Estimating Discharge in Seti Watershed of Gandaki Basin using Water Evaluation and Planning

Angana Shrestha[1]*, Kaushal Chandra GC[1], Madan Pokhrel[1]
[1] Department of Civil Engineering, Pashchimanchal Campus, Institute of Engineering, Tribhuvan University, Nepal
*angnashrestha@gmail.com

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Abstract

Accurate estimation of river discharge is essential for assessing water availability and supporting sustainable water resource development. While hydropower is considered a renewable energy source, its impacts on other water demands are often overlooked. Comprehensive water accounting is crucial to balance hydropower generation with competing needs, ensuring equitable and efficient water use. In a small country like Nepal, water resource management is often underprioritized due to the high costs, need for advanced tools, and reliance on specialized expertise. This study aims to estimate the discharge in the Seti Watershed of the Gandaki Basin using the Water Evaluation and Planning (WEAP) model, chosen for its integrated approach to simulating water availability, demand, and allocation. The hydrological model is developed with the goal of evaluating the software at the catchment level using criteria for assessing model efficiency. The modeling was conducted using the Runoff-Rainfall method, along with the soil moisture simulation method integrated within WEAP. The study area was divided into sub basins, allowing for a more detailed understanding of the runoff pattern. The study recorded a mean maximum monthly flow of 248 m3/s in August and a mean minimum monthly flow of 18 m3/s in March at the outlet point. Similarly, the highest mean monthly rainfall was observed in July at 1104.51 mm, while the lowest was recorded in December at 11.41 mm. The statistical performance of model for calibration was NSE = 0.82, R^2 = 0.82, PBIAS = -0.046%, and RSR = 0.42, while for the validation period, NSE = 0.84, R^2 = 0.93, PBIAS = 8.7, and RSR = 0.39. The results demonstrate the reliable efficiency of the software in performing hydrological modeling at the sub-basin level on a monthly basis. Additionally, the model can be used to estimate the discharge at each catchment outlet point and assess its efficiency.

Keywords: Runoff-Rainfall method, soil moisture method, statistical performance

1. Introduction

Water has social and economic value (Rogers, 2000). Water is an essential resource for economic growth, ecological sustainability, and human survival. Nepal ranks 36th globally in overall water availability and 59th in per capita water availability (Dhoj Adhikari, 2024), yet it holds the 45th position in the water-stressed ranking(World Population Review, 2025), highlighting the challenges of water management despite abundant resources. Water accounting, which involves quantifying available water resources, and water allocation, which focuses on distributing these resources among users based on demand, priority, and sustainability considerations, are the distinct aspects of Water Resource Management (WRM) that must be considered for effective management.

Seti River is Nepal's one of the significant rivers that originates from Annapurna Himalayas. It carves a spectacular gorge, giving the valley its characteristic V-shape. This river drains the Pokhara Valley, with its two main tributaries, Mardi Khola and Modi Khola, joining the Seti River (Negi, 1991). The other main tributaries include the Sardi, Yamgdi, Kali, Kotre and Bijayapur rivers. A basin is situated between latitudes 27°50'N and 28°10' N and longitudes 83°50'E and 84°50' E, with an elevation ranging from 540 m to 1,020 m above mean sea level, covering an area of 200 km². The total catchment area of the basin spans 7,427 km². The Seti River Basin experiences climate ranging from subtropical to sub-alpine, with an average annual temperature of 19.3°C and annual precipitation of approximately 3,710 mm. This region receives heavy rainfall, with more than 80% of the total precipitation occurring during the monsoon season from June to September(Gandaki Province Government, 2024).

The river is the main source of water for more than 1 million 76 people residing in core urban area and the neighborhood region (Rupakheti et al., 2017). The Seti River, along with its tributaries, hosts numerous hydropower projects, both operational and under development. There are many potential hydropower sites in the basin, as a major hydropower hub, the study area contains a total of 39 hydropower projects at various stages of progress. Hydropower electricity generation largely depends on monthly flow, making its estimation a crucial aspect of hydropower development. Additionally, water allocation for other uses, such as water supply and irrigation, along with future expansions, may impact hydropower operations. Several empirical methods, including the Water and Energy Commission Secretariat/ Department of Hydrology and Meteorology (WECS/DHM) 1990 method, Nepal Electricity Authority(NEA) 1997 method, DHM 2004 method, Drainage Area Ratio (DAR) method, and General Transposition (GT) method (Marahatta et al., 2021), are used in Nepal to estimate site discharge; however, the complexity of hydrological processes and the need for accurate predictions highlight the necessity of advanced modeling techniques. While empirical methods offer quick estimates, they may lack precision in complex hydrological conditions, making advanced models necessary for accurate flow predictions.

Various hydrological models, in addition to WEAP, can be used to effectively analyze, manage, and predict the hydrological behavior of the Seti River. These models provide insights into river flow dynamics, water balance, flood forecasting, and climate change impacts. Hydrological models are mathematical representations of real-world water systems, enhancing our ability to understand and predict hydrologic processes (Pacheco, 2015). Different hydrological modelling tools like model VIC, HBV, soil and water assessment tool (SWAT) model, TOPMODEL, MIKESHE, HECHMS, WEAP are available to understand the various components of earth like, infiltration, water balance, evapotranspiration etc. (Gayathri K Devi et al., 2015) . Mostly used tools for hydrological modelling in Nepal area SWAT, HECHMS, GIS, WEAP etc. However, integrated hydrological and water resource models have not yet been studied.

