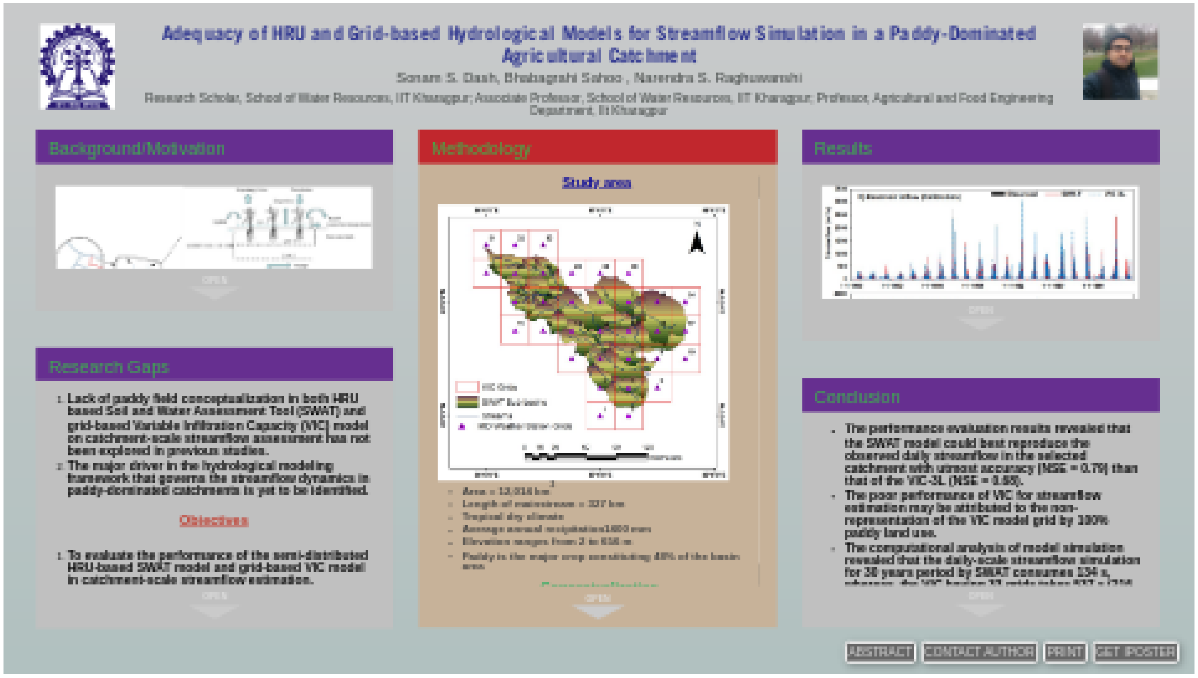
Adequacy of HRU and Grid-based Hydrological Models for Streamflow Simulation in a Paddy-Dominated Agricultural Catchment



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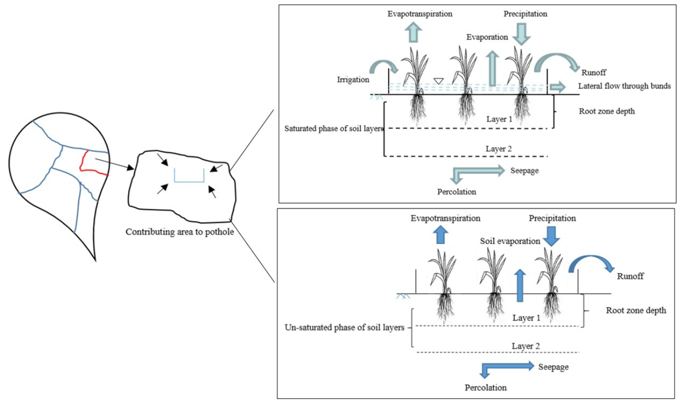
PRESENTED AT:

AGU FALL MEETING

Online Everywhere | 1–17 December 2020

BACKGROUND/MOTIVATION



- **The presence of standing water in the paddy fields reduces the flow at downstream catchments to a greater extent**
- **High water requirement stimulates the irrigation operation**
- **Near saturated field condition in the paddy fields alters the catchment hydrology substantially**
- **The water-saving Alternate Wetting and Drying (AWD) approach poses a dynamic hydrologic behavior due to the presence of intermittent drainage phases**
- **Accurate assessment of water resources is crucial from a management perspective**

Motivation

- **The inherent complexity and heterogeneity associated with hydrologic interactions over a wide range of spatiotemporal domain are the major challenges in conceptualizing hydrologic cycle**
- **Catchment-scale hydrologic models often possess distinct structures and methodology in conjunction with varying model inputs.**
- **A relatively flexible representation of catchment heterogeneity by HRU-based model may have an edge over grid-based models**
- **Simulation across larger spatiotemporal domain may have varying computational efficiency based on the grid or HRU representation**

