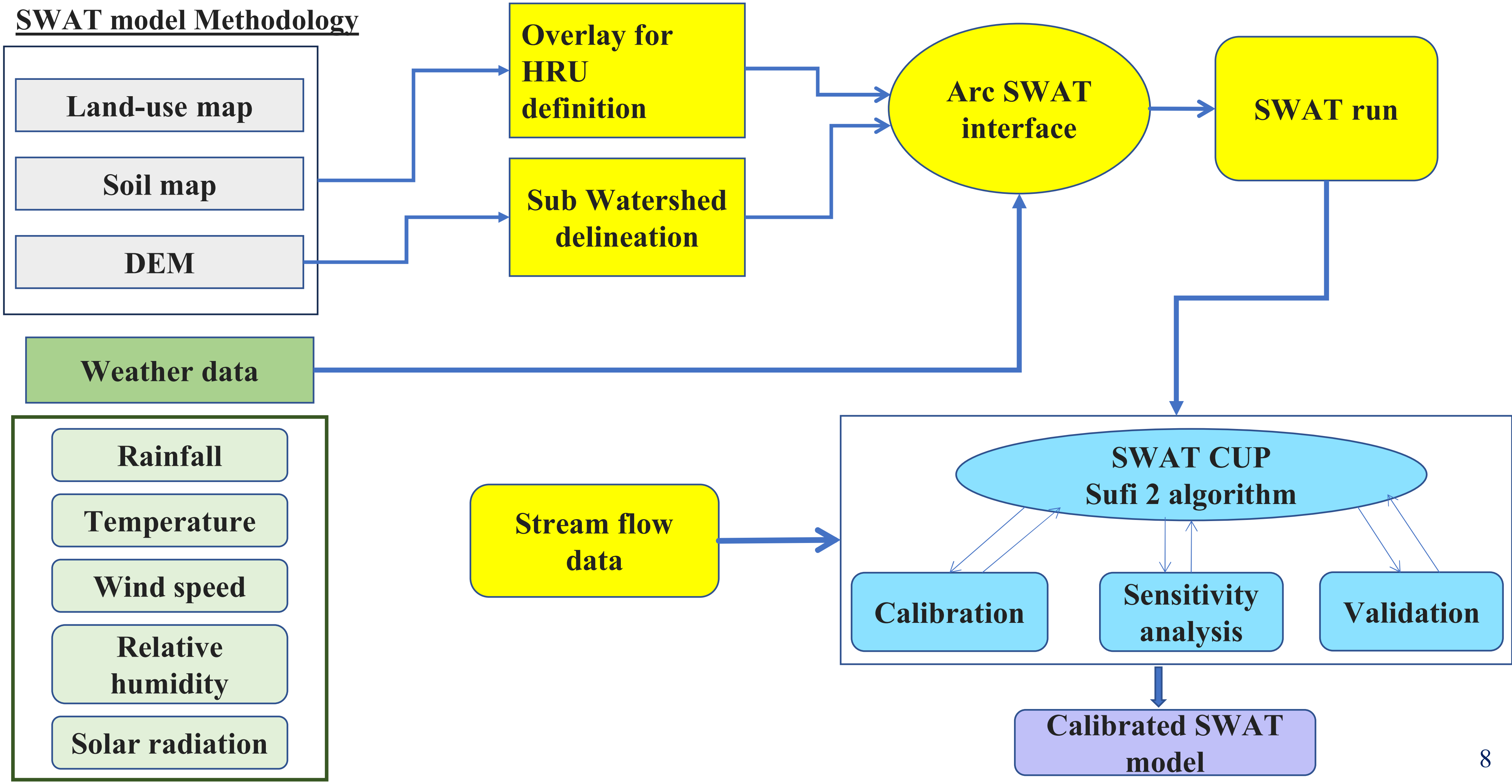


Catchment area: 9002.15 sq. km

River Length: 288.42

Hydrological Modeling

SWAT model Methodology



Land-use map

Soil map

DEM

Overlay for HRU definition

Sub Watershed delineation

Arc SWAT interface

SWAT run

Weather data

- Rainfall
- Temperature
- Wind speed
- Relative humidity
- Solar radiation

Stream flow data

SWAT CUP
Sufi 2 algorithm

Calibration

Sensitivity analysis

Validation

Calibrated SWAT model

Hydrological Modeling

SWAT Modelling Process / SWAT overview

- Arc-SWAT is a tool in ArcGIS software which is used for watershed modellings.
- The ***Soil and Water Assessment Tool (SWAT) is river basin*** scale, semi distributed and continuous-time model.
- Used to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods of time.
- SWAT delineate the watershed into number of sub basins which are joined by a stream network and further divides each sub basins into hydrologic response units (HRUs), with unique combinations of land cover, slope, and soil type.