Due to the limited number of hydrological stations and the challenges in obtaining accurate flow data for headworks design, Marahatta et al. (2021) emphasize the importance of conducting thorough hydrological analysis, where hydrological modeling is essential for providing reliable flow estimates compared to empirical models. The study was conducted with the primary objective of evaluating the applicability of the software for hydrological modeling and estimating discharge at the pour points. The study provides valuable insights into the WEAP's applicability for discharge estimation at pour points, thus supports better infrastructure planning and decision-making.

2. Literature review

The hydrological cycle precipitation, runoff, and soil moisture plays a key role in water redistribution and ecosystem support, impacting water security and climate adaptation (Grafton R Quentin & Hussey Karen, 2011). Hydrological models, simplifies representations of real systems, enhances understanding and prediction of water processes (Gayathri K Devi et al., 2015; Pacheco, 2015). Rainfall-runoff models vary in complexity, from simple approaches like the Rational Method to sophisticated ones such as SWAT and MIKE SHE, which incorporate climate and land-use effects (Jain Scientist G & Roorkee, 2025). While global modeling advances, Nepal relies on empirical methods like WECS/DHM and NEA, using regression-based equations (Marahatta et al., 2021).

WEAP integrates biophysical and socio-economic factors for water allocation (Yates et al., 2005). It addresses water management challenges with minimal data needs, aiding planning and forecasting (Kandera & Výleta, 2020). Successful applications in Egypt, West Africa, and Iraq demonstrate its effectiveness in irrigation optimization and supply-demand balancing(Al-Weshah, 2009; Esraa et al., 2023; Hamdi et al., 2023). Its ability to combine climate, hydrology, and policy makes it ideal for sub-basin management.

Due to the diverse approaches to hydrological modeling and their varying applications, selecting an appropriate tool requires balancing complexity, data availability, and management objectives. While empirical methods remain prevalent in data-limited regions like Nepal, integrated models such as WEAP offer a robust framework for assessing water allocation under changing climatic and socio-economic conditions. This study employs the WEAP model to analyze water resource dynamics in Seti river basin using the limited geospatial, hydrological and climate data.

3. Methodology

The methodology shown on Fig is used for the study purpose.

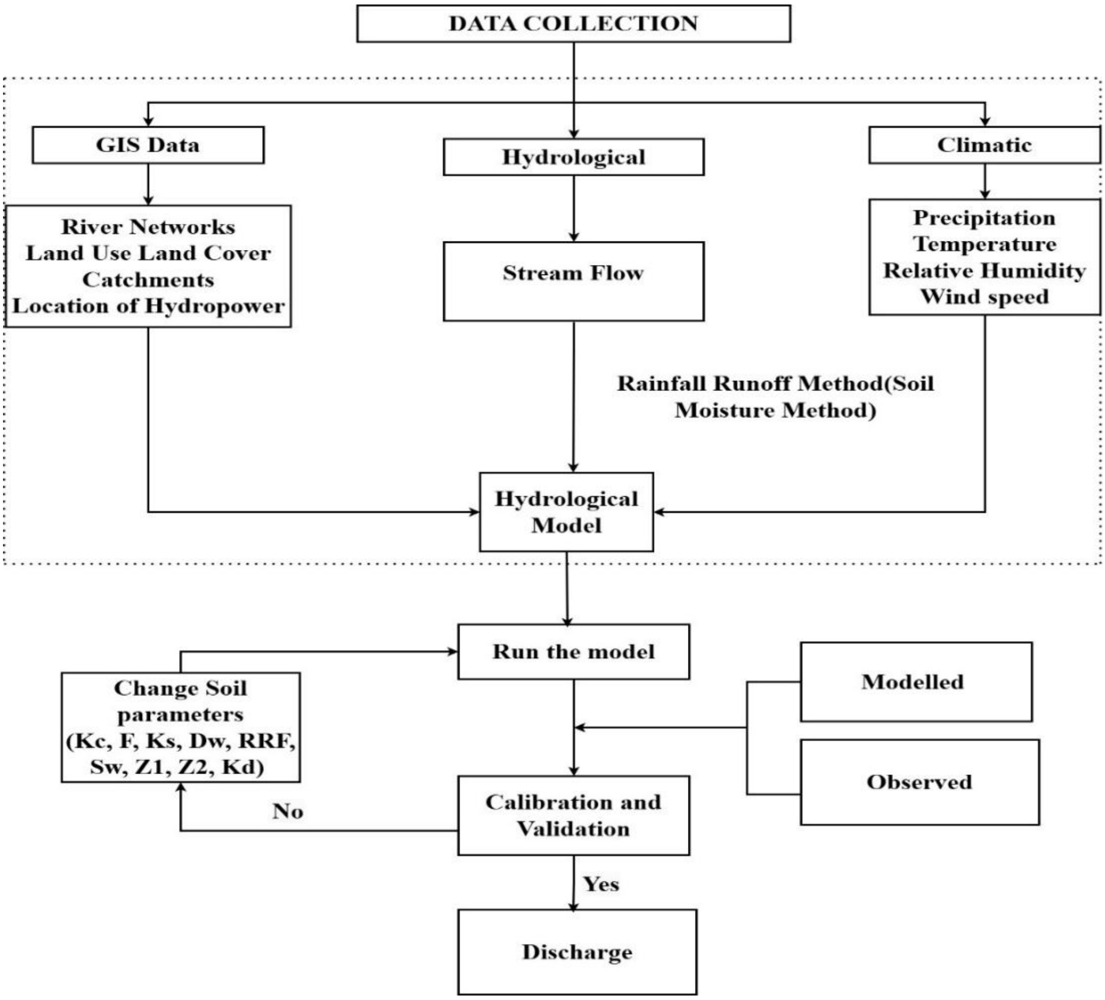


Fig. 1: Methodology Flow Chart used for the research

3.1 Study area

The study area (Seti River) is located in Nepal's western part (province-Gandaki) within Kaski district. The river extends from 28°35’06.64” N, 83°59’29” E to 28°32’18.23” N, 84°5’6.87” E on the north and 28°13’43” N, 83°47’57.37” E to 28°5’32.69” N, 84°4’52.9” E on the south. The total area taken for research is 871 Sq. Km. The elevation ranges from 7465m to 540 from mean sea level. The length of river taken for study is approximately 62 km.

