

Impact of Climate Change on Water Resources in the Swarnamukhi River Basin

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Abstract: Climate change is impacting the hydrological cycle and water availability across the globe. This research evaluates how climate change influences water resources and explores hydrological uncertainty within the Swarnamukhi basin. Utilizing advanced tools such as the Hydrological Engineering Center-Hydrological Modelling System (HEC-HMS), as well as Remote Sensing (RS) and Geographical Information Systems, alongside historical climate data, the study examines hydrological dynamics and water flow in the basin. Findings indicate that notable shifts in precipitation patterns, temperature, and various hydrological factors contribute to increased uncertainty in water resource management.

Keywords – Adaptive Water Resources Management, Climate Change, Geographical Information System, Hydrological Uncertainty, and Remote Sensing.

I. INTRODUCTION

Water is one of the most crucial natural resources for sustaining life. As the population increases, the demand for water rises as well. It is vital for industries, agriculture, and the needs of both humans and animals. Therefore, it's important to manage this precious resource sustainably. Effective management and development planning are essential to replenishing or recharging water in areas with significant runoff caused by various topographical factors. Preserving the balance of natural land and water resources is essential, particularly at the watershed level. The significance of water as the fundamental element for human existence cannot be overstated. Water resources support ecosystem balance, drive economic development, and are necessary for life to continue.

This study aims to evaluate the effects of climate change on water resources and to analyze hydrological uncertainty within the Swarnamukhi River Basin. The research employs hydrological modeling through HEC-HMS, GIS-based watershed

analysis, remote sensing data, and statistical methods to assess the rainfall-runoff process.

The Swarnamukhi Basin, which spans an area of 919.96 square kilometers, was mapped using digital elevation model data in QGIS. Climate data from 2000 to 2024, including rainfall, temperature, wind speed, solar radiation, and relative humidity, were examined to identify trends and changes over time.

II. STUDY AREA

The Swarnamukhi River is one of the major rivers among the 13 that flow through the Chittoor District in Andhra Pradesh, India. It begins in the Seshachalam hills of Chandragiri Mandal and stretches approximately 83 km within the district. Overall, the river spans around 142 km. The course of the river starts through a valley between Tirupati and Chandragiri towns and meets the Srikalahasti town; thereby, the river finally joins into the Bay of Bengal at Siddavaram village in Nellore District. River Swarnamukhi, an ephemeral river, is the east-flowing river between Penna and Kaveri Rivers. The Swarnamukhi is a river in southern India.

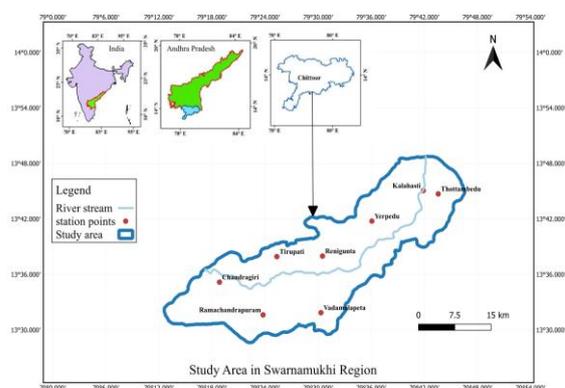


Figure 1 Study Area Map

This river, which rises from an elevation of 300 m above sea level in the Eastern Ghats near Pakala in the Tirupati district, is independent in nature. In

1977, the Kalyani Dam was built on its tributary, the Kalyani River, with a live storage capacity of 25 million cubic meters. The river basin is located between latitudes 13°25' 30" and 14°28' 30" North and longitudes 79°08' 39" and 80°11' 00" East, spanning the Chittoor and Nellore Districts. For our study, we focus on the section of the Swarnamukhi River within the Nellore and Chittoor districts, delineated by latitudes 13°54'39" and 14°28'30" North and longitudes 79°11'10" and 80°11'10" East. The area under investigation covers 919.96 km². Refer to Figure 1 for the study area map.

III. DATA USED

Satellite Data Liss-3 and DEM satellite imagery was used to delineate and determine the Land Use and Land Cover of the study area collected from the Bhuvan website.