Hydrological Modeling

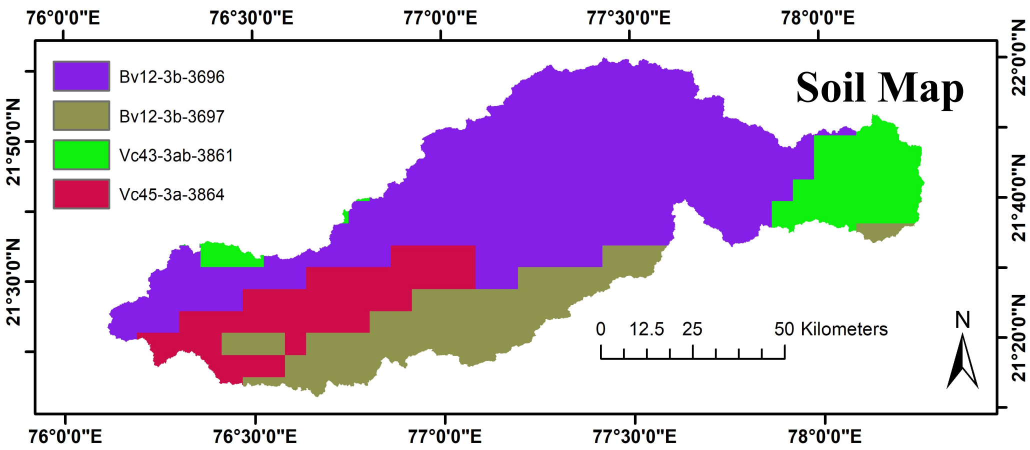
- SWAT uses curve number (CN) (USDA-SCS 1972) to estimated runoff, the Penman–Monteith method (Penman 1956; Monteith 1965) for evapotranspiration, groundwater balance equation for groundwater return flow.

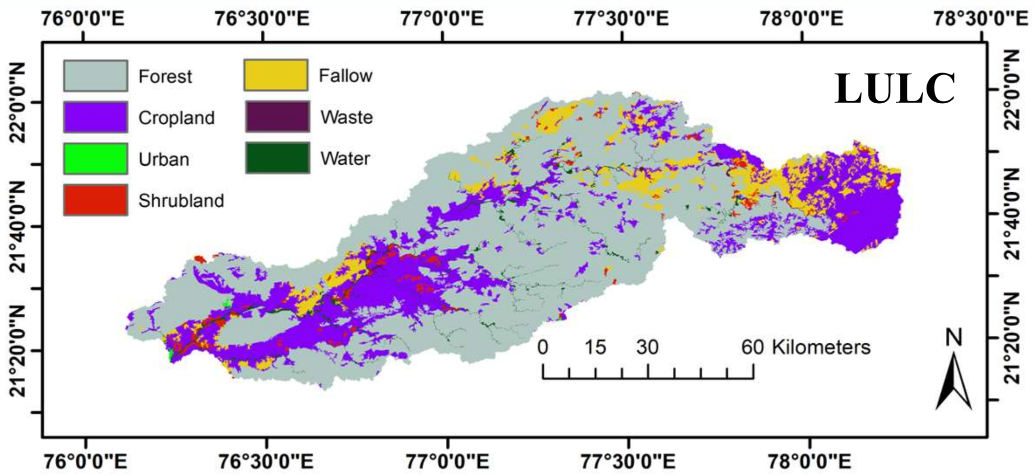
- Simulation was performed on the basis of both land and routing phases, in which the land phase was based on a water balance equation and the routing phase was based on the Muskingum method. The land phase controlled the water movement on land, and in the routing phase, water was routed in the channel network.

