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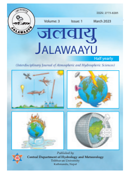

Research Article

Application of SWAT Hydrological Model to Simulate Flow of Seti-Gandaki Basin

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Abstract: The Soil and Water Assessment Tool (SWAT), a semi-distributed hydrological model, has been used for the Seti-Gandaki River Basin (SGRB) to simulate streamflow. Further, SWAT was assessed to study water balance of the basin. This study primarily focuses on different features of hydrological modeling like multi-site calibration and validation of the streamflow with a view to check the reliability of the model in the high precipitation basin of Nepal. The statistics performance of the model is evaluated using various statistical test like Nash-Sutcliffe, RMSE, and Kling Gupta Efficiency (KGE). Moreover, the study used various statistical parameters like Nash-Sutcliffe efficiency (NSE), Percentage Bias (PBIAS), Coefficient of Variation (R^2), ratio of the root mean square error to the standard deviation of measures data (RSR), and Kling Gupta Efficiency (KGE) to evaluate the performance of the model and carryout 0.93(0.89), -0.04(-21.87), 0.95(0.94), 0.26(0.34), and 0.85(0.76), respectively, for calibration(and validation) at Damauli station. The mean annual flow and annual precipitation at SGRB was observed to be 209 m^3/s and 2866 mm,

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respectively. About 20% of annual precipitation seems to be lost as evapotranspiration. The statistics results showed that the model performed better for daily and monthly periods. Overall, the versatility and reliability of SWAT is an appropriate hydrological modeling tool for water resources over the study region. The output of the study can be helpful for the planning and management of water resources in high precipitation basins.

1. Introduction

Precipitation is a complex variable to predict as it varies over space and time— due to the region's large-scale atmospheric circulation patterns of the region and geographical and topographical factors (Hu et al., 2016; Li, 2020). Widespread precipitation variability in Nepal ranges from ~150 mm/year north of the Annapurna range to ~5,000 mm/year on the southern slope of the Annapurna range (Sharma et al., 2020). The southern slope (windward side) of the Annapurna range which receives highest annual precipitation in Nepal, Lumle, is also located in the Seti-Gandaki River Basin (SGRB), with an average annual precipitation of about 5,400 mm (Nayava, 2018). Precipitation is one of the major factors causing environmental changes and disasters such as drought, floods, and landslides across Nepal and is a major driving force of the hydrological cycle (Kansakar et al., 2004; Shrestha et al., 2019). The hydrological cycle has many interconnected components that run off water bodies. Surface runoff causes water to flow into the river channels, increasing the discharge level. Stream flow records are required to plan, operate and control water resource projects (Marahatta et al., 2021). This requires the installation of measuring devices in river basins; especially in high rainfall basins, there should be more flow measuring stations to control water-induced risk. Due to the diverse physiography and topographic nature of SGRB, water resource planning is complicated. Therefore, in order to get a clear picture of every component of the hydrological cycle, it is necessary to determine the amount of precipitation to be stored in water surface flow, base flow, subsurface flow, percolation, and various forms such as snow, glaciers, ponds, pits, etc. Thus, it can be concluded that a detailed study of the water cycle is an integral part of policymakers, various stakeholders, and the public as it provides a clear vision of the problems and solutions related to water-induced hazards. For this, the different hydrological model has been used for the analysis of water balance components but most of the hydrological models available today only focus on model construction and single-site calibration whereas the efforts directed at multi-site calibration are minimal. Therefore, this study focuses on multi-site calibration of high precipitation zone with analysis of water balance components.

To support the development of water resource management policies and to evaluate water quality issues, hydrological models like HBV, HEC-HMS, SWAT, TOPMODEL, MIKE-SHE, J2000 have been stated as very useful tools (Abbaspour et al., 2015; Beven & Freer, 2001). A model is made up of various parameters that define the model's characteristics, and the best model is one that produces results that are close to reality while using the minimum parameters and complexity of the model (Devia et al., 2015). Among these models, the Soil and Water Assessment Tool (SWAT) has been chosen among many hydrological models for this study. The SWAT model, which is a tool linked with ArcGIS, has been widely used in the Nepalese river basin as well as in neighboring countries for water balance and quantifying the effects of climate change (Bajracharya et al., 2018; Bharati et al., 2014; Dahal et al., 2016). The model has been implemented from the catchment 0.38 km^2 of Cunha Municipality, Brazil (Lucas-borja et al., 2020), to the basin 900,480 km^2 of Upper Parana River Basin (Rafee et al., 2019). Similarly, the model has been successfully used from the low annual rainfall records of 102 mm and 179 mm at Sarbaz river basin in South Iran with arid climate characteristics (Galavi & Mirzaei, 2020) to high annual precipitation of 3600 mm at coastal areas of North Johnstone catchment (Rafiei et al., 2020). The model has also been used in different elevation range, low altitude, and high-altitude glaciered river basins and the tropical basins. For example, the Damma glacier in the Alps Switzerland (Andrianaki et al., 2019), the high glacial basins of Andes, Alps and Central Asia (Omani et al., 2017), as well as the low-lying basins in Nigeria with elevation range 100 -394 m (Ayanshola et al., 2018), and Gomti river basin where elevation of the basin varies from 98 and 216 m in India (Das et al., 2019). The SWAT model has also been frequently used in different basins for multi-site calibration. For instance, Karnali-Mohana basin of Nepal, Blue Nile River of East Africa, and Narmada Basin of Central India (Pandey et al., 2020b; Tehsome et al., 2021; Thomas et al., n.d.). Therefore, based on the above literature review, a semi-distributed physically based hydrological model SWAT has been selected for this multi-site calibration study and it is a basin-scale model used to simulate rainfall-runoff. The main aim of this study is to apply the SWAT model in highly precipitated basin of Nepal for simulating the runoff process.