RESEARCH GAPS

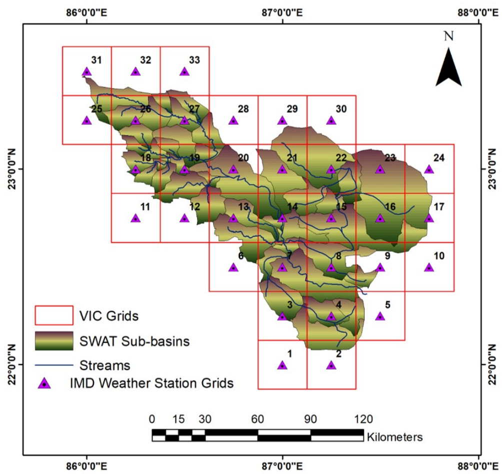
1. **Lack of paddy field conceptualization in both HRU based Soil and Water Assessment Tool (SWAT) and grid-based Variable Infiltration Capacity (VIC) model on catchment-scale streamflow assessment has not been explored in previous studies.**
2. **The major driver in the hydrological modeling framework that governs the streamflow dynamics in paddy-dominated catchments is yet to be identified.**

Objectives

1. **To evaluate the performance of the semi-distributed HRU-based SWAT model and grid-based VIC model in catchment-scale streamflow estimation.**
2. **To analyze the computational burden caused due to varying spatiotemporal representation of catchment heterogeneity by both HRU and grid-based modeling approaches.**

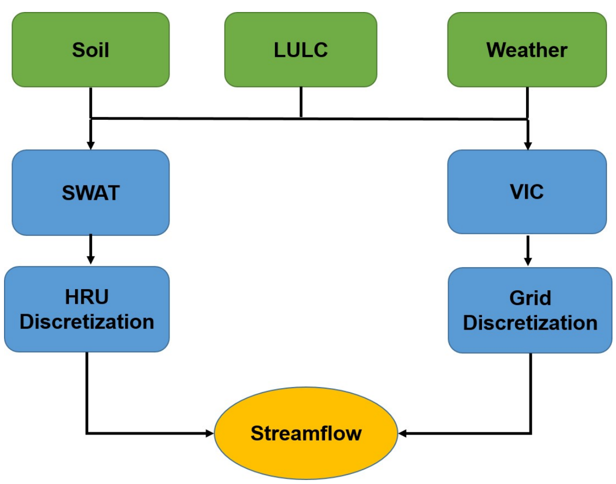
METHODOLOGY

Study area



- **Area = 12,014 km^2**
- **Length of mainstream = 327 km**
- **Tropical dry climate**
- **Average annual recipitation1400 mm**
- **Elevation ranges from 2 to 656 m**
- **Paddy is the major crop constituting 48% of the basin area**