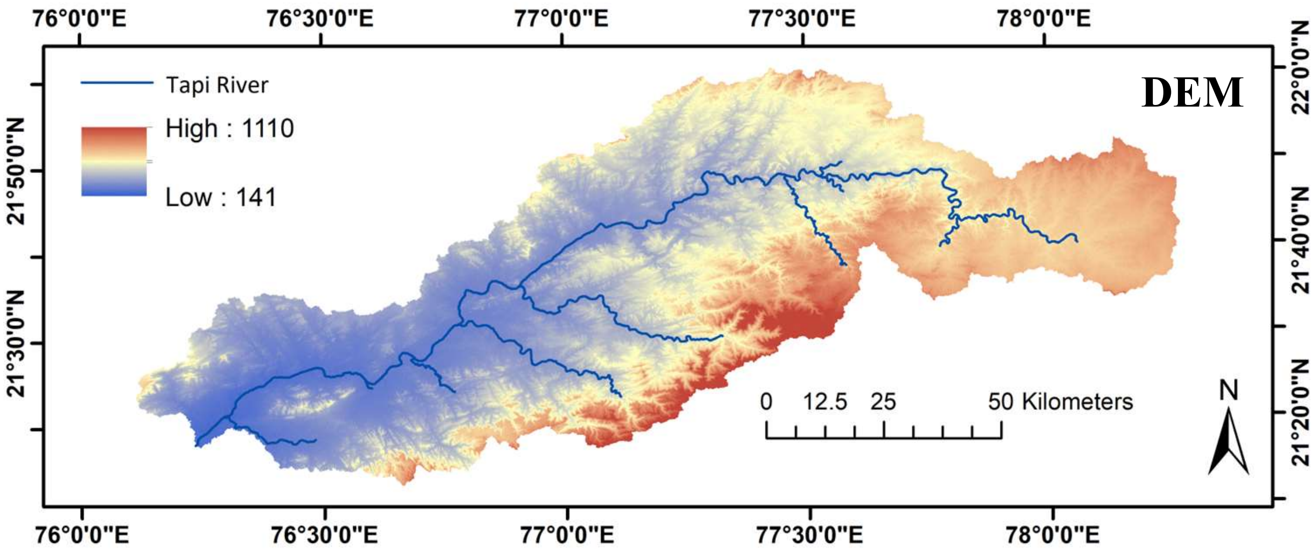
Hydrological Modeling

Data type	Resolution	Data	Source
DEM	30 m	SRTM data	(https://earthexplorer.usgs.gov/)
Soil Map	5 km	FAO-UNESCO Soil Map of the World 1971-1981 (DSMW)	(http://www.fao.org/nr/land/soils/digital-soil-map-of-the-world/Landuse)
Land use	30 m	Landsat 7	https://earthexplorer.usgs.gov/
Weather data		IMD & CFSR	
Stream flow data		Burhanpur (1979 – 2007)	CWC (https://indiawris.gov.in/wris/#/DataDownload)