2. Materials and Methods

2.1 Study Area

The Seti-Gandaki River (SGRB) lies in the central part of Nepal. It is snow-fed and has its origin near the base of Mount Machhapuchhre (6997 m above sea level (masl)) and Mount Annapurna IV (7525 masl). The study area, SGRB lies between longitudes from 83^{0}47′54.68″ E to 84^{0}30′23.61″ E and latitudes from 27°47′57.00″ N to 28°35′40.55″ N. The topographical variation ranges from 190 to 7474 masl **(Figure 1)**. The Mardi and Vijaypur are the two major tributaries of the river. The Mardi originates from the Mardi Himal (5127 masl), runs downstream about 25 km and joins the Seti-Gandaki River near Lahachowk. The Vijaypur has its origin at the foot of the Mahabharat range, situated northeast of the valley. It runs about 15 km before joining the Seti-Gandaki River at the Seti–Vijaypur confluence area.

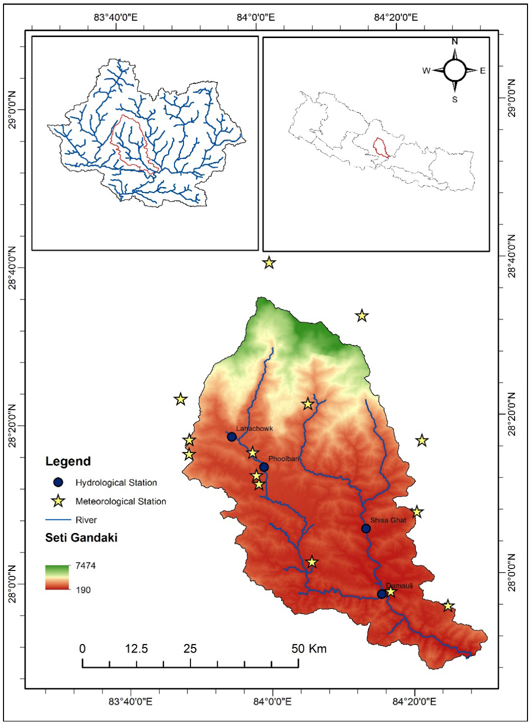

Figure 1. Study area, and location of surrounding hydro-meteorological station.

2.2 Data Used

SWAT, a physical and semi-distributed model, requires wide spatial information of the basin. The model setup and watershed simulations require different input data and should be organized in specified formats so that the model can recognize. In this study, Digital elevation model, Land use/cover, and Soil map are used as spatial data whereas, the hydro-meteorological data that have been used for this study are precipitation (mm), and minimum and maximum temperature (^{o}C). The Hargreaves method was used for estimation of potential evapotranspiration (PET).

Table 1. *Sources of data.*

S.N	Data	Source	Type
1	Digital Elevation Model (DEM)	SRTM	Spatial grids
2	Soil map	DoWRI	Spatial grids
3	Land use/ cover	DoWRI	Spatial grids
4	Precipitation and Temperature	DHM	Time series
5	River flow	DHM	Time series

**SRTM is Shuttle Radar Topography Mission, DoWRI is Department of Water Resources and Irrigation, and DHM is Department of Hydrology and Meteorology.*

2.2.1 Spatial Data

The Digital Elevation Model (DEM), 30 m × 30 m resolution was used to define the topography of the watershed. The physical properties of basin-like catchment area, stream network, channel slope, channel length, etc. were extracted from DEM. For the study, land use/cover and soil map data were used from DoWRI to delineate HRUs within the sub-basin. The practice of land cover directly affects the quality and quantity of runoff. Soil affects various hydrological processes, including infiltration to swallow aquifer, percolation to deep aquifer, and discharges to the river through interflow and baseflow. The classified land use/cover and soil map of the study area are presented in **Figure 2.** The total classes of land used were nine, among which the highest and lowest area covered by forest 52.2% and barren land 0.4%, respectively. Likewise, the total class of soil map is twelve, among which the highest and lowest areas covered by IncSkel 23.8% and EntClay 0.1%.

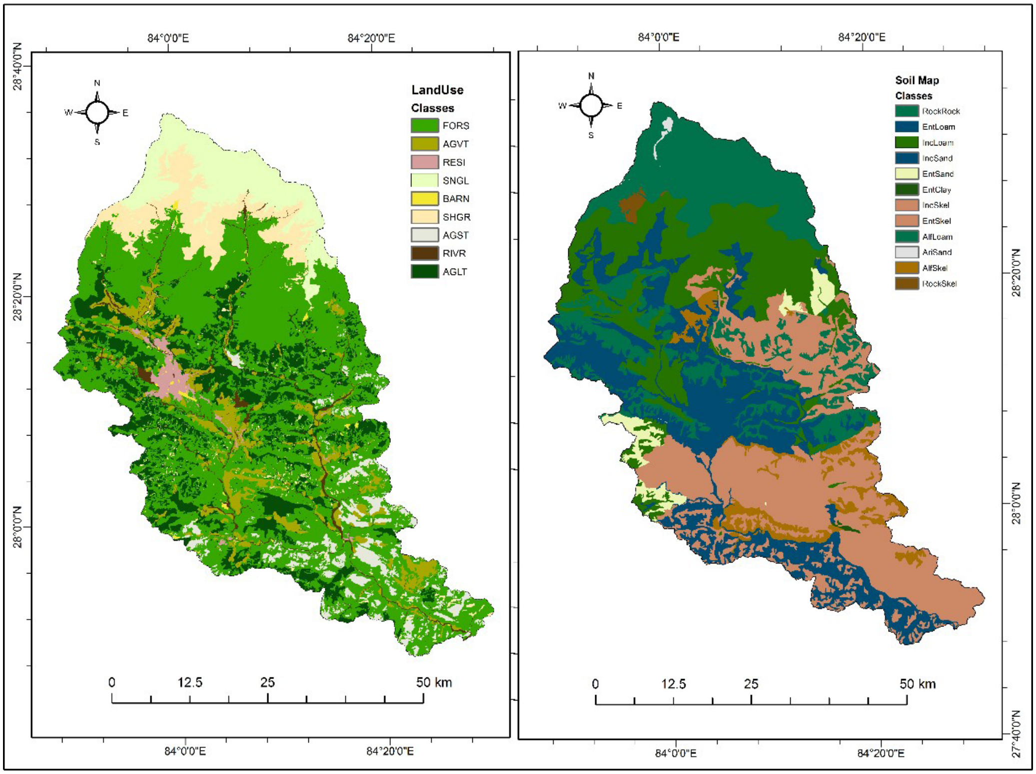

Figure 2. *Land use and Soil map of the study area with their classes.*

2.2.2 Hydro-meteorological Data

The maximum temporal resolution of the data acknowledged by the SWAT model exists at a daily interval. The meteorological data used for the model were daily precipitation (mm) and daily minimum and maximum temperature (^{o} C). Meteorological data from fourteen stations in and around the study basin (1980–2016) were used as input to the model in **Figure 1.** Data quality was done through various methods like homogeneity, outlier, consistency, spatial, and double mass curve analysis. The average regional precipitation of the catchment was calculated using the Thiessen polygon method (Marahatta et al., 2021). The calibration and validation of the model was performed by long-term daily discharge data at two stations (Damauli and Shisaghat) and data from Mardi (lahachowk) and Phoolbari stations were used for further validation.

