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APPLICATION OF SOIL WATER ASSESSMENT TOOL (SWAT) FOR HILLY REGION OF TONS RIVER BASIN

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ABSTRACT

In high altitude regions, with a dominant cover of snow, snow melt contribution to river flow is an important factor in increasing the discharge. Hydrological modelling of a hilly watershed provides useful information about the water balance of the region. Knowledge of various hydrological components helps in assessing the components that have a significant bearing on the water balance, which also assists in planning a suitable water supply and allocation design for the downstream areas. SWAT can simulate the contribution of different hydrological components which is useful in assessing the water availability in downstream areas for irrigation, domestic and industrial purposes. Tons river is a major tributary of the Yamuna river and 14% of the river basin is perennially covered with the snow. In the present study, SWAT has been used to develop a hydrological model for the snow covered hilly watershed of the Tons river basin. Calibration results rank the model performance as satisfactory.

INTRODUCTION

The hydrological processes in a watershed are complex and depend on precipitation, temperature, land use, topography and soil characteristics. In hilly regions, climatic parameters exhibit systematic changes with altitude. In higher altitudes, major precipitation falls in the form of snow and snowmelt contributes water to the rivers. Snowmelt plays an important role in governing the hydrological processes of such watersheds. In Himalayan regions, snowmelt contributes significantly to runoff during spring and summer season.Nowadays, many models such as temperature index model, energy balance model, rainfall-runoff models and variable infiltration capacity method etc. are available to simulate the snowmelt in a hilly area (Liu *et al*., 2020).The Soil Water Assessment Tool (SWAT), which is a semi-distributed hydrological model, has the capability to simulate the various hydrological components in hilly areas, including snowmelt, on a basin or sub-basin scale. Chiphang *et al*. (2020) applied the SWAT hydrological model and accessed the water balance components successfully over the Mago River basin situated in the Eastern Himalayan region, where elevation ranges from 2289 to 6436m.The Tons river basin is located at a high altitude and receives snowfall as well as rainfall and both components affect the hydrological processes. The hydrological processes in river basin have not been studied by researchers. The purpose of the present study is to carry out hydrological modelling for the Tons river basin.

MATERIALS AND METHODOLOGY

Study area

Tons river originates from Bandarpunch mountain in Uttarakhand. The river basin is located between 30°30" to 31°30"N and 77°25" to 78°45"E. The elevation of Tons river basin ranges from 462 to 6280 m and the maximum part of the basin lies in Uttarakhand while a portion of the basin falls in Himachal Pradesh (Fig. 1). Tons river is a major tributary of Yamuna river and contributes the highest amount of water to the river. Within the basin area, snowmelt besides precipitation are the sources of water. Within the basin, precipitation varies from 1500 to 2200mm per year, while in the winter season almost 50% area receives significant snowfall. Two type of soils i.e. clay and clay-loam exist within the basin.