Hydrological Modeling





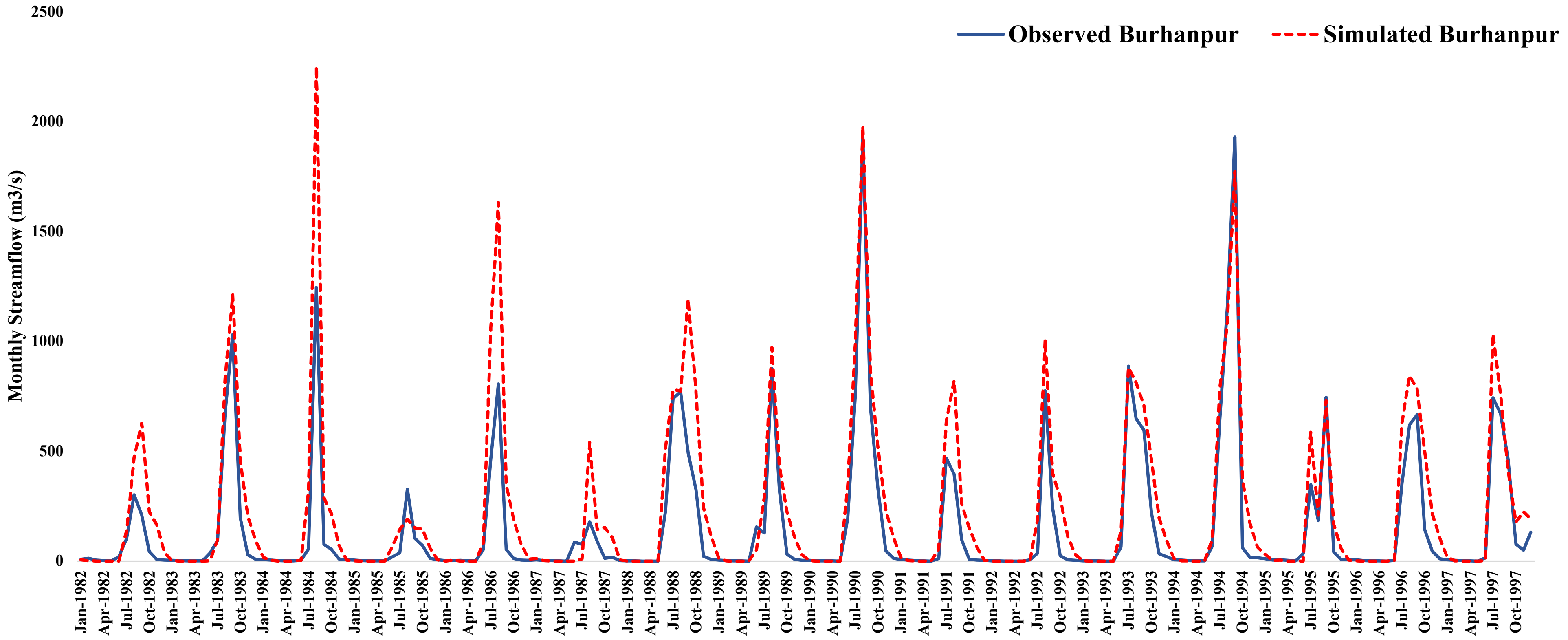


Hydrological Modeling

Weather Data	Resolution	Data Availability	Data used	Source
Rainfall	0.25° × 0.25°	1901-2018	1979-2007	IMD (http://www.imdpune.gov.in/Clim_Pred_LRF_New/Grided_Data_Download.html).
Temperature	1° × 1°	1951-2018	1979-2007	
Relative humidity	0.5° × 0.5°	1979-2013	1979-2007	CFSR (Climate Forecast System Reanalysis(CFSR)) (https://globalweather.tamu.edu/)
Solar radiation	0.5° × 0.5°	1979-2013	1979-2007	
Wind speed	0.5° × 0.5°	1979-2013	1979-2007	

Hydrological Modeling

Default run/ Pre-calibration result



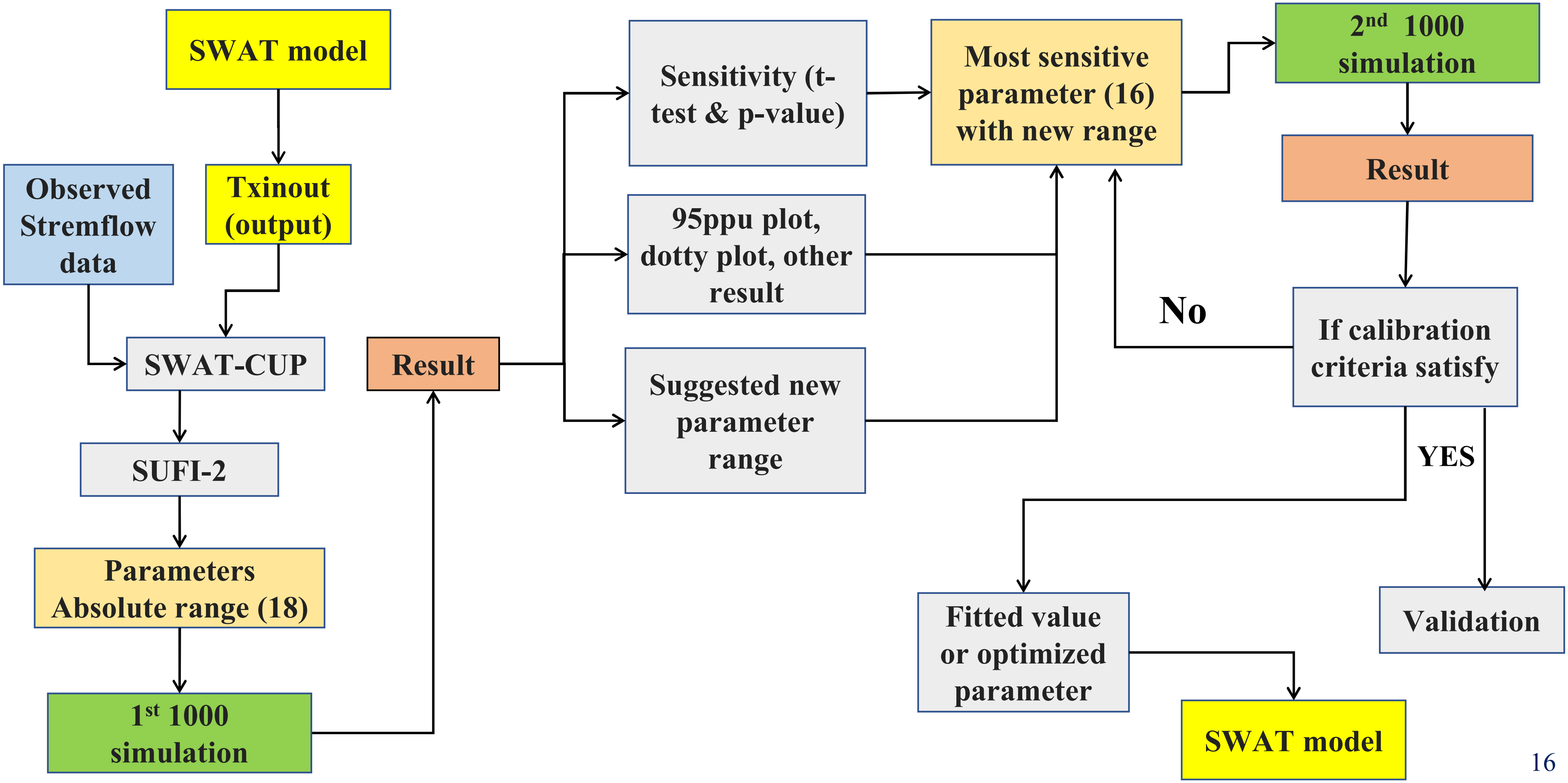
Calibration, Uncertainty & Parameter Sensitivity

- The SWAT Calibration and Uncertainty Program (SWAT-CUP) with sequential uncertainty fitting (SUFI-2) algorithm (Abbaspour et al. 2007) was used for sensitivity analysis, calibration, and validation.