3.2 Data source

WEAP is a conceptual model that uses water balance approach to simulate water supply scenarios. The study gathered relevant data from various sources, including hydrological records, climate data, and existing research studies. The data source and type are shown in Table .

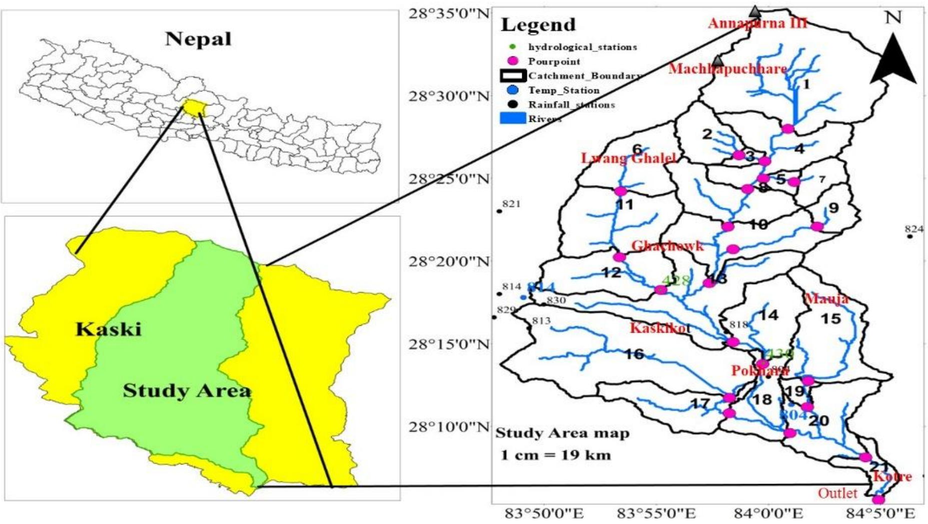


Fig. 2: Location Map of Seti River Catchment

Table 1: Data source

SN	Data Type	Source	Year
1	Digital Elevation Model (DEM)	SRTM -30m resolution	Accessed 2025-01-26
2	River Network	DMG	2020
3	Land Use Land Cover (LULC)	Sentinel-2 10m land use/land cover	2023
4	Soil Data	FAO Soil Map	Accessed 4th march 2025
5	Meteorological/ Hydrological Data	DHM	1995-2023
6	Hydropower	DOED	Updated on: Feb 21, 2025

*****_SRTM is Shuttle Radar Topography Mission, DMG is Department of mines and Geology, FAO is Food and Agriculture Organization, DHM is Department of Hydrology and Meteorology, DOED is Department of Electricity Development_

3.2.1 Geospatial Data

A Digital Elevation Data (DEM) with a 30-meter spatial resolution was utilized for catchment delineation, using the hydropower location as the pour point in GIS. A total of 21 Catchments were delineated and given a name as catch 1 to catch 21 for analysis. Land Use Land Cover (LULC) data from Sentinel-2 with a 10-meter resolution was used to classify the catchments into different land cover classes. The land cover was categorized into 8 classes, as shown in the table, and the percentage of each land cover class within each catchment was subsequently delineated.

3.2.2 Hydrological and Climate Data

Hydrological data such as streamflow and climate data such as precipitation, temperature, relative humidity and windspeed were collected from DHM from the year 1995 to 2023. Monthly climatic data for each catchment was calculated by aggregating the data from the nearest hydrological and climatic stations using the Thiessen polygon method (Marahatta et al., 2021). Only the available discharge data was used to assess the reliability of the model. Due to data scarcity, only one hydrological station of

Lahachowk (station number 428) was used for calibration and validation of the model. Further calibration and validation can be conducted if reliable discharge data from the hydropower headworks becomes available.

3.2.3 Model Overview

WEAP model was used as the tool to assess the discharge on various pourpoints. The WEAP hydrological model was used to evaluate the hydrological behavior at the sub-basin or land-use level. It is a lumped continuous model based on the rainfall-runoff method (soil moisture method), which incorporates a one-dimensional, two-layer (or "bucket") soil moisture dynamic system. This system uses empirical functions to partition water into evapotranspiration (ET), surface runoff, subsurface runoff (interflow), and deep percolation at the root zone of a sub-basin unit (Eq. 1) as shown in Fig. 3 (SEI, 2007). A key input to the model is the climate dataset, which includes precipitation, temperature, relative humidity, and wind speed. Each sub-basin is assigned a unique climate dataset that is uniformly distributed across the sub-basin.

$$\mathrm{R\,d_f}\frac{dz_{1\cdot f}}{dt} = P_e(t) - ET_0(t)k_{c\cdot j}(t)\left(\frac{5z_{1\cdot f}-2z_{1\cdot f}^2}{3}\right) - P_e(t)z_{1.f}^{RRF_j} - f_j\cdot k_{s\cdot j}z_{1\cdot f}^2 - \left(1-f_j\right)\cdot k_{s\cdot f}z_{1\cdot f}^2 \qquad (1)$$

Where $Z_{1.f}\varepsilon[0,1]$ is relative soil water storage, **j** is land use and land cover, Rd_f is soil water holding capacity of land use [mm], P_e is effective precipitation[mm], $ET_0(t)$ is reference evapotranspiration [mm/day], $K_{c.}$ is crop coefficient land use, RRF is runoff resistance factor, $P_e(t)z_{1.f}^{RRF_1}$ is the surface runoff, $f_jk_{z.j}Z^2_{1.f}$ is interflow from the first layer j, f is partitioning coefficient related to the land cover type, soil, and topography for the area j, that divides flow into horizontal f_j and vertical $(1\text{-}f_j)$ flows, and $K_{s.j}$ is saturated hydraulic conductivity of the root zone layer of land use j [mm/time].