2.3 Model Overview

The Soil and Water Assessment Tool (SWAT) has been used in this study to assess the water balance of the basin and is used as a tool for hydrological modeling. The model was developed by the Agricultural Research Service of United stated Department of Agriculture (Arnold et al., 1998). The model contains process-based and semi-distributed parameters that have been developed to predict the effect of land-use changes, climate changes, and management practices in basins. The model uses specialized information related to climatology, soil topography, vegetation, and land cover in the basin. The model splits the basin into sub-basins connected by a stream network and further divided into numbers of Hydrological Response Units (HRUs) in regards to increasing model calculation accuracy. HRUs represent a combination of soil, land-use/cover, and slope type in each sub-basin.

The SWAT model requires calibration and validation in the study basin to ensure that the model parameters represent the study area. It operates the following hydrological balance equation for the hydrological cycle simulation.

$$SW_t = SW_0 + \sum_{1=1}^{t} \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right) \tag{1}$$

Where, SW_t = final soil water content (mm)
SW_0 = initial soil water content (mm)
R_{day} = amount of precipitation on i^{th} day (mm)
Q_{surf} = amount of surface runoff on i^{th} day (mm)
E_a = amount of evapotranspiration on i^{th} day (mm)
W_{seep} = amount of percolation on i^{th} day (mm)
Q_{gw} = the amount of return flow on i^{th} day (mm)
t= time in days

2.4 Model Setup and Simulation

The watershed delineation of the Seti-Gandaki watershed in SWAT generated an area of 2957 km^2. The model discretizes the whole Basin into 44 sub-basin. The five-elevation band at an interval of 500 m were defined and 10% threshold area value was applied for each land use, soil map, and slope category to define HRUs. The sub-basin is further divided into 684 HRUs based on Land use, soil type, and slope. The methodological framework for model setup and simulation is given in **Figure 3**.

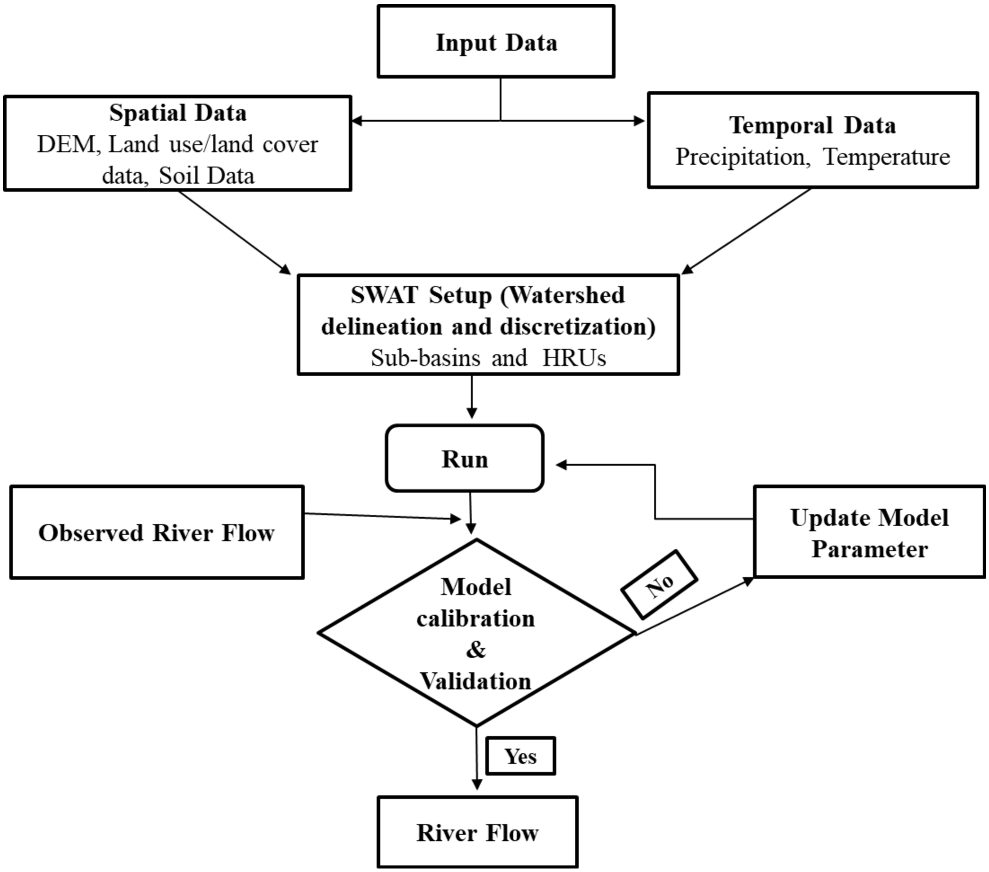

Figure 3. *The methodological framework for the application of the SWAT hydrological model.*

2.5 Performance Evaluation Criteria

The performance of SWAT was assessed by using statistical and graphical representations; Nash-Sutcliffe efficiency (NSE), Percentage Bias (PBIAS), Coefficient of Determination (R^2), Kling Gupta Efficiency (KGE), and the ratio of the root mean square error to the standard deviation of measured data (RSR) (Moriasi et al., 2007; Knoben et al., 2019; Schaefli & Gupta, 2007).