- SUFI-2 uses the Latine Hypercube Sampling (McKay et al. 1979), where parameter uncertainty was quantified in terms of a 95% prediction uncertainty (95 PPU) band, assisted by p-factor and r-factor.

- SWAT model was calibrated for the period 1979-1997 (16 years + 3 years(warm up periods) (1979 to 1981 as warm up periods) and validated for 1998-2007 (10 years) to simulate monthly stream flow (Abbaspour et al. 2011).

Calibration, Uncertainty & Parameter Sensitivity



SWAT model

Txinout (output)

Observed Stremflow data

SWAT-CUP

SUFI-2

Parameters Absolute range (18)

1st 1000 simulation

Result

Sensitivity (t-test & p-value)

95ppu plot, dotty plot, other result

Suggested new parameter range

Most sensitive parameter (16) with new range

2nd 1000 simulation

Result

If calibration criteria satisfy

No

YES

Fitted value or optimized parameter

Validation

SWAT model

Calibration, Uncertainty & Parameter Sensitivity

Sensitivity Analysis

- A global sensitivity analysis approach was followed where all the parameters were allowed to change simultaneously.

- Initially 18 parameters were selected based on the SWAT-CUP manual (Abbaspour 2011) and other related works (Abbaspour et al. 2007; Arnold et al. 2012; Daggupati et al. 2015; Singh et al. 2013; Uniyal et al. 2015).

- Of the 18 parameters used for calibration, Initially, a wider parameter range was given as input because of a lack of knowledge of the behavior of the parameters in the basin.

Calibration, Uncertainty & Parameter Sensitivity

Sensitivity Analysis

- Initially first 1000 SWAT-CUP simulation is performed and after that the global sensitivity analysis carried out.
- Following observation of the t-stat and p-value, 16 parameters were considered most sensitive (Table) and used for model calibration and validation.
- Following the global sensitivity plot (t-stat and p-value plot), 16 parameters were considered most sensitive (Table) and used for model calibration and validation.

Calibration, Uncertainty & Parameter Sensitivity

Model Calibration and Validation

- Perform the second 1000 simulation for most sensitive parameter based on global sensitivity analysis, dotty plot, 95 ppu (percentage prediction uncertainty) plot and new suggested range by first 1000 simulation .

- If result after second simulation is satisfying than perform the validation for same range of parameter. If result is not satisfying than run third 1000 simulation for new range of parameter suggested by the second simulation.

- In current study total five times-1000 simulation is perform (Adhikary et al. (2019)) and third 1000 simulation found less uncertainty (p and r factor) and good correlation coefficient (NSE, R2, PBIAS, RSR) compare to other simulation.

Calibration, Uncertainty & Parameter Sensitivity

Model Calibration and Validation

- To predict uncertainty, the p-factor and r-factor were determined. Closeness to 1 for the p-factor and a small r-factor value (closer to 0) gave better results in the prediction of uncertainty (Abbaspour et al. 2007; Abbaspour 2011).

1) **p-factor**: percentage of observed data enveloped by modelling result
2) **r-factor**: achievement of a small uncertainty band or thickness of 95 PPU envelope
3) **R^2** : coefficient of determination
4) **NSE** (Nash–Sutcliffe coefficient): The NSE indicates how well the simulated and observed data fit the 1:1 line.
5) **RSR** (root-mean square and standard deviation ratio): RSR is an error index statistic that varies from 0 to 1. A lower RSR value gives better model simulation performance.
6) **PBIAS** (percentage bias): PBIAS is the statistical tendency of simulated data to be smaller or larger than the observed data. A positive value indicates bias underestimation, while a negative value indicates bias overestimation (Gupta et al. 1999).