In Eq. (1), the second term represents the reference ET; it is estimated using the Penman-Monteith equation modified for a standardized crop of grass, 0.12 m in height and with a surface resistance of 69 s/m. Continuing with Eq. (1), the $K_{c.j}$ is the crop/plant coefficient for each fractional land cover. The third term represents surface runoff, where RRF_j is the runoff resistance factor of the land cover. Higher values of RRF_j lead to less surface runoff. The fourth and fifth terms are the interflow and deep percolation terms, respectively, where the parameter $K_{s.j}$ is the estimate of the root zone saturated conductivity[mm/time] and f_j is a partitioning coefficient related to soil, land cover type, and topography that fractionally partitions water both horizontally and vertically.

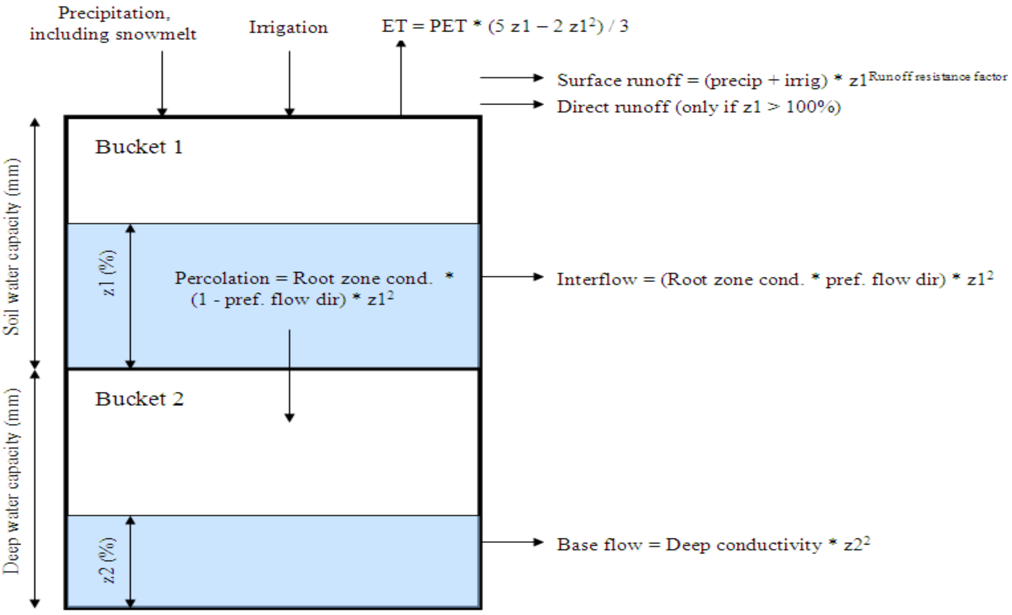


Fig. 3: Conceptual Diagram used in WEAP(Yao et al., 2021)

3.2.4 Performance Evaluation Criteria

The model performance was evaluated using statistical measures, including the Coefficient of Determination (R^2), Nash-Sutcliffe Efficiency (NSE), Root Mean Square Error (RMSE), and Percentage Volume Bias (PBIAS), to assess the accuracy and reliability of the model's predictions.

Coefficient of Determination (R^2) – R^2 measures the strength of the linear relationship between observed and estimated values. It is calculated using Equation (2) (Marahatta et al., 2021).

$$R2=\left[\frac{\sum_{i=0}^{n}(Qoi-\overline{Qo})\,(Qei-\overline{Qe})^2}{\sqrt{\sum_{i=0}^{n}(Qoi-\overline{Qo})^{\,2}}\sqrt{\sum_{i=0}^{n}(Qei-\overline{Qe})^2}}\right]^2 \qquad (2)$$

Nash-Sutcliffe Efficiency (NSE) – NSE is a normalized statistic that evaluates the relative magnitude of the residual variance in relation to the observed value variance. It is calculated using the equation (7)

$$NSE = 1- \frac{\sum_{I=0}^{12}(Qoi-Qei)^2}{\sum_{I=0}^{12}(Qoi-\overline{Qo})^2} \qquad (3)$$

Criteria: The larger the value of NSE, the better the model performance(Marahatta et al., 2021).

Root Mean Square Error (RMSE) – Measures the difference between observed and estimated values, with lower values indicating better performance.

$$\mathbf{RMSE}= \sqrt{\frac{1}{n}\sum_{2i=1}^{12}\left(\mathrm{Qoi}-\overline{\mathrm{Qo}}\right)^{2}} \qquad (4)$$

Criteria: Smaller value of RMSE is considered better (Marahatta et al., 2021).

Ratio of the Root Mean Square Error (RSR) – RSR is a normalized statistical metric used to evaluate the performance of hydrological models. It provides a standardized measure of model error relative to the variability in observed data, making it useful for comparing model performance across different watersheds or time periods. RSR is calculated as:

$$\mathbf{RSR}=\frac{RMSE}{\sigma_{obs}} \qquad (5)$$

where:

- **RMSE** = Root Mean Square Error (measures prediction error)
- **σobs**= Standard Deviation of observed data

Criteria: Value lesser than 0.5, better the performance (Marahatta et al., 2021).