Rainfall and Discharge data is collected for the different Rain gauge stations in the study area, i.e., Renigunta, Yerpedu, Kalahasti, Thottambedu, Vadamalapeta, Ramachandrapuram, Tirupati, and Chandragiri. Daily rainfall data for the years 2000 to 2024 was collected from the Office of Chief Planning Officer, Chittoor, wris.gov.in, and cwc.gov.in websites.

Thissen Polygons are plotted for the study area to find the rain gauge stations that are influenced, Each polygon represents the area that is closest to a particular rain gauge station; this method ensures that the rainfall is accurately distributed across the basin, which is shown in Figure 2.

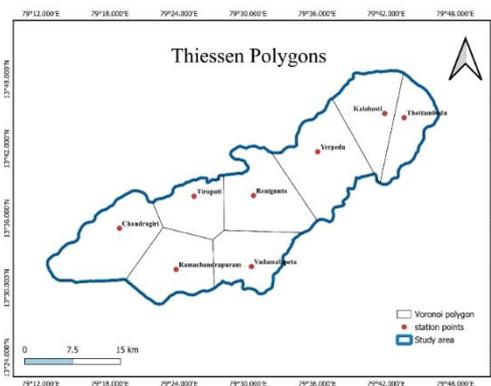


Figure 2 Thiessen Polygon Map

The weightage of the rain gauge stations are Renigunta (138.075 km²), Yerpedu (155.7478 km²), Kalahasti (106.539 km²), Thottambedu (74.404 km²), Vadamalapeta (97.138 km²), Ramachandrapuram (113.679 km²), Tirupati (80.309 km²), and Chandragiri (153.682 km²). Among all stations, Yerpedu has the largest influence at 155.7478 km²,

while Thottambedu has the smallest at 74.404 km². The total area of catchment covered by these stations adds up to 919.96 km².

IV. LAND USE LAND COVER (LULC)

LULC analysis is essential for comprehending the geographical distribution of various land types and their effects on ecology and socio-economic conditions. This research involved classifying land use and land cover (LULC) in the Swarnamukhi River Basin, which spans an area of 919.96 km². The classification utilized satellite imagery and Geographic Information System (GIS) techniques, dividing the land into five primary categories: water bodies, forest areas, agricultural land, barren land, and built-up land. A significant portion of the study area is identified as built-up land, while a smaller area consists of water bodies. The remainder includes agricultural land, barren land, fallow land, and floodplains. The LULC map and its corresponding results are illustrated in Figure 3 and Table 1.

Table 1 Land Use Land Cover Classification

LULC Map Classification	Area Sq.km	% of Area
Water bodies	93.80	10.20
Forest area	178.84	19.44
Agricultural Land	168.79	18.34
Barren land	216.24	23.50
Built Up land	262.29	28.51
Total	919.96	100

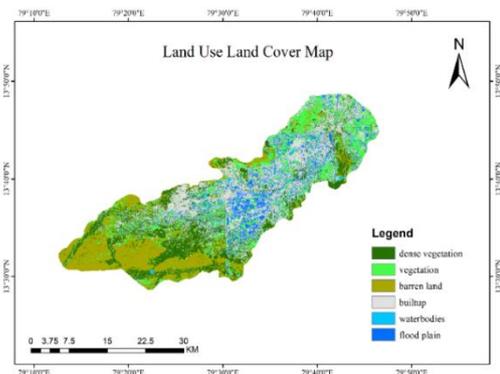


Figure 3: Land Use and Land Cover Map

V. SOIL CLASSIFICATION

Soil classification is vital for understanding the productivity of land, its capacity to retain water, and its potential for erosion in a river basin. Different soil types affect farming methods, rates of water absorption, and general land stability.

The Swarnamukhi River Basin features a wide variety of soil types, which are key to conserving water, selecting appropriate crops, and planning for sustainable land use. In GIS (Geographic Information System), soil classification employs spatial analysis and mapping techniques to sort soils into various categories based on their properties. The soil map is illustrated in Figure 4.