Calibration, Uncertainty & Parameter Sensitivity

Parameter		t-Stat	P-Value
r_CN2.mgt (-0.2, 0.2)	SCS runoff curve number	-12.69	0.00
v_RCHRGDP.gw (0, 1)	Deep aquifer percolation fraction.	-4.26	0.00
v_GWREVAP.gw (0, 0.25)	Groundwater "revap" coefficient.	3.14	0.00
v_GWDELAY.gw (0, 300)	groundwater delay	2.96	0.00
v_ALPHABNK.rte (0, 1)	base flow alpha factor for bank storage	2.17	0.03
r_SLSUBBSN.hru (-0.2, 0.2)	Average slope steepness	1.85	0.06
r_SOLK(1).sol (-0.2, 0.2)	saturated hydraulic conductivity	1.26	0.21
v_ALPHA_BF.gw (0, 1)	Baseflow alpha factor (days).	1.16	0.24
v_HRU_SLP (0, 1)	Average slope steepness	1.07	0.29
v_REVAPMN.gw (0, 500)	threshold depth of water in shallow aquifer required for “revap” to occur	0.75	0.46
v_GWQMN.gw (0, 5000)	Threshold depth of water in the shallow aquifer required for return flow to occur (mm).	-0.44	0.66
v_SURLAG.bsn (0.05, 24)	Surface runoff lag time.	0.31	0.75
v_OVN.hru (0.01, 30)	Manning’s “n” value for overland flow	-0.21	0.83
r_SOLBD(1).sol (-0.2, 0.2)	moist bulk density	0.19	0.85
v_ESCO.hru (0, 1)	Soil evaporation compensation factor.	0.06	0.95
v_CHN2.rte (0, 0.3)	Manning's "n" value for the main channel.	-0.05	0.96
v = replacement of parameter values, r = percentage change in parameter value			