Percentage Volume Bias (PBIAS) – PBIAS measures the degree of volume bias between the observed and estimated values. It is calculated using the following equation:

$$PBIS = \frac{\sum_{i=0}^{n}(Qei-Qoi)}{\sum_{i=o}^{n}Qoi} \text{ X } 100 \qquad (6)$$

where, Qo¯= Observed Annual Average Flow(m3/s), Qe¯ = Estimated Annual Average Flow(m3/s), Q_{0i} = Observed monthly average flow of month I, Q_{ei} = Estimated monthly average flow of month I, n = number of data. As number of months are 12, n = 12 in this case.

The coefficient of determination (R^2)- R^2 is the square of the coefficient of correlation.

Criteria: Larger the value of R^2, better the performance (Marahatta et al., 2021).

4. Results and Discussion

4.1 Model: Calibration and Validation

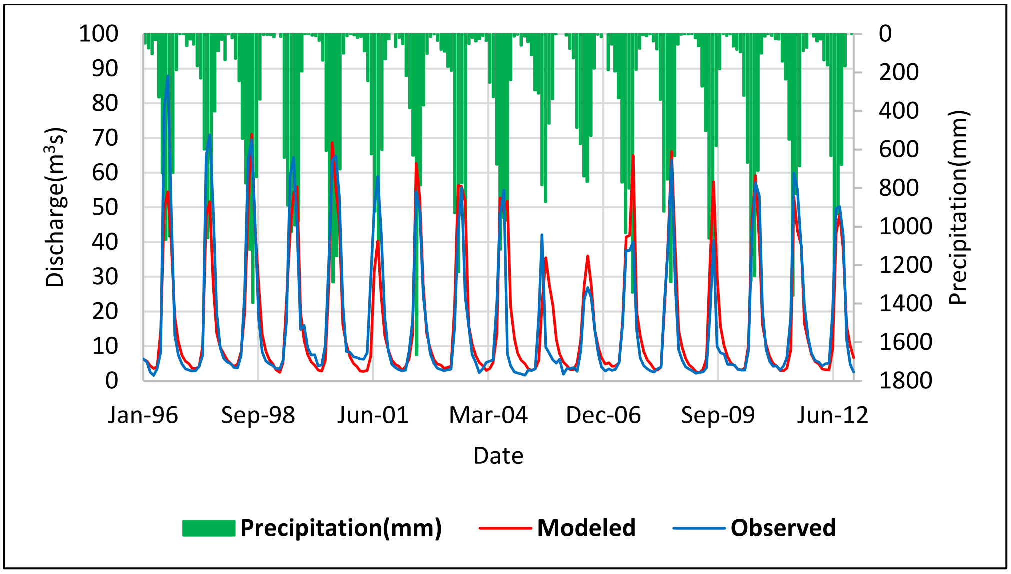
The calibration of WEAP model parameters refined the simulation of hydrological processes by adjusting key variables within appropriate ranges. The crop coefficient (Kc), which influences evapotranspiration rates, was calibrated from 0.72 to 1.4, reflecting variations in land use and vegetation. Soil water capacity (Sw), crucial for moisture retention, was adjusted from 150 to 1500 mm, indicating different soil characteristics across catchments. The runoff resistance factor (RRF) was modified from 0.05 to 6.01, affecting surface runoff generation. Root zone conductivity (Ks) increased from 100 to 500 mm/month, enhancing water movement through soil layers. The preferred flow direction (f) was adjusted from 0.53 to 1, indicating a greater tendency for deep percolation. The initial soil moisture content (Z1 and Z2) increased to 43.57–59.65% and 54.46%, respectively, suggesting wetter initial conditions. Additionally, deep conductivity (Kd) was raised to 250 mm/month, signifying higher groundwater recharge, while deep water capacity (Dw) was reduced to 500 mm, reflecting limited deep aquifer storage. These adjustments improved the model's ability to replicate observed hydrological patterns, ensuring more reliable water availability estimates for the study area.

Table 3: Soil parameters adopted for calibration

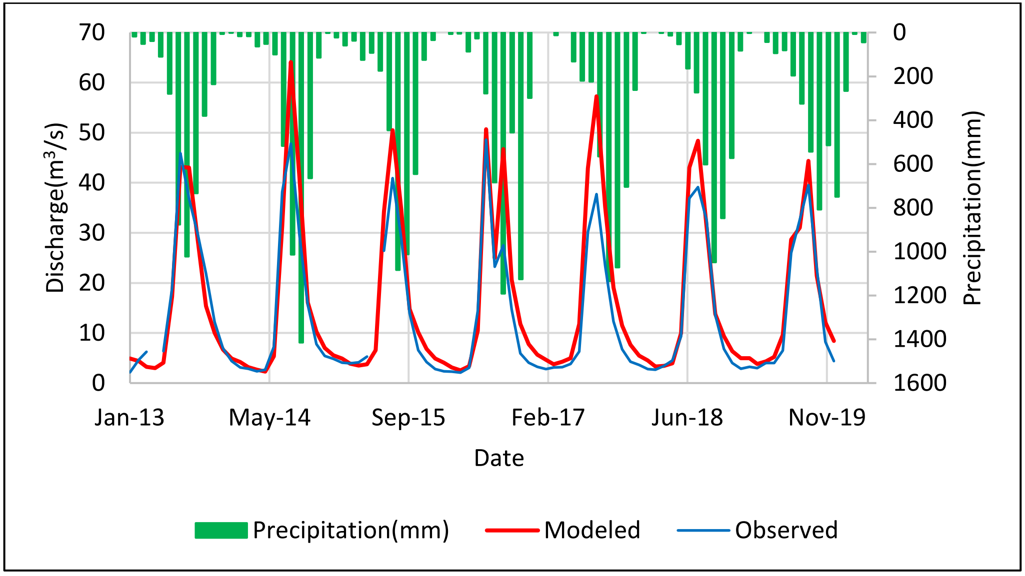
Input Parameters	**Unit**	**Calibration Range**	**WEAP Default Value**	**Range used for calibration**
Crop Coefficient(Kc)		0 and higher	1	0.72-1.4
Soil Water Capacity(Sw)	Mm	0 and higher	1000	150-1500
Runoff Resistance Factor(RRF)		0 to 1000	2	0.05-6.01
Root Zone Conductivity(Ks)	mm/month	0 and higher	20	100-500
Preferred Flow Direction(f)		0 to 1	0.15	0.53-1
Initial Z1	%	0 to 100%	30	43.57-59.65
Initial Z2	%	0 to 100%	30	54.46
Deep Conductivity(Kd)	mm/month	0.1 and higher	20	250
Deep Water Capacity(Dw)	mm	0 and higher	1000	500