NSE indicates the accuracy of the model output compared to the mean of referred data. The NSE ranges from 0 to 1, with values close to 1 perfect fit between observed and simulated values. NSE is computed as shown

$$NSE = 1 - \frac{\sum\left(Q_{obs,t} - Q_{sim,t}\right)^2}{\sum\left(Q_{obs,t} - \overline{Q}_{obs}\right)^2} \qquad \mathbf{2}$$

The coefficient of determination (R^2) is used to analyze how variation in one variable can be explained by variation in another variable.

$$R^2 = \frac{\sum\left(Q_{obs} - \overline{Q}_{obs}\right)^2 - \sum\left(Q_{sim} - \overline{Q}_{sim}\right)^2}{\sum\left(Q_{obs} - \overline{Q}_{obs}\right)^2} \qquad 3$$

PBIAS indicates the simulated flow's average tendency to be larger or smaller than the observed flow. The low value of PBIAS indicates a good adjustment of the simulated results in the observed data. PBIAS expressed as a percentage is calculated as shown:

$$PBIAS = \frac{\sum\left(Q_{obs,t} - Q_{sim,t}\right)}{\sum Q_{obs,t}} * 100 \qquad 4$$

Root Mean Square Error (RMSE) is used to measure the difference between values predicted values by the model and observed values. RSR standardizes the RMSE using the observations standard deviation and combines an error index (Moriasi et al., 2007). The lower RSR, the lower the RMSE, and the better the model simulation performance. RSR is calculated as the ratio of the RMSE and the standard deviation of measured data as shown:

$$RSR = \frac{RMSE}{\acute{o}_{obs}} = \frac{\sqrt{\sum\left(Q_{sim,t} - Q_{obs,t}\right)^2}}{\sqrt{\sum\left(Q_{obs,t} - \overline{Q}_{obs}\right)^2}} \qquad 5$$

In recent years, KGE has been widely used to calibrate and evaluate hydrological models. KGE combines three components of NSE of model errors (i.e. correlation, PBIAS, coefficients of variation).

$$KGE = 1 - \sqrt{\left(r-1\right)^2 + \left(\frac{\acute{o}_e}{\acute{o}_o} - 1\right)^2 + \left(\frac{\overline{Q}_e}{\overline{Q}_o} - 1\right)^2} \qquad 6$$

Where $\overline{Q}_{obst}$ is the observed, $\overline{Q}_{obst}$ is the average observed, $Q_{sim,t}$ is the average simulated value. Also, r is the correlation coefficient between observed and simulated flow, σ_0 and σ_e are standard deviations of observed and simulated flows, respectively.

3. Results

3.1. Evaluation of SWAT Model

The SWAT model was calibrated and validated for the daily time scale as well as the monthly time scale. Given the availability of short time data, the calibration period was selected from 2002 to 2008, while the years 2009 to 2015 as validation periods for Damauli and Shishaghat stations. Additional validation was done for the Lahachowk station (2008 - 2015) and Phoolbari station (1981 - 1982).

Table 2. *Selected SWAT parameters and their calibrated values*

Parameter	Description	Range	Fitting Value	
			Damauli	Shisaghat
ALPHA_BF	Base flow alpha factor (days)	0 to 1	0.048	0.048
CN2	Initial SCS runoff curve	35-98	60-75	60-75
GWQMIN	Threshold depth of water in the shallow aquifer required to start the return flow (mm H_2O)	0 to 5000	1200	1300
GW_REVAP	Groundwater "revap" coefficient	0.02 to 0.2	0.029	0.2
GW_DELAY	Groundwater delay (days)	0 to 500	70	80
LAT_TIME	Lateral flow travel time(in days)	0 to 180	5	11
OV_N	Manning's "n" value for overflow flow	0.01 to 30	0.14	0.14
REVAPMN	Threshold depth of water in the shallow aquifer for "revap" or percolation to the deep aquifer (mm H_2O)	0 to 1000	750	600
SFTMP	Snowfall temperature melt point (ºC)	-5 to 5	2	0
SMFMN	Melt factor for snow on December 21 (mm/ºC/day)	0 to 10	4.5	0.5
SMFMX	Melt factor for snow on Jun 21 (mm/ºC/day)	0 to 10	4.5	2
SMTMP	Snow melt base temperature (ºC)	-5 to 5	0.5	0
SOL_Z	Depth from soil surface to bottom of layer (mm).	0 to 3500	400-500	500-515
SOL_K	Saturated hydraulic conductivity (mm/hr).	0 to 2000	10-20	4-10
SOL_AWC	Available Water Capacity (mm H2O/mm soil)	0 to 1	0.02-0.2	0.2-0.9
SURLAG	Surface Runoff time lag (days)	1 to 24	0.1	0.01
TIMP	Snow pack temperature lag factor	0 to 1	0.01	0.01
TLAPS	Temperature laps rate (ºC/km)	-50 to 50	-5	-5.5

3.1.1. Damauli Station

Observed and simulated hydrographs for the calibration and validation period are shown in **Figure 4**. The monthly mean and standard deviation of the observed (simulated) flows are 104(104) m^3/s and 111(94) m^3/s for the calibration and 86(105) m^3/s and 93(101) m^3/s for the validation period. The model simulated the flow pattern very well and the hydrographs are in good terms with the rainfall pattern. The scatter plot between the observed and simulated discharge chains showed that the model overestimates the flow at low discharges and underestimates the flow at high discharges. As shown by the proximity of the slope of the trend line, such over and underestimation is much less during the calibration period Figure 4(e and f).