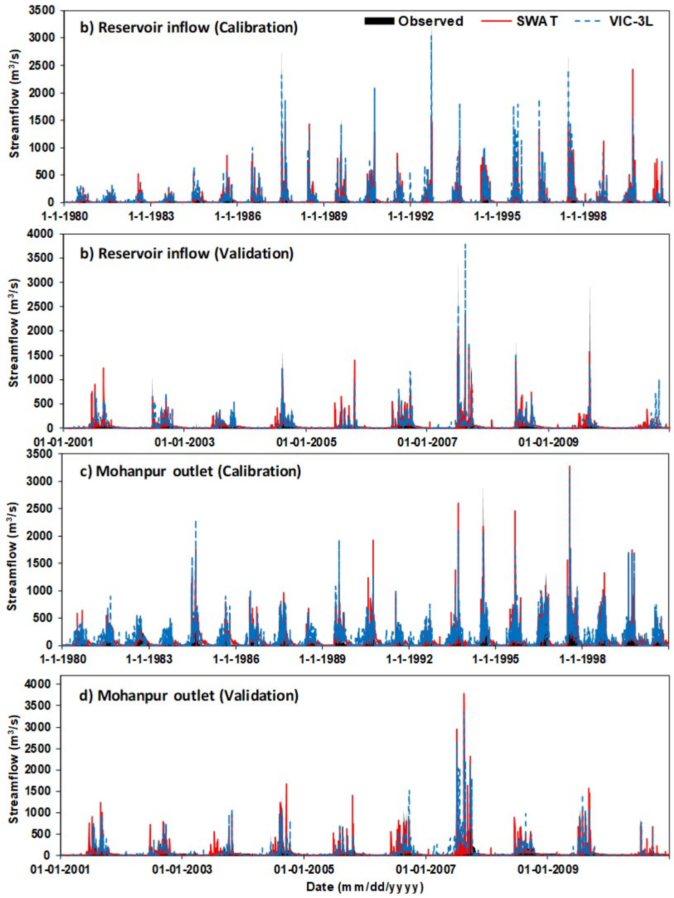
Conceptualization

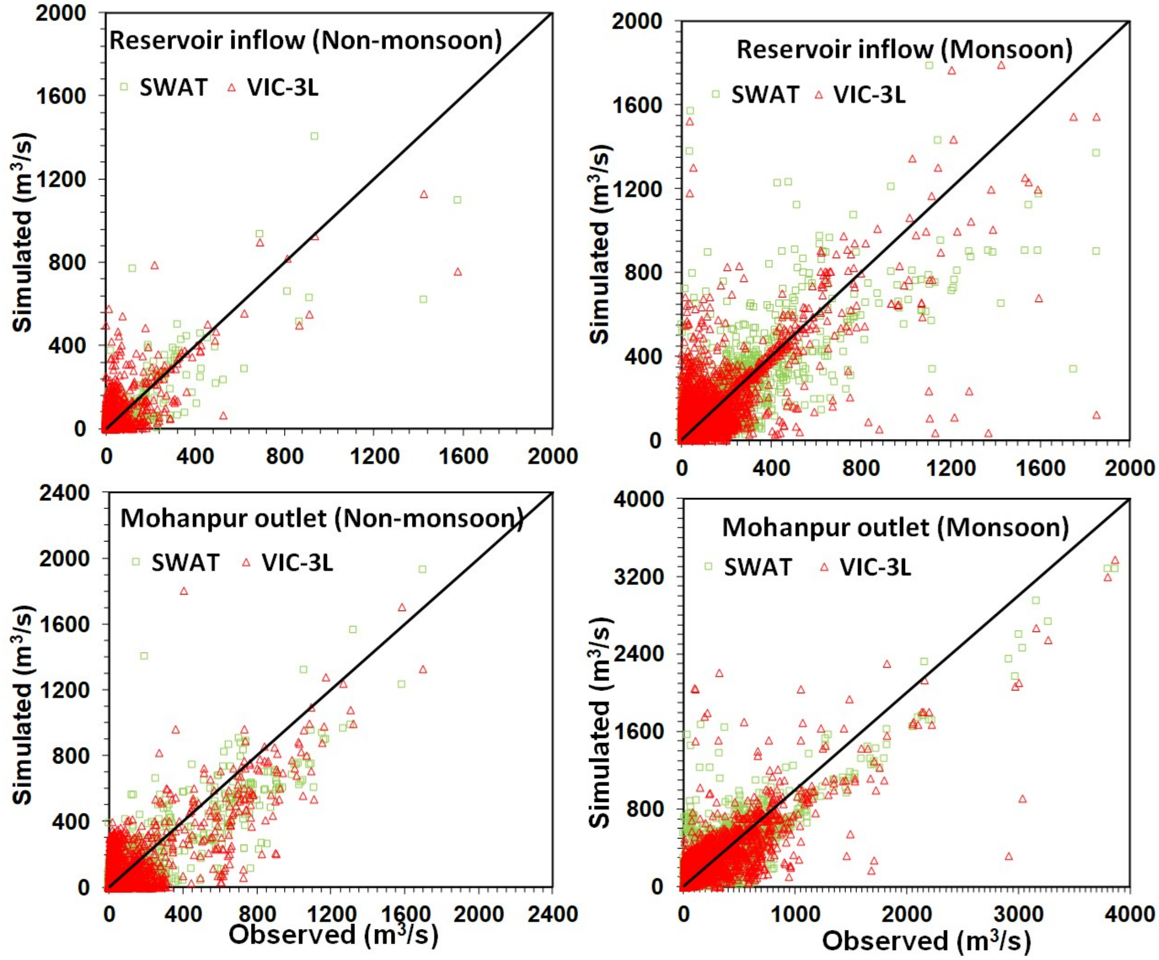


Sensitivity ranking	Parameter	Description	Calibrated value
1	GW_REVAP.gw	Groundwater revap coefficient	0.71
2	SOL_K.sol	Soil hydraulic conductivity (mm/h)	2.27-8.45
3	CN2.mgt	Curve number for AMC-II condition	37.43-80.72
4	CH_K2.rte	Effective hydraulic conductivity in main channel alluvium (mm/h)	50.65
5	REVAPMN.gw	Threshold depth of water in the shallow aquifer for percolation or revap (mm)	15.37
6	ALPHA_BF.gw	Baseflow alpha factor (1/days)	0.72
7	GWQMN.gw	Threshold depth of water in the shallow aquifer for return flow (mm)	132.89
8	OV_N.hru	Manning's "n" value for overland flow	0.04-0.14
9	SOL_AWC.sol	Available soil water content (mm/mm)	0.17-0.35
10	HRU_SLP.hru	HRU slope (m/m)	0.21-0.54