4.1.1 Result at Lahachowk (428) Station

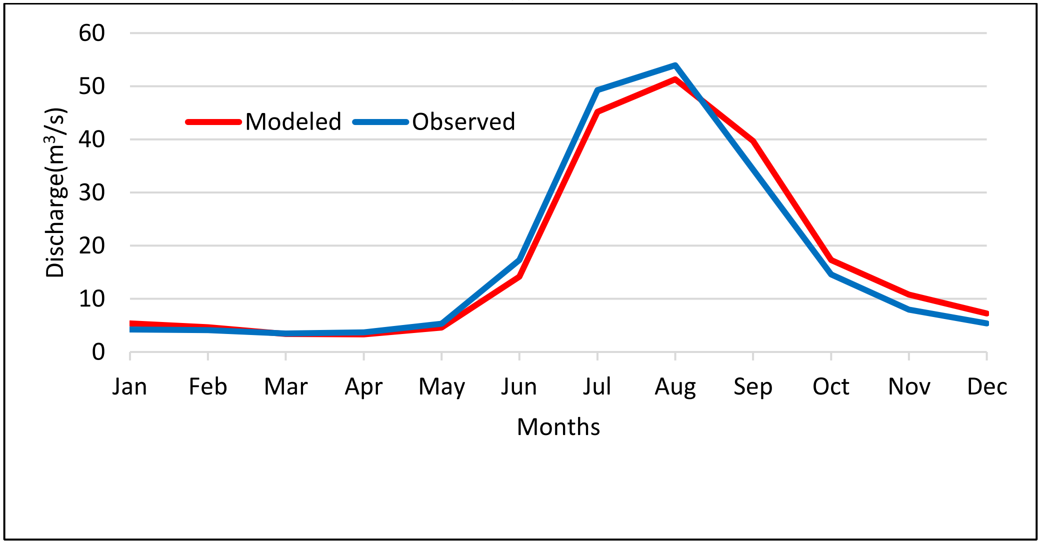
The observed and modeled discharge values from the Lahachowk station, as shown in Fig. 4, reveal a strong correlation, indicating that the model accurately captures the overall hydrological trends. However, discrepancies arise during peak flow events, with the model slightly overestimating the discharge, as reflected in the differences between the observed and simulated monthly mean and standard deviation values for both the calibration and validation periods. The monthly mean and standard deviation of observed values are 16.41 m^3/s and 19.69 m^3/s, respectively, while those of simulated values are 17.84 m^3/s and 18.44 m^3/s for the calibration period. Similarly, the monthly mean and standard deviation of observed values are 13.49 m^3/s and 13.47 m^3/s, respectively, while those of simulated values are 15.67 m^3/s and 15.81 m^3/s for the validation period.


Discharge(m³s)
100
90
80
70
60
50
40
30
20
10
0
Precipitation(mm)
0
200
400
600
800
1000
1200
1400
1600
1800
Jan-96
Sep-98
Jun-01
Mar-04
Dec-06
Sep-09
Jun-12
Date
Precipitation(mm)
Modeled
Observed