Calibration, Uncertainty & Parameter Sensitivity

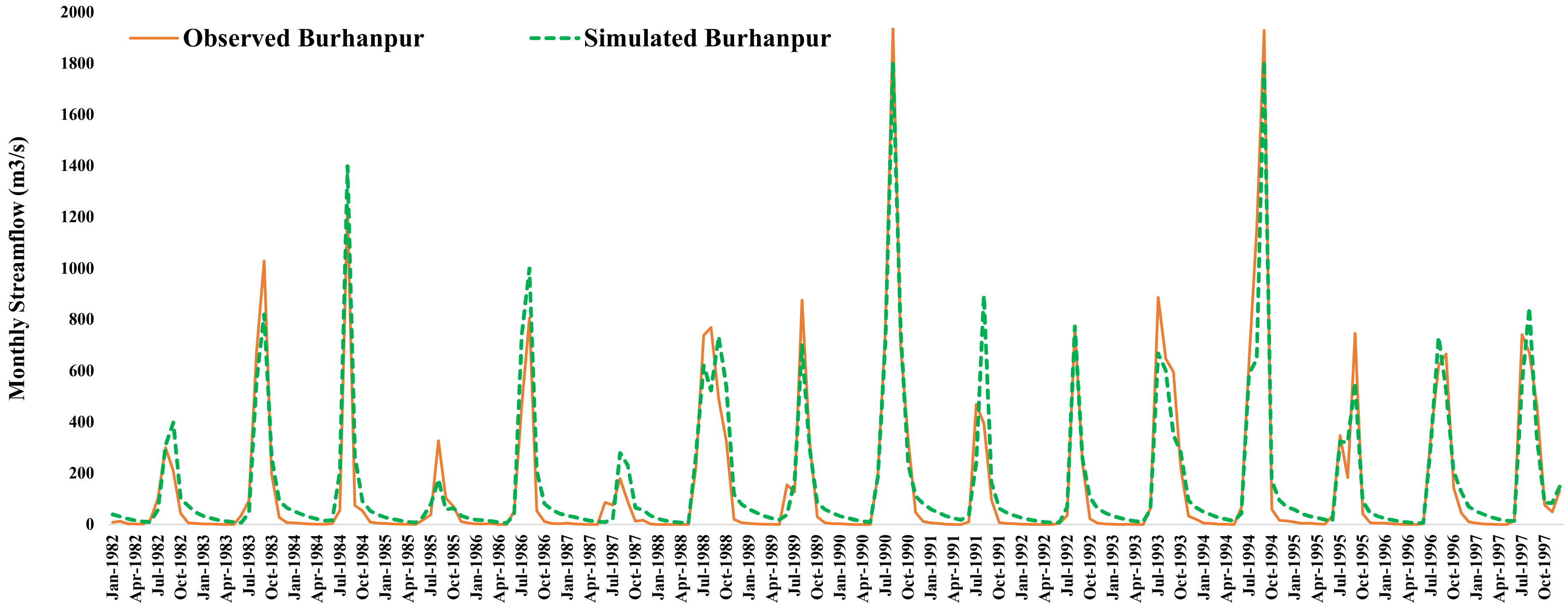
Final each parameter fitted value

Parameter	Fitted Value	Min value	Max value
R__CN2.mgt	-0.06	-0.14	0.09
V__ALPHA_BF.gw	0.65	0.40	1.00
V__GW_DELAY.gw	34.08	0.00	153.18
V__GWQMN.gw	2694.50	2000	5000
V__GW_REVAP.gw	0.17	0.03	0.18
V__ESCO.hru	0.75	0.26	0.79
V__CH_N2.rte	0.23	0.12	0.30
R__HRU_SLP.hru	0.12	0.00	0.20
V__ALPHA_BNK.rte	0.71	0.30	1.00
R__SOL_K(..).sol	-0.02	-0.07	0.18
R__SOL_BD(..).sol	0.06	-0.01	0.20
V__REVAPMN.gw	246.40	170	500
V__RCHRG_DP.gw	0.24	0.00	0.65
V__SURLAG.bsn	16.56	8.95	25.00
V__OV_N.hru	19.71	10	30
R__SLSUBBSN.hru	0.01	-0.20	0.04

Calibration, Uncertainty & Parameter Sensitivity

Model Calibration Result

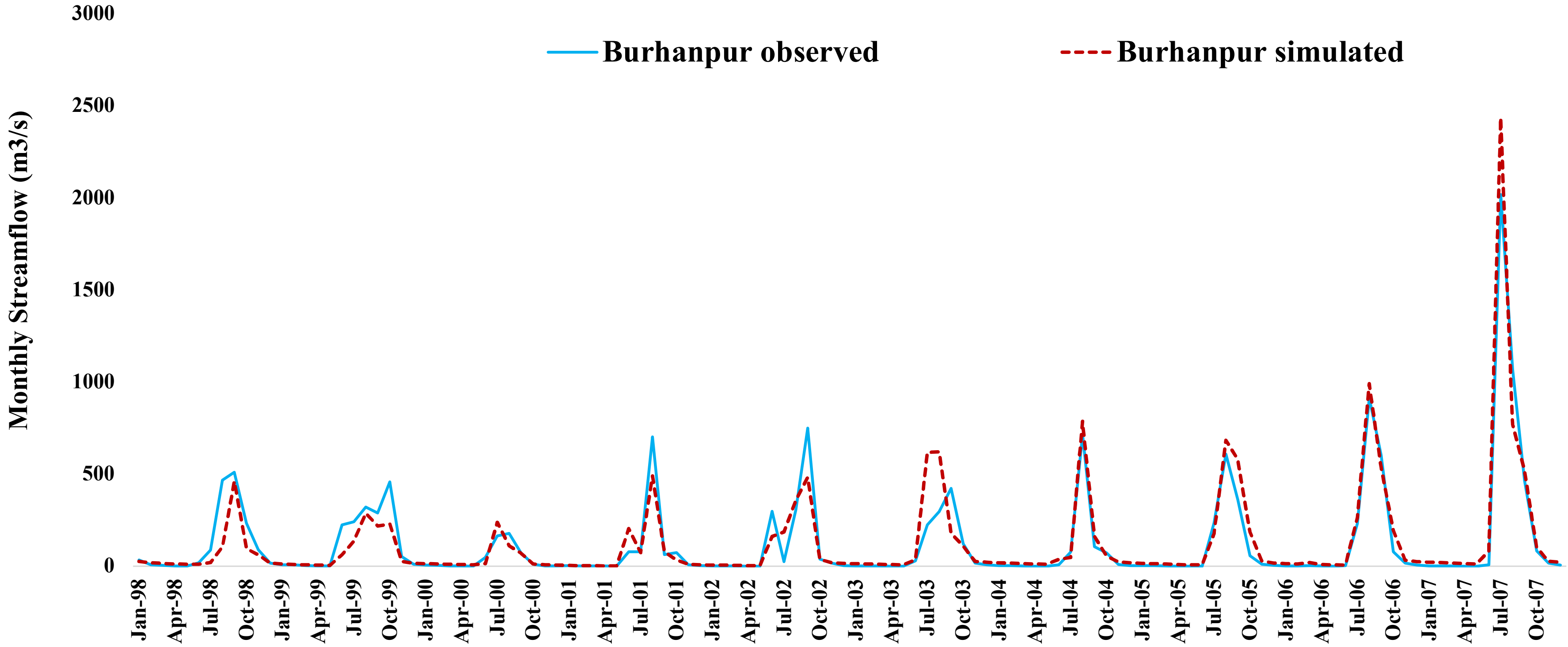
p-factor	r-factor
0.7	0.46



Calibration, Uncertainty & Parameter Sensitivity

Model Validation Result

p-factor	r-factor
0.68	0.32



Calibration, Uncertainty & Parameter Sensitivity

Station	**Period**	**R^2**	**NSE**	**RSR**	**PBIAS**
Burhanpur	Calibration	0.85	0.84	0.4	-12.8
	Validation	0.79	0.77	0.45	11.7