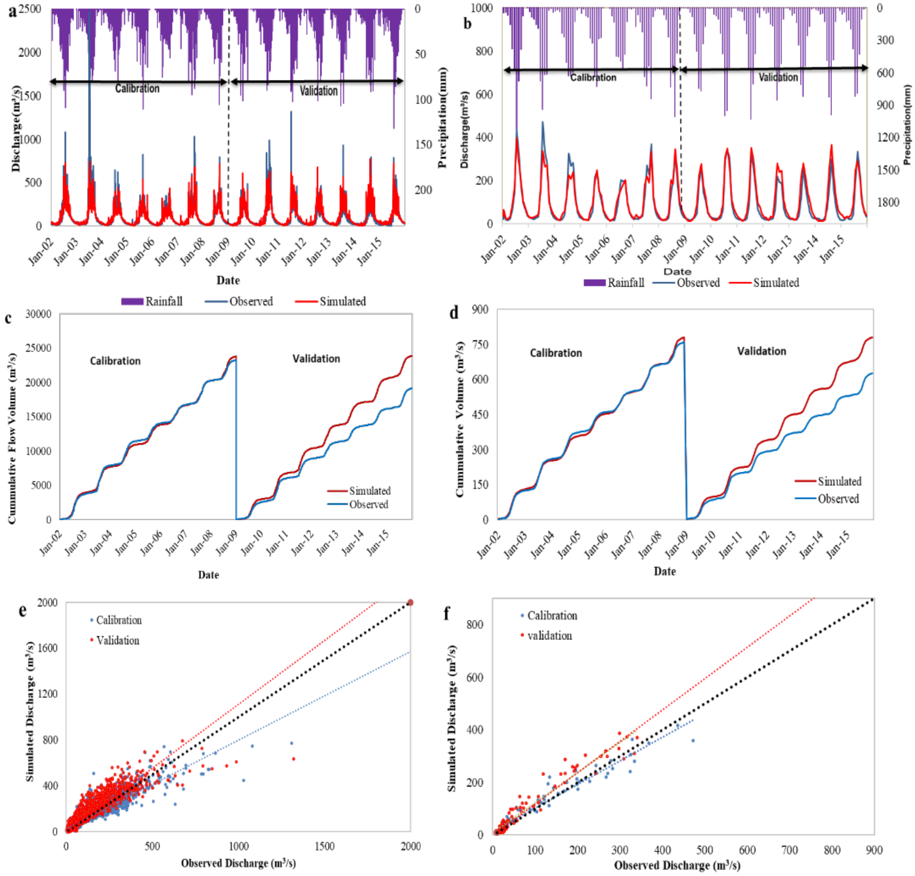

Figure 4. *(a) Daily and (b) Monthly Simulation results, (c) Daily (d) Monthly Volume balance, and (e) Daily (f) Monthly Scattered plot between Observed and Simulated discharge.*

Table 3. *Statistical performance for Damauli Station.*

Performance Statistic	Daily		Monthly		Entire Simulation	
	Calibration	Validation	Calibration	Validation	Daily	Monthly
NSE	0.80	0.80	0.93	0.89	0.80	0.91
PBIAS	0.14	-21.77	-0.04	-21.87	-9.75	-9.90
R^2	0.80	0.85	0.95	0.94	0.80	0.92
RSR	0.45	0.45	0.26	0.34	0.45	0.29
KGE	0.78	0.76	0.85	0.76	0.83	0.88

The Table 3 shows that all statistics performances are better for both the calibration and validation period. Using the performance rating, NSE, RSR, PBIAS, R^2, and KGE can be considered very well for the calibration and validation periods except for PBAIS. For the entire simulation, all the statistics performances show very good results. The graph and statistical performance show that the calibrated SWAT model can simulate the monthly flows well.

3.1.2 Shisaghat Station

The observed and simulated daily and monthly runoff for the calibration and validation period are shown in **Figure 5**. The statistical evaluation of the model performance for Shisaghat station (2002-2015) based on the daily and monthly discharge is present in **Table 4**. The graphs depict an almost identical distribution of the observed and simulated streamflow hydrograph for both calibration and validation. However, the predicted runoff values were much more consistent with the observed data for the calibration period than for the validation period.

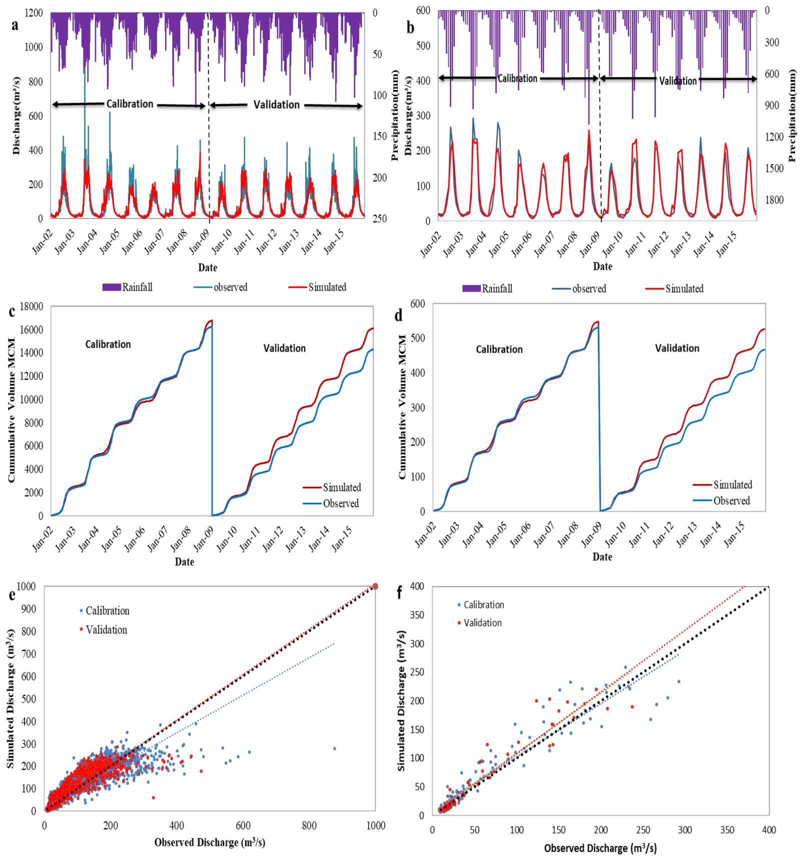

__Figure 5.__ (a) Daily and (b) Monthly Simulation results, (c) Daily (d) Monthly Volume balance, and (e) Daily (f) Monthly Scattered plot between Observed and Simulated discharge.

Table 4. *Statistical performance of Shisaghat Station*

Performance Statistic	Daily		Monthly		Entire Simulation	
	Calibration	**Validation**	**Calibration**	**Validation**	**Daily**	**Monthly**
NSE	0.81	0.80	0.90	0.87	0.80	0.89
PBIAS	-3.20	-12.54	-3.30	-12.62	-7.57	-7.66
R2	0.81	0.83	0.91	0.91	0.81	0.90
RSR	0.44	0.45	0.31	0.36	0.44	0.33
KGE	0.83	0.84	0.90	0.82	0.86	0.91

The trend analysis of the scatter plot between the observed and simulated discharge series shows that the model is well-calibrated and validated for the Shisaghat station as well. The graph and the statistical performance show that the calibrated SWAT model is capable of simulating the daily and monthly flows.