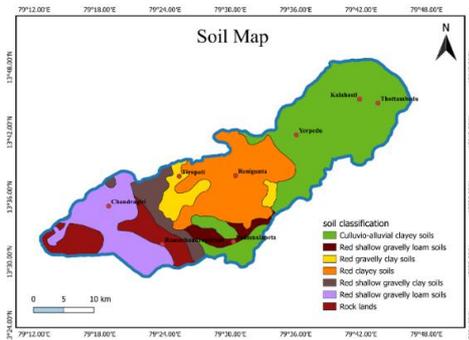


Figure 4 Soil Classification Map

The study area is entirely covered by red clayey soils, rocky lands, red shallow gravelly clay soils, and colluvial-alluvial clayey soils. It is categorised under the Type C and Type D Hydrological Soil Groups, as mentioned in Table 2.

Table 2 Soil Classification

Soil type	Area
Culluvio-Alluvial Clayey Soils	352.42
Culluvio-Alluvial Calc Clayey Soils	44.76
Red Shallow Gravelly Loam Soils	155.43
Red Gravelly Clay Soils	69.55
Red Clayey Soils	172.75
Red Shallow Gravelly Clay Soils	44.82
Rock Lands	80.23
Total area	919.96

VI. SOIL MOISTURE ACCOUNTING

The Hydrologic Engineering Centre Hydrological Modelling System (HEC-HMS) contains a Soil Moist Accounting (SMA) model that models the flow of water across a watershed's soil and groundwater layers. Processes including infiltration, percolation, and groundwater recharge, all of which are crucial to hydrological modeling, can be analyzed with this model. Land use (LU), land cover (LC), and soil properties are some of the criteria that are used to determine the parameters for the SMA approach. The SMA approach requires the following

parameters: (a) storage of canopy interception; (b) storage of surface depressions; (c) maximum infiltration rate; (d) storage of soil; (e) storage of tension zones; and (f) percolation rates within soil zones. Streamflow recession was analysed using historical data to establish the depths and coefficients of groundwater layers 1 and 2. The soil percolation rate was calculated using the hydraulic conductivity of the relevant soil profile.

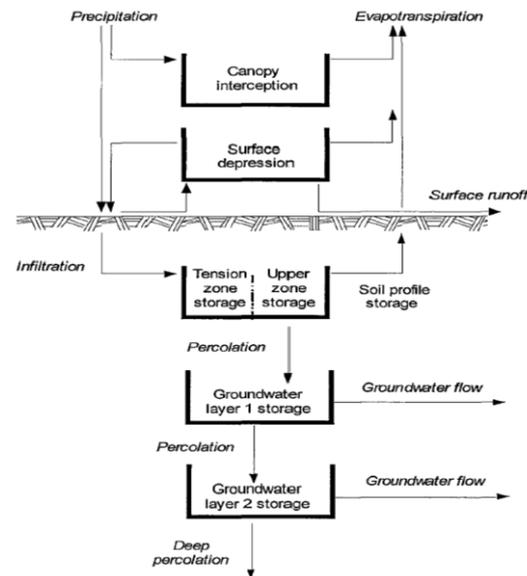


Figure 5 Schematic of SMA algorithm

Figure 5 shows how the technique is followed in the Hydrological Modelling System.

In the Swarnamukhi River Basin, Vertical Electrical Surveys (VES) were carried out at chosen sites to evaluate subsurface features, focusing particularly on groundwater potential and aquifer boundaries. The investigation utilized the Schlumberger electrode configuration, recognized for its effectiveness in identifying variations in layer resistivity, hydraulic conductivity, and thickness.

Table 3 VES Results

Station	N	P	K	Min	Max
Kalahasti	ρ1	7.47	1.04	7.18	7.77
	ρ2	1085	10	152	189
	h1	8.43	1.13	7.48	9.5
	z1	8.43	1.13	7.48	9.5
Vadamalpeta	ρ1	20.6	1.06	19.4	21.9
	ρ2	348	10	309	378
	h1	55.5	10	10.2	16.2
	z1	55.5	10	10.2	16.2
Chandragiri	ρ1	16.6	1.02	16.3	16.9
	ρ2	1085	10	278	302
	h1	25.6	1.53	16.7	39.2
	z1	25.6	1.53	16.7	39.2

Renigunta	ρ_1	6.79	1.05	6.48	7.11
	ρ_2	1085	10	137	175
	h1	14.9	1.22	12.2	18.2
	z1	14.9	1.22	12.2	18.2
Tirupati	ρ_1	24.6	1.01	24.5	24.7
	ρ_2	288	1.39	207	400
	h1	20.3	1.05	19.3	21.3
	z1	20.3	1.05	19.3	21.3

Low Resistivity Values: Found in regions with high moisture content, clay deposits, or weathered/fractured rock formations. Kalahasti and Renigunta stations show lower resistivity values, suggesting possible saturated zones.