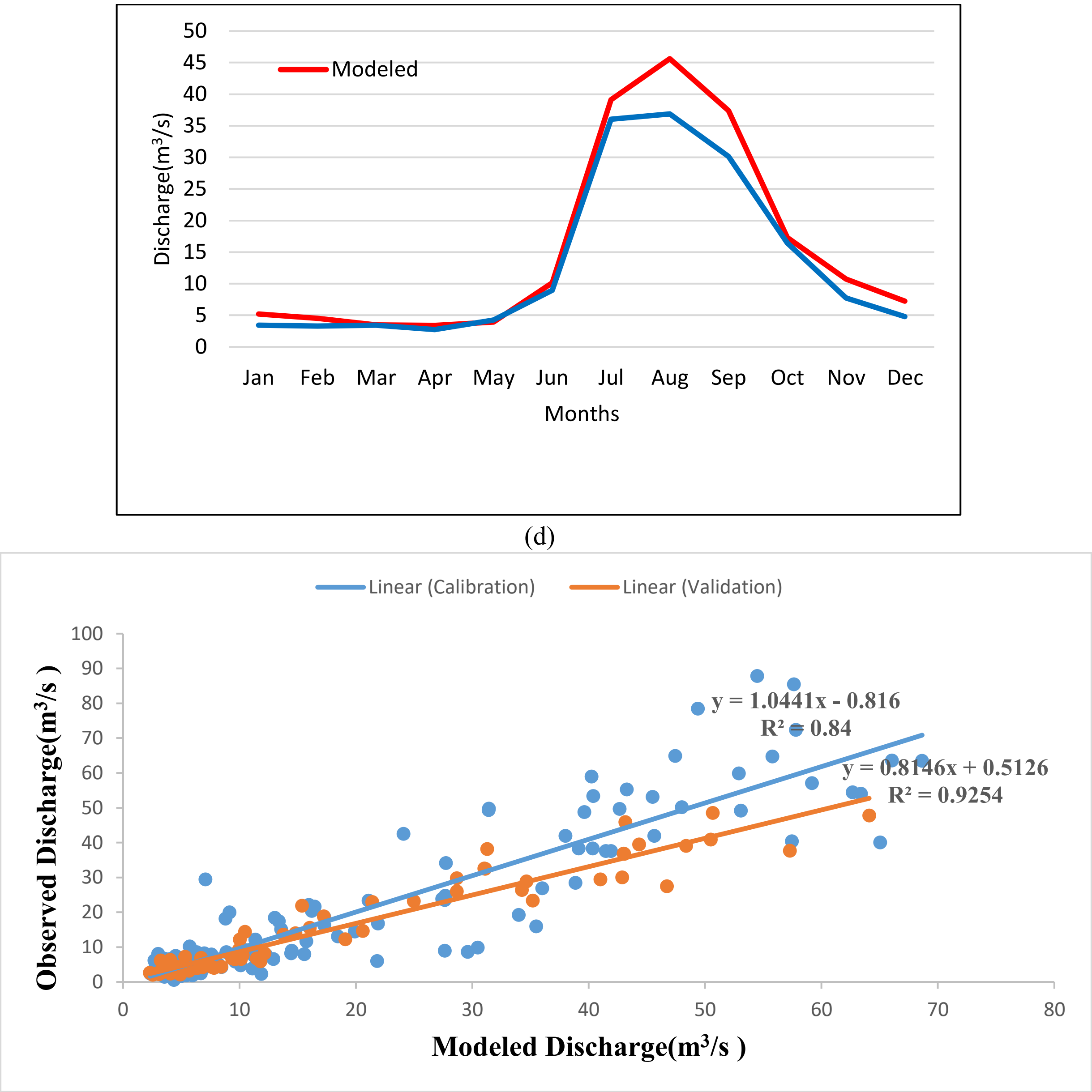
(a)


Discharge(m³/s)
70
60
50
40
30
20
10
0
Precipitation(mm)
0
200
400
600
800
1000
1200
1400
1600
Jan-13
May-14
Sep-15
Feb-17
Jun-18
Nov-19
Date
Precipitation(mm)
Modeled
Observed

(b)


Discharge(m³/s)
60
50
40
30
20
10
0
Modeled
Observed
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

(c)



(e)

Fig. 4: Result at Lahachowk Station (a) Monthly Simulation result for Calibration Period, (b)Monthly Simulation result for Validation Period (c) Monthly Average Simulation Result for Calibration Period, (d) Monthly Average Simulation Result for Validation period (e)Monthly Scattered Plot between Observed and Modeled Discharge to see the correlation

The statistical performance of the model indicates strong reliability in both the calibration and validation phases (Table 4). The NSE values of 0.82 for calibration and 0.84 for validation suggest that the model performs well in replicating observed data, with even higher monthly average values of 0.97 and 0.92. This shows strong predictive capability at a monthly scale. Similarly, the R² shows a high correlation between simulated and observed values, with 0.82 in calibration and 0.93 in validation, while the monthly averages (0.98 and 0.99) indicate the model captures long-term trends effectively. The Root Mean Square Error (RMSE), which measures prediction error, is very low in calibration (0.42) but increases in validation (8.7), suggesting some discrepancies in the validation phase. The Percent Bias (PBIAS) value in calibration is nearly zero **(**-0.046%**)**, indicating negligible systematic error, while the validation PBIAS (18%) suggests slight overestimation or underestimation, though still within an acceptable range. The RMSE-Standard Deviation Ratio (RSR), which helps normalize RMSE values, remains below 0.5 in both phases, further confirming good model performance.

However, even minor flow estimation errors such as those implied by the slightly higher validation RMSE and PBIAS can have significant practical consequences. In hydropower planning, such discrepancies could lead to energy deficits during low-flow periods or infrastructure strain during unexpected high-flow events. For irrigation scheduling, inaccuracies may result in crop stress due to underwatering or inefficient water use from overallocation. Ecological systems are particularly sensitive to flow variations, as underestimating minimum flow requirements could degrade aquatic habitats, while overestimating might disrupt natural flow patterns essential for sustaining biodiversity. Thus, while the model demonstrates strong statistical performance, careful consideration of these potential impacts remains crucial for real-world water resource management.

Table 4: Performance statistical value of Lahachowk Station

Performance statistic	**Monthly**		**Monthly Average**	
	Calibration	Validation	Calibration	Validation
NSE	0.82	0.84	0.97	0.92
R^2	0.82	0.93	0.98	0.99
RMSE	0.42	8.7	28	3.7
PBIS	-0.046%	18%	9.6%	19%
RSR	0.42	0.39	0.16	0.27

4.2 Flow Duration Curve

The Flow Duration Curve (FDC) shown on Fig. represents the discharge variation over time at outlet point of study area, High discharge of 350 m3/s occur only for 0.5 % of time. The curve then gradually declines, indicating moderate flows, 100-200 m3/s occurs 20-50% of the time, representing baseflow contributions and sustained river discharge beyond peak events. As the curve flattens towards the right, low flows (20-40) m3/s dominate for more than 80% of the time. This highlights the river's minimum flow conditions, crucial for ecological balance and water availability during dry periods for hydropower designs.