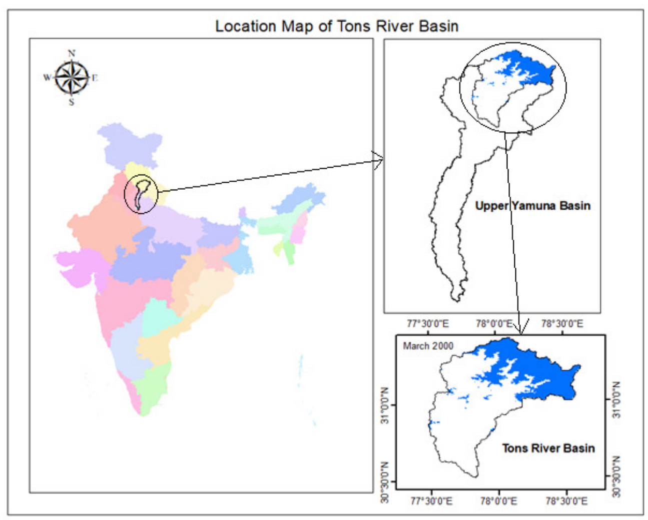

Fig. 1: Location map of Tons basin

Data processing

The SRTM DEM of 90m resolution was acquired from the USGS earth explorer. FAO soil map from SWAT Tamu and LULC from NRSC (*National Remote Sensing Centre)* were extracted for the basin (Fig. 2). ERA-interim reanalysed precipitation and temperature data acquired from Copernicus, was extracted and converted into mm/day and °C units, respectively. Wind velocity, solar radiation and relative humidity gridded data for the study area wereutilized from SWAT Tamu. Snow cover extraction has been carried to access information regarding the snow cover pattern using MODIS/Terra Snow Cover 8 Day data. The extracted snow cover reveals that the maximum area of the

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basin is covered with snow during the month of February and minimum during September. Figure 3 shows the step by step procedure to extract the snow cover data after removing the cloud cover from the MODIS data.

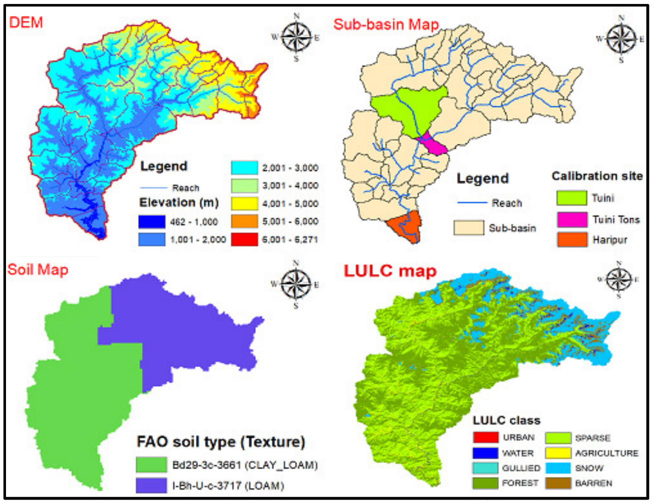

Fig. 2: Thematic map of the Tons basin

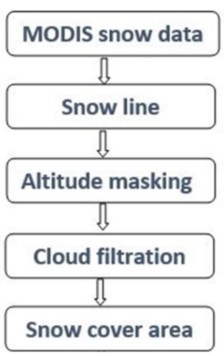

Fig. 3: Snow data extraction procedure

Model setup

The flowchart shows the steps to simulate the runoff in hilly areas using SWAT. For simulation SWAT model was used and for the calibration purpose SWATCUP was used (Figure 4).

Model calibration and sensitivity analysis using SWAT-CUP

An automated calibration model creates random set of selected parameters systematically and runs the model with all the sets of parameters. The goal of model calibration is to determine a unique set of model parameters that provide a good match between simulated and observed data. The SWAT-CUP interface was developed for SWAT and currently supports programs SUFI2, GLUE, and ParaSol and runs for SWAT versions 2009 and 2012 etc. SUFI-2interprets the parameter uncertainty including all sources of uncertainties such as uncertainty in driving variables (e.g., rainfall), conceptual model, parameters, and measured data, and the uncertainties are quantified by the p-factor (95PPU) (Abbaspour, K. C., 2007). In present study, higher elevation area receives snow, therefore, snow components were also incorporated in the model calibration. Table 1 shows the parameters which were used to calibrate the model.

Performance evaluation

There are several ways to evaluate the significance of the model. The SWAT model efficiency was assessed by the statistical performing indicators such as coefficient of determination, p-factor and r-factor (Duan *et al*., 2020).The coefficient of determination (R2) varies from 0 to 1, where 1 depicts the perfect correlation. The p-factor values ranges from 0 to 1 where 1 depicts the major data bracketed by the 95PPU and r-factor $\leq$ 1.5considered as satisfactory in case of discharge (Abbaspour *et al*., 2015).