3.1.3 Additional Validation (Lahachowk and Phoolbari Station)

Due to limited and inconsistent data, model is validated at two more stations upstream of Damauli for the short period of time compared to other two stations. **Figure 6** correlate the simulated and observed streamflow, showing that most simulated values imitate the observed values for both the stations except the peak flow, which is undervalued.

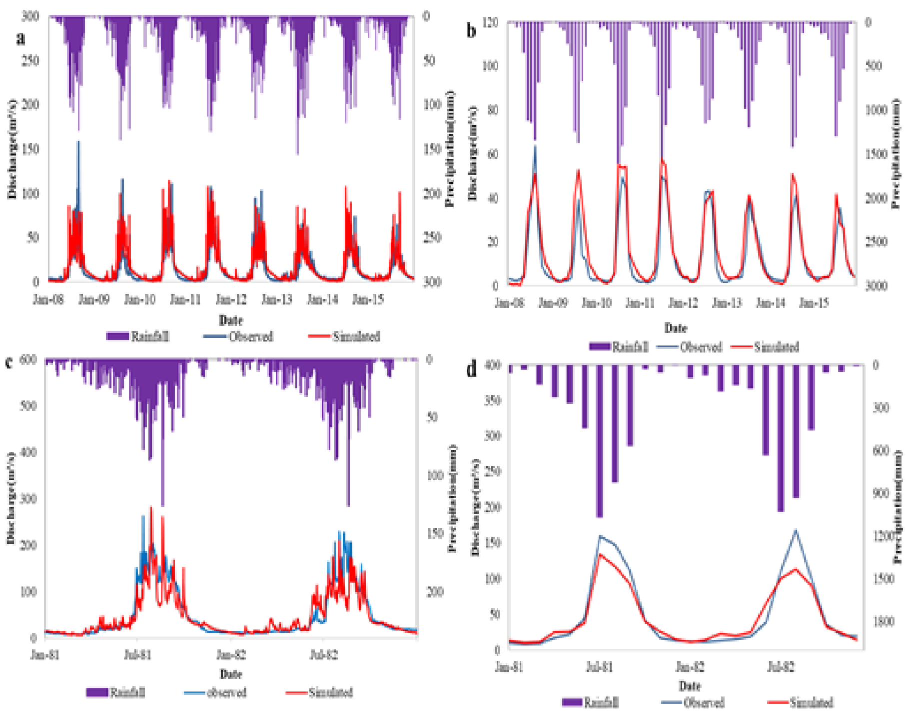

Figure 6. *(a) Daily and (b) Monthly Simulation results, (c) Daily (d) Monthly Volume balance, and (e) Daily (f) Monthly Scattered plot between Observed and Simulated discharge*

From **Table 5**, we can see that all the statistic parameters in both time steps show good results at the Phoolbari station. NSE, R^2, and KGE seem good for the Lahachowk station, but there is variation in the PBIAS. The PBIAS of -22 shows poor performance of the model. In this case, 22% of the simulated values are overrated.

Table 5. *Statistical Performance test*

Performance Statistic	Daily Validation		Monthly Validation	
	Lahachowk	**Phoolbari**	**Lahachowk**	**Phoolbari**
NSE	0.58	0.80	0.80	0.90
PBIAS	-22.22	7.52	-22.32	7.28
R2	0.71	0.81	0.88	0.96
RSR	0.65	0.45	0.45	0.31
KGE	0.69	0.77	0.72	0.74

3.2. Flow Duration Curve

The flow duration curve (FDC), also called discharge frequency flow, is a plot of discharge against a percentage of the time the flow was equaled or exceeded. FDC is widely used in the planning and design of hydropower projects, design systems, and flood control studies. Flow at the outlet of SGRB generated by SWAT was applied to create FDCs. The FDC was prepared from the simulated daily flow at the final outlet (**Figure 7**). Figure 7, further shows that the simulated flow volumes at 10%, 40%, 70%, and 90% exceeded probability are 528 m^3/s, 167 m^3/s, 61 m^3/s, and 39 m^3/s for daily flow.

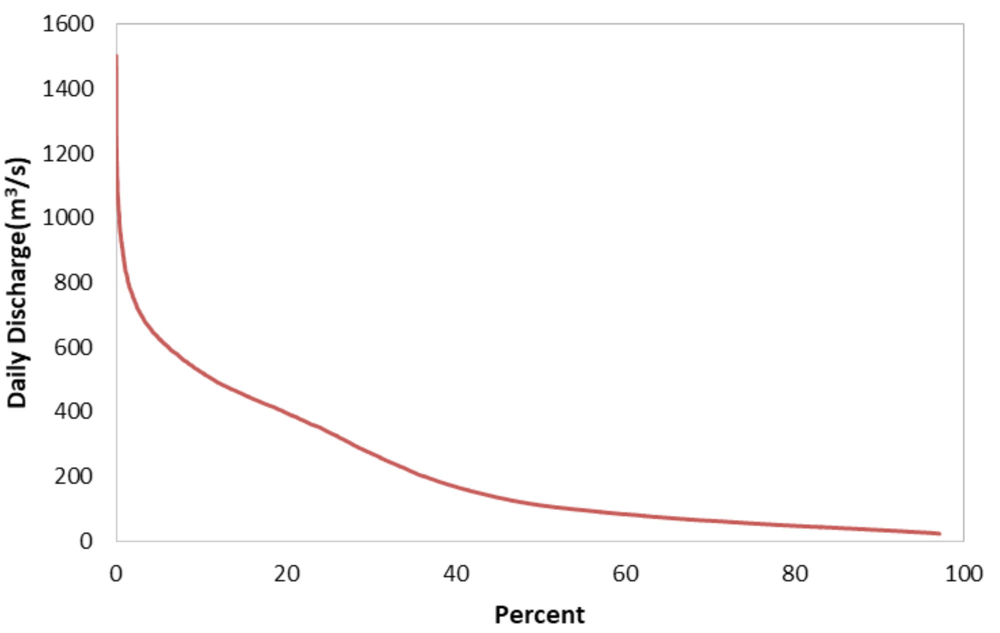

Figure 7. *Flow Duration Curve of SGRB.*

3.3 Hydrograph

The long-term average annual precipitation and simulated flow from 1982 to 2016 at SGRB in Figure 8e show that the basin's flow follows the precipitation pattern. The long-term annual basin precipitation has been calculated as 2958 mm, where July contributes maximum rainfall (727), November contributes minimum rainfall (16), and the long-term average annual flow of SGRB is calculated as 209 m^3/s where the highest flow was in August (531), and lowest flow was in February (39). The highest flow occurs in August i.e., 21%, and the lowest flow occurs in February i.e., 1.5%.