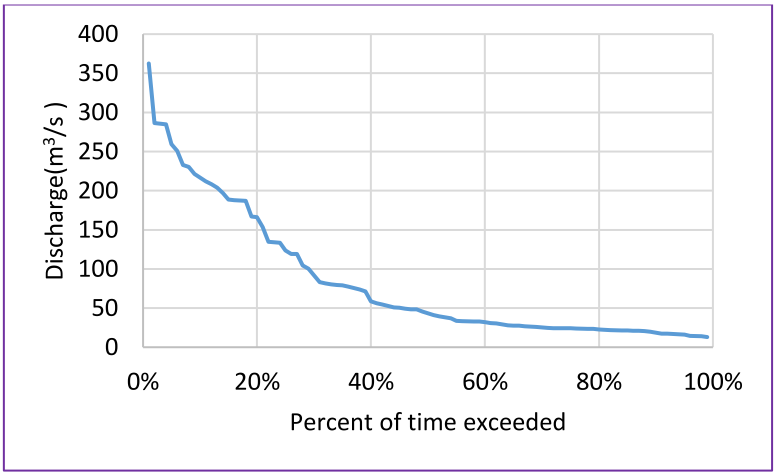


Fig. 5: Flow Duration Curve at outlet point showing exceedance of discharge

4.3 Monthly Average Discharge

Fig. 6 represents the monthly discharge (m^3/s) and precipitation (mm), showing a clear relationship between rainfall and river discharge throughout the year. Precipitation is lowest in December (11.41 mm) and highest in July (1104.51 mm), reflecting the monsoon season's dominance in the region. Similarly, discharge is lowest in March (18.46 m^3/s) and peaks in August (247.67 m^3/s), showing a delayed response of river flow to precipitation. During the monsoon months (June–September), both precipitation and discharge significantly increase, with the highest discharge (247.67 m^3/s) in August, indicating strong runoff contributions. Conversely, in the dry months (November–April), both precipitation and discharge remain low, suggesting groundwater dependency and minimal direct runoff. This pattern is typical for monsoon-fed river systems, where seasonal rainfall variations strongly influence streamflow dynamics.

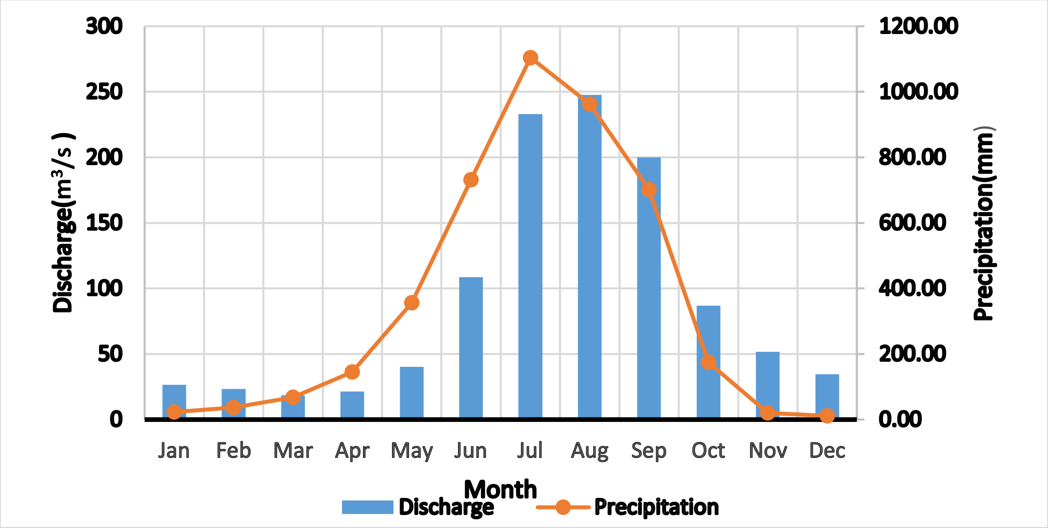


Fig. 6: Monthly Average flow at outlet point over time

5 Conclusion and Recommendations

The study successfully estimated the discharge in the Seti Watershed of the Gandaki Basin using the Water Evaluation and Planning (WEAP) model, demonstrating its reliability for hydrological modeling at the sub-basin level. The model's performance, validated through statistical measures such as NSE (0.82–0.84), R^2 (0.82–0.93), and PBIAS (near zero in calibration), confirmed its accuracy in simulating monthly flow patterns. The results highlighted the strong correlation between precipitation and discharge, with peak flows occurring during the monsoon season, while low flows persisted in dry months, providing critical insights for water resource planning. The WEAP model approach proved effective in capturing hydrological processes, making it a valuable tool for assessing water availability, optimizing allocation, and supporting sustainable development in data-scarce regions like Nepal.

To enhance the accuracy and applicability of future studies, additional discharge data from multiple gauging stations and hydropower headworks can be incorporated for comprehensive model calibration and validation. Further research could explore the impacts of climate change and land-use dynamics on water availability in the Seti Watershed, ensuring long-term resilience in water resource management. Policymakers and stakeholders should leverage WEAP's scenario-analysis capabilities to balance competing water demands, prioritize equitable allocation, and optimize hydropower operations while safeguarding ecological and agricultural needs. By integrating advanced modeling with empirical data, WEAP model can be used to strengthen its water management strategies.

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