RESULT AND DISCUSSION

In the study area, significant snowfall occurs up to Tuini,

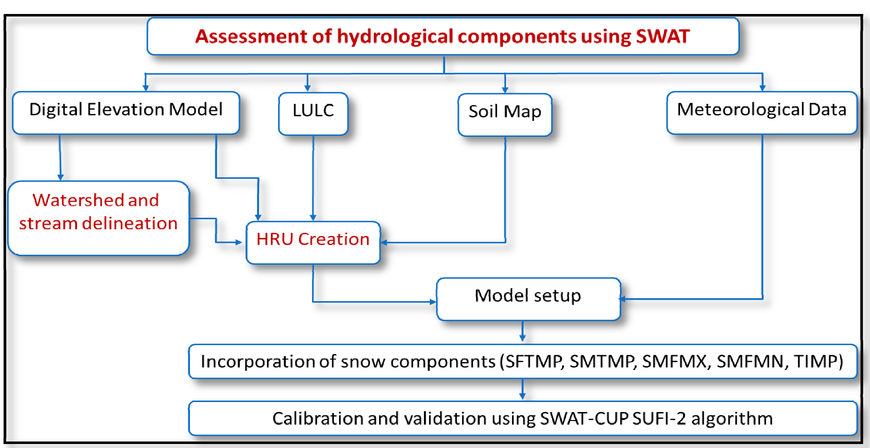

Fig. 4: SWAT model setup with snow component for the hilly regions

Table 1- Parameter sets used in the calibration

S.No.	Parameter Name	Parameters meaning	Min.	Max.
1	R__CN2.mgt	initial SCS runoff curve number II	-0.2	0.2
2	V__ALPHA_BF.gw	Base flow alpha factor	0	1
3	V__GW_DELAY.gw	Ground water delay time	30	450
4	V__GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0	1000
5	R__SOL_BD(..).sol	Soil bulk density	-0.3	0.3
6	R__SOL_K(..).sol	Saturated hydraulic conductivity	-0.3	0.3
7	R__REVAPMN.gw	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	0	200
8	R__SNO50COV.bsn	Snow water equivalent that corresponds to 50% snow cover.	-0.2	0.2
9	R__ SFTMP(..).bsn	Snowfall temperature	-0.2	0.2
10	R__ SMTMP(..).bsn	Snow melt base temperature.	-0.2	0.2
11	R__ SMFMX(..).bsn	Maximum melt rate for snow during year (occurs on summer solstice).	-0.2	0.2
12	R__ SMFMN(..).bsn	Minimum melt rate for snow during year (occurs on summer solstice).	-0.2	0.2
13	R__ TIMP(..).bsn	Snow pack temperature lag factor.	-0.2	0.2

Note: V- replacement and R- relative change

however, the discharge data is available at three sites, namely, Tuini Tons, Tuini, and also at Haripur which is located at downstream of Tuini. The calibration was carried out for the period 2003 to 2012. For model calibration, 13 relevant parameters were utilized, out of which 7 parameters were found sensitive. If the p-value is less than 0.05, parameter is considered as a sensitive parameter. Table 4 shows the parameters and their ranking according to sensitivity.

Sensitivity Analysis

The main aim of sensitivity analysis is to find the sensitive parameter or set of sensitive parameters based on p-value and t-stats. In present study, sensitive parameters were identified by the global sensitivity analysis based on SUFI-2 algorithm in SWAT-CUP. Table 2 depicts the parameter sensitivity for the stream flow of the Tons river based on p-value and t-stats.

Table 2 -Sensitive parameters and their ranking

Rank	Parameter Name	t-Stat	P-Value
1	CN2.mgt	-34.99	0.00
2	SOL_BD(..).sol	-7.33	0.00
3	GW_DELAY.gw	7.12	0.00
4	SOL_K(..).sol	-3.71	0.00
5	ALPHA_BF.gw	-2.84	0.01
6	SMFMN(..).bsn	2.62	0.01
7	SMTMP(..).bsn	-2.46	0.02
8	SFTMP(..).bsn	1.21	0.23
9	SNO50COV.bsn	-0.84	0.40
10	SMFMX(..).bsn	0.64	0.53
11	TIMP(..).bsn	-0.53	0.60
12	REVAPMN.gw	0.46	0.64
13	GWQMN.gw	-0.33	0.74

Calibration

Table 3 and Figs. 5 to 7 shows the scatter plot of observed and simulated discharge for different gauging sites. The coefficient of determination ranges from 0.50 to 0.67, which falls under satisfactory category.