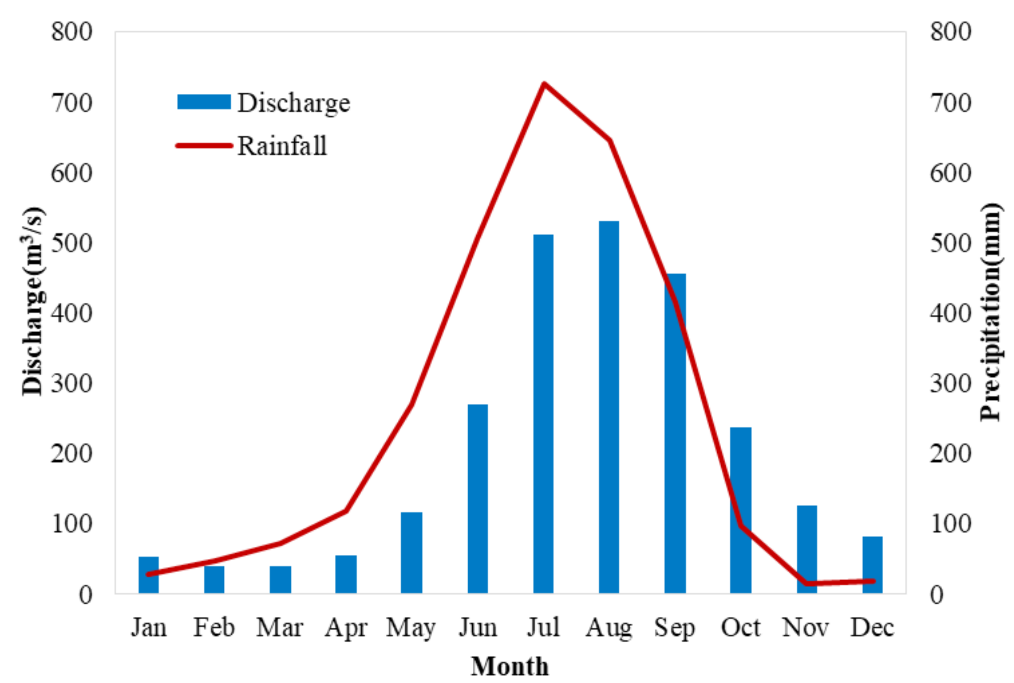

Figure 8. *Average monthly precipitation and discharge of SGRB from 1982 to 2016.*

3.4 Water Balance of Seti-Gandaki River Basin

Water balance is an evaluation of key components of a hydrological system and includes the interaction between groundwater and the surface water system. As aforementioned, the model runs from 1982-2016 with daily meteorological data and the outcome represents average results over 35 years. **Figure 9** shows the monthly water balance of SGRB, which portrays the distribution of water balance components. The components are precipitation (P), actual evapotranspiration (AET), and net water yield (NWY). The average annual precipitation over the basin is 2866 mm. The annual precipitation percentage falling in pre-monsoon, monsoon, post-monsoon and winter seasons are 16%, 76%, 3.9%, and 4.1%, respectively. AET is linked to precipitation, land use/cover, and temperature. AET from the basin is about 20 % of the annual precipitation (580 mm) and the ET rate is higher during the monsoon season. NWY refers to a combination of lateral, surface, and groundwater flow with a reduction in transmission losses and pond abstractions (Arnold et al., 1998). The NWY at the basin outlet is 74%. It does not continuously track the pattern of precipitation but is affected by the factors such as rainfall intensity, soil properties, and land use/cover characteristics (Bharati et al., 2019). The 'Delta storage' is negative in the monsoon season, indicating recharge to aquifer, and positive in the post-monsoon until January, and again it becomes negative from February. The highest positive value of 142 mm in October indicates groundwater contribution to streamflow, which might have appeared because of recharge during the monsoon season and discharge of that recharge water in the post-monsoon. Negative values from February onwards can be explained as the result of winter precipitation. The result shows that all the water balance components are highest during the winter. Therefore, it is clear that the main hydrological driver source for water balance is the monsoon.

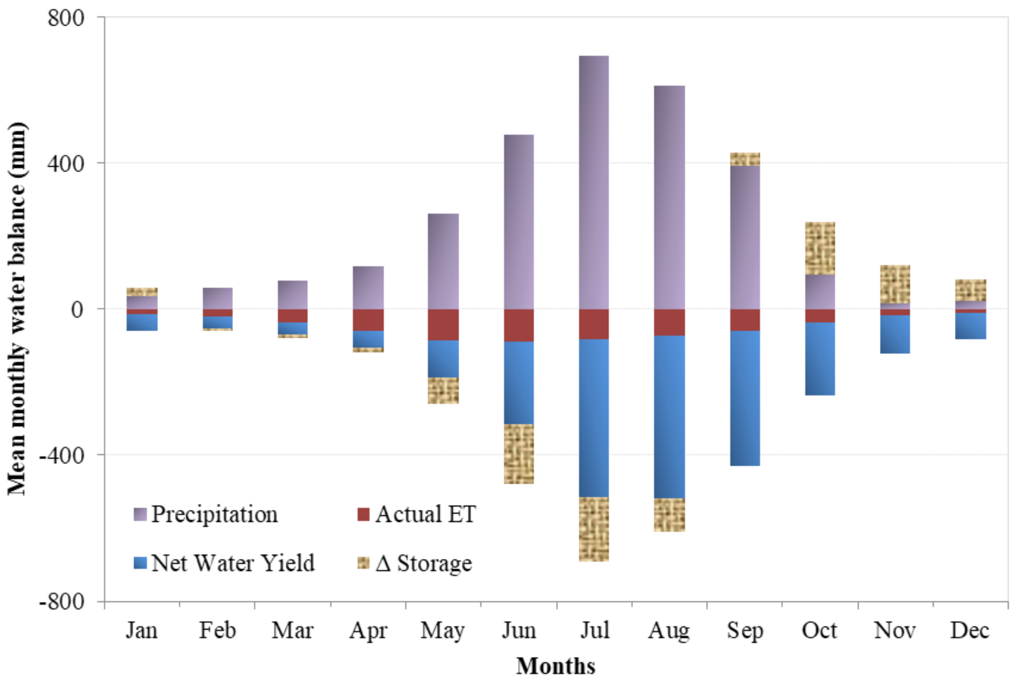

Figure 9. *Mean Monthly simulation of (1982-2016) Water Balance in Seti-Gandaki Basin.*