Performance rating	**NSE**	**RSR**	**PBIAS**
Very good	$0.75 \leq NSE \leq 1.00$	$0.00 \leq RSR \leq 0.50$	$PBIAS < \pm 10$
Good	$0.65 < NSE \leq 0.75$	$0.50 < RSR \leq 0.60$	$\pm 10 \leq PBIAS < \pm 15$
Satisfactory	$0.50 < NSE \leq 0.65$	$0.60 < RSR \leq 0.70$	$\pm 15 \leq PBIAS < \pm 25$
Unsatisfactory	$NSE \leq 0.50$	$RSR > 0.70$	$PBIAS \geq \pm 25$

(Moriasi et al. (2007) Suggested a general performance rating for recommended statistics for a monthly time step)

Conclusion

- The calibration and validation statistics of the model indicate that it performs well in predicting observed discharges.
- This suggests that the model can be effectively applied to various watershed management studies and related purposes.

Future Scope

- Incorporate projected downscaled climatic data to assess the impact of climate change on water resources within the catchment.

- Utilize high-resolution spatial data and advanced climatic data, such as ERA 5 data, to enhance accuracy.

References

- USDA-SCS (U.S. Department of Agriculture-Soil Conservation Service). 1972. National engineering handbook hydrology chapters.Washington, DC: USDA.

- Penman, H. L. 1956. “Estimating evaporation.” Trans. Am. Geophys. Union 37 (1): 43–50. https://doi.org/10.1029/TR037i001p00043.

- Monteith, J. L. 1965. “Evaporation and environment.” Vol. 19 of The state and movement of water in living organisms: Symposia of the society for experimental biology, edited by P. G. Fogg, 205–234. Cambridge, UK: Cambridge University Press.

- Abbaspour, K. C., J. Yang, I. Maximov, R. Siber, K. Bogner, J. Mieleitner, J. Zobrist, and R. Srinivasan. 2007. “Modelling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT.” J. Hydrol. 333 (2–4): 413–430. https://doi.org/10.1016/j.jhydrol.2006.09.014.

- Mckay, M. D., R. J. Beckman, and W. J. Conover. 1979. “A comparison of three methods for selecting values of input variables in the analysis of output from a computer code.” Technometrics 21 (2): 239–245. https://doi.org/10.2307/1268522.

References

- Abbaspour, K. C. 2011. SWAT calibration and uncertainty programs: A user manual. Dubendorf, Switzerland: Swiss Federal Institute of Aquatic Science and Technology, Eawag.

- Arnold, J. G., et al. 2012. “SWAT: Model use, calibration and validation.” Trans. ASABE 55 (4): 1491–1508. https://doi.org/10.13031/2013.42256.

- Daggupati, P., H. Yen, M. J. White, R. Srinivasan, J. G. Arnold, C. S. Keitzer, and S. P. Sowa. 2015. “Impact of model development, calibration and validation decisions on hydrological simulations in West Lake Erie Basin.” Hydrol. Process. 29 (26): 5307–5320. https://doi.org/10 .1002/hyp.10536.

- Singh, V., N. Bankar, S. S. Salunkhe, A. K. Bera, and J. R. Sharma. 2013.“Hydrological streamflow modeling on Tungabhadra basin: Parameterization and uncertainty analysis using SWAT CUP.” Curr. Sci. 104 (9): 1187–1199.

- Uniyal, B., M. K. Jha, and A. K. Verma. 2015. “Parameter identification and uncertainty analysis for simulating streamflow in a river basin of Eastern India.” Hydrol. Process. 29 (17): 3744–3766. https://doi.org/10.1002/hyp.10446.

References

- Gupta, H. V., S. Sorooshian, and P. O. Yapo. 1999. “Status of automatic calibration for hydrologic models: Comparison with multilevel expert calibration.” J. Hydrol. Eng. 4 (2): 135–143. https://doi.org/10.1061/(ASCE)1084-0699(1999)4:2(135).

- Moriasi, D. N., M. W. Van Liew, R. L. Bingner, R. D. Harmel, and T. L. Veith. 2007. “Model evaluation guidelines for systematic quantification of accuracy in watershed simulations.” Trans. ASABE 50 (3): 885–900. https://doi.org/10.13031/2013.23153.

- SRTM and Landsat data: (https://earthexplorer.usgs.gov/).

- FAO-UNESCO Soil Map of the World 1971-1981 (DSMW): (http://www.fao.org/nr/land/soils/digital-soil-map-of-the-world/Landuse).

- IMD Pune: (http://www.imdpune.gov.in/Clim_Pred_LRF_New/Grided_Data_Download.html).

- CFSR: (https://globalweather.tamu.edu/).

Thank You