Table 3- Model evaluation

Variable	p-factor	r-factor	R^2
Tuini	0.22	1.71	0.50
Tuini Tons	0.45	0.78	0.65
Haripur	0.07	0.89	0.67

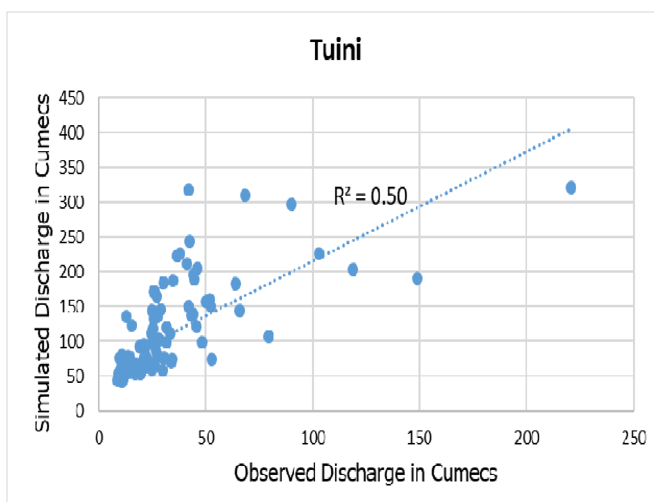

Fig. 5: Tuini Gauging site

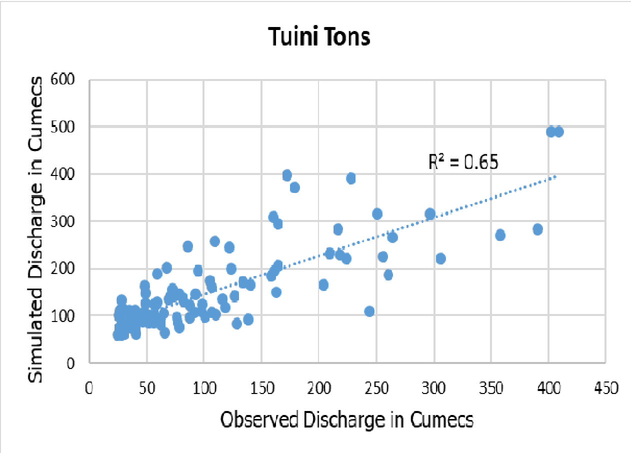

Fig. 6: Tuini Tons Gauging site

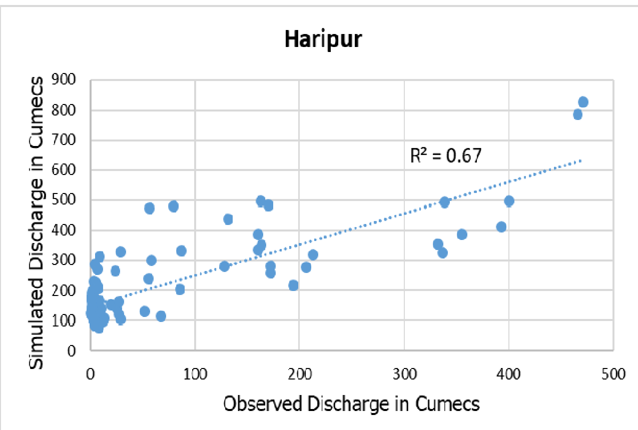

Fig. 7: Haripur Gauging site

CONCLUSION

The SWAT hydrological model has the capability to estimate the hydrological components for the plains as well as hilly regions. Tons river basin is located in the hilly regions of Upper Yamuna basin and 14% of the basin is covered with snow throughout the year. Hydrological modelling has not been carried out for the high altitude region of the Tons river basin. The study presents the hydrological model of Tons river basin developed using SWAT, which can be utilized to assess the hydrological components for the Tons river basin, for judicious planning of water supply and allocation for agricultural, domestic and industrial purposes for the downstream users during different seasons.

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