4. Discussion

This study evaluates the performance of the SWAT model in the high precipitation basin of Nepal. The calibration and validation are performed for Damauli and Shisaghat stations and additional validation is performed at the basin's Lahachowk and Phoolbari stations. The model was calibrated and validated using seven years, each for two stations i.e., 2002 to 2008 and 2009 to 2015, respectively. This study's performance indices NSE (and PBIAS) were found to be better or similar in the context of SWAT simulation.

For example, Upper Argos 0.62(-20.60%), North Johnstone 0.88 (-8.5%), Ib River0.75(-19.10),Wangjiaba basin 0.76(5.72), Karnali 0.59 (-11.1%), Thuli Bheri 0.83 (-0.6), Bheri 0.70 (-4.4%), and Kaligandaki 0.78 (-4.0%) for calibration period while these values are 0.70 (-16.09%), 0.87 (16.5%), 0.55 (-24.80), 0.80 (8.38), 0.71 (16.4), 0.71 (18.8), 0.71 (-8.9%), and0.8 (+9.6%), respectively for validation period (Martínez-Salvador & Conesa-García, 2020; Rafiei et al., 2020;Singh & Saravanan, 2020;Yu et al., 2018; Bajracharya et al., 2018; Mishra et al., 2018; Pandey et al., 2020). Pokharel et al., (2020) previously used SWAT model in SGRB for the purpose of hydropower potential. In this model, 334 sub basin and 4143 HRUs were generated and calibrated and validated at Damauli station for the period of 2000-2010 and 2011-2015, respectively with NSE, PBIAS and R^2 parameters. The study carryout the 0.76 NSE, 13.59 PBIAS, and 0.79 R^2 for the entire simulation whereas the study carry out 0.91 NSE, -9.90 PBIAS and 0.92 R^2 for entire simulation at Damauli station.

Although the model simulates the flow very well, it underestimated/overestimated the high flow in some cases. For example, in the case of a calibrated site, 2002, 2003, 2005, 2007, 2010, and 2011, it underestimated the high flow, while overestimated for the years 2006, 2009, and 2012 **(Figure 4 and Figure 5)**. On 2003 July 9, the average daily discharge is 2470 m^3/s which is not possible as the precipitation is not that much i.e., only 87mm. This might be because of the absence of an observer, instrument failures, or miss readings. To get this much flow, precipitation should be 145 mm. Furthermore, from the figure, we can see that the simulated flow data follows the precipitation pattern and as a result, the simulated hydrograph can be considered reasonable.

In the SGRB, the average annual precipitation over the entire basin is 2866 mm**,** out of which AET is 20% and NWY is 74%. Monsoon season contributes 76%, 52%, and 70% of average annual precipitation, AET, and NWY, respectively. In the KarMo basin, with the precipitation 1375 mm has 34% average annual AET and the monsoon season contributes 73%, 71% and 71% in the average annual Precipitation, AET and NWY, respectively (Pandey et al., 2020a). Similarly, in the basin of Gandaki, Karnali, Mahakali, Bagmati, and Koshi the AET and NWY are 26% and 66%, 25% and 69%, 15% and 79%, 23% and 71%, and 30% and 65%, respectively (Marahatta et al., 2021; Dhami et al., 2018; Pandey et al., 2019; Manjan & Aggarwal, 2014; Bharati et al., 2019)

The average annual flow of SGRB is 209 m^3/s out of which the monsoon season contributes 70.3%, post-monsoon contributes 14.4%, pre-monsoon contributes 8.4%, and the winter season contributes only 6.9% of the total annual flow. Similarly, August contributes the highest flow (21%), while February contributes the lowest flow (1.5%). The fractional difference between these months was calculated as about 14, which shows high seasonal runoff variability in this basin. Comparing these values with other basins of Nepal give different fractional ranges. For example, the basin of WestSeti, Budhigandaki, and Karnali has fractional differences ranging from 13 to 18 (Budhathoki et al., 2021; Marahatta et al., 2021; Pandey et al., 2020b). Thus, we can mention that a longer simulation and observation period would add more confidence in the model performance at these locations.

5. Conclusion

Multi-site calibration and validation has been adopted to represent better spatial heterogeneity and for this purpose, four hydrological stations were selected. The model performed calibration and validation at Damauli and Shisaghat stations, while Lahachowk and Phoolbari stations was selected for additional validation. In weather data, daily precipitation and maximum and minimum temperature were used. Different period of discharge data has been taken for calibration and validation for different stations based on the good quality and availability of continuous time series.

The Statistical evaluation of the model shows a good performance according to rating statistics (D. N. Moriasi et al., 2007). Comparatively low PBIAS was observed during the calibration period to the validation period. Along with NSE, the statistical parameter KGE was also used to evaluate a more confident model than NSE. Even in such a long duration, the model's performance was found to be quite good both graphically and statistically for daily and monthly time scales; however, better performance has been found on the monthly time scale.

The study estimated that the mean annual flow at the SGRB outlet to be 209 m^3/s with annual precipitation of 2866 mm. The AET and NWY at the basin outlet have precipitation of about 580 mm and 2112 mm respectively. The monsoon season contribution is about 76% of annual precipitation, 68% of NWY, and 52% of AET. These components of water balance simulated by SWAT provided a basic understanding of the hydrological processes to deal with water management issues in the basin.

This study provides the SWAT user with further evidence of its use to simulate the rainfall-runoff characteristics of a high precipitate basin. Additionally, the SWAT model is found to be a great tool for simulating water balance in high precipitation basins. This type of comprehensive multi-site study will help future researchers in developing the SWAT model.

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