Sensitivity ranking	Parameter	Description	Fitting value (Lower basin)	Fitting value (Upper basin)
1	b_{inf}	Variable infiltration curve parameter	0.21	0.26
2	D_s	D_{smax} fraction where nonlinear baseflow originates	0.42	0.54
3	W_s	Fraction of soil moisture where nonlinear baseflow originates	0.50	0.70
4	d_1	Thickness of top (first) soil layer (m)	0.10	0.10
5	d_2	Thickness of second soil layer (m)	0.20	0.20
6	d_3	Thickness of third soil layer (m)	0.70	0.90

RESULTS


b) Reservoir inflow (Calibration)
Observed
SWAT
VIC-3L
Streamflow (m³/s)
b) Reservoir inflow (Validation)
c) Mohanpur outlet (Calibration)
d) Mohanpur outlet (Validation)
Date (mm/dd/yyyy)



Model	Location	Calibration				Validation			
		NSE (-)	R^2 (-)	RMSE (m^3/s)	PBIAS (%)	NSE (-)	R^2 (-)	RMSE (m^3/s)	PBIAS (%)
SWAT	Reservoir inflow	0.73	0.72	75.20	-1.5	0.68	0.67	95.80	-12.30
	Mohanpur	0.79	0.79	99.78	9.70	0.64	0.66	111.26	-21.50
VIC	Reservoir inflow	0.68	0.71	80.17	25.40	0.66	0.67	97.74	-1.20
	Mohanpur	0.66	0.69	120.65	13.70	0.60	0.67	116.26	-6.7

CONCLUSION

- **The performance evaluation results revealed that the SWAT model could best reproduce the observed daily streamflow in the selected catchment with utmost accuracy (NSE = 0.79) than that of the VIC-3L (NSE = 0.68).**
- **The poor performance of VIC for streamflow estimation may be attributed to the non-representation of the VIC model grid by 100% paddy land use.**
- **The computational analysis of model simulation revealed that the daily-scale streamflow simulation for 30 years period by SWAT consumes 134 s, whereas, the VIC having 33 grids takes 537 s (216 s for flux generation and 521 s for routing) with the possibility of getting stuck with an increased number of grids and model simulation periods.**

References

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Chu, X., Lin, Z., Nasab, M.T., Zeng, L., Grimm, K., Bazrkar, M.H., Wang, N., Liu, X., Zhang, X., Zheng, H., 2019. Macro-scale grid-based and subbasin-based hydrologic modeling: joint simulation and cross-calibration. Journal of Hydroinformatics, 21(1),77-91.

ABSTRACT

Catchment-scale streamflow assessment in the paddy-dominated catchments using the available hydrological models is highly intricate due to the presence of significant ponding water during the rainy season and irrigation events. While the Soil and Water Assessment Tool (SWAT) and Variable Infiltration Capacity (VIC) model could be some suitable options for this, the model conceptualization, discretization of spatial domain, involved computational time, and these integrated effects on streamflow simulation are yet to be evaluated. Hence, this study evaluates the performances of the semi-distributed hydrologic response unit (HRU) based SWAT-pothole and grid-based VIC model for catchment-scale streamflow simulation; and subsequently, assesses the effect of the spatial domain representation of the catchment on the model computational requirement. The selected study is the 12,014 km^2 Kangsabati River basin (KRB) of eastern India that consists of about 46% paddy land use with the tropical monsoon type climate having complex paddy field dynamics.

SWAT is set up for the whole KRB using the add-in reservoir module; whereas the VIC model, due to the absence of reservoir module, is set up individually for the upstream river catchment and the downstream reservoir-catchment command. The SWAT setup consisted of 44 and 191 discrete sub-basins and HRUs, respectively. Conversely, the VIC setup resulted in 31 grids with 0.25°0.25° spatial discretization. The model simulation results reveal that the SWAT-pothole approach performed better with the Nash-Sutcliffe Efficiency (NSE) estimate of 0.79 than the standalone VIC model (NSE=0.68). However, the other water balance components, viz. evapotranspiration, baseflow, and percolation are far away from reality in both the models which could be attributed to the non-accountability of irrigation return flow by the SWAT-pothole model. The inferior water balance simulation in VIC could be aggravated due to the absence of crop management module and ignorance of explicit paddy land use class in a VIC grid. These findings highlight the future scope of including more dynamic spatial representation of paddy land use in the SWAT and VIC model domain for their application in other similar world river basins.