High Resistivity Values: Found in consolidated rock formations, dry zones, or impermeable layers. Stations such as Vadamalpetta and Tirupati have relatively higher resistivity values, indicating the presence of hard rock or less water-bearing formations.

Deep Aquifer Zones: Some stations exhibit significant depth variations, particularly Vadamalpetta and Tirupati, which indicate deeper aquifer potential.

Layer Continuity: Multiple stations exhibit similar resistivity values at different depths, suggesting continuity in the geological formations.

- **Conductivity (K)** in soil moisture accounting (SMA) parameters represents the rate at which water moves through the soil profile.
- **Resistivity (ρ):** Represents the resistance of a material to electrical current flow, typically measured in ohm-meters (Ω m).
- **h1:** Represents the thickness of the first layer in the subsurface.
- **z1:** Represents the depth to the bottom of the first layer.
- **Depth Ranges (Min and Max values):** Indicate the depth at which each layer is encountered, providing an estimation of the thickness of different subsurface strata.

VES results for selected stations are presented in Table 3 in the Swarnamukhi River Basin, including locations such as Kalahasti, Vadamalpetta, Chandragiri, Renigunta, and Tirupati.

The values selected for the SMA method in HEC-HMS were derived from a combination of field data, literature sources, and calibration against observed

hydrological data. The following factors were considered.

- **Land use and land cover classification:** Determining impervious areas and infiltration capacity.
- **Soil type and texture:** Assessing soil storage, tension storage, and percolation rates.
- **Vertical Electrical Sounding (VES) data:** Estimating groundwater storage and percolation.
- **Local hydrological studies:** Refining groundwater coefficients and infiltration rates.

Table 4 Estimation of SMA parameters

SMA Parameter	Estimated value
Soil (%)	64
Ground water 1 (%)	27
Ground water 2 (%)	18
Max Infiltration (mm/hr)	4.5
Impervious (%)	29
Soil storage (mmmm)	87
Tension storage (mm)	32
Soil Percolation (mm/hr)	2.78
GW 1 Storage (mm)	80
GW 2 Storage (mm)	380
GW 1 Percolation (mm/hr)	0.8
GW 2 Percolation (mm/hr)	0.5
GW 1 Coefficient (hr)	197
GW 2 Coefficient (hr)	500

The selected SMA parameters in Table 4 provide a realistic representation of the hydrological processes in the Swarnamukhi River Basin. These inputs help in accurately modeling rainfall-runoff processes, infiltration, groundwater recharge, and overall water balance within the basin. The calibrated values will further improve the reliability of simulations, aiding in the assessment of climate change impacts on water resources in the region.

VII. HEC-HMS OUTPUT

The Hydrologic Engineering Center- Hydrologic Modelling System (HEC-HMS) produces various hydrological outputs that help in evaluating how climate change is affecting water supplies. Tables 5, 6, 7, 8, and 9 display the main outputs, which include runoff hydrographs, peak discharge, total runoff volume, and other statistical characteristics crucial to comprehending hydrological responses.

Analysing hydrological uncertainty in the Swarnamukhi River Basin requires these outputs.

Runoff hydrographs, which show how discharge changes over time, are provided by HEC-HMS. The hydrographs, which are displayed in Figures 6, 7, 8, 9, 10, and 11, visualise how rainfall converts into runoff at various locations around the basin.

Runoff Hydrographs

Table 5 HEC-HMS OUTPUT

Years	Hydrological Element	Basin Rainfall (mm)	Peak Discharge (mm ³ /s)	Time of Peak	R ²
2000-2004	Basin	7524.168	3423.6	5-Oct-01	0.73
2005-2009	Basin	8610.714	6059.5	26-Oct-05	0.71
2010-2014	Basin	7565.584	2759.1	6-Nov-10	0.56
2015-2019	Basin	7277.882	6326.8	15-Nov-15	0.78
2020-2024	Basin	9819.934	7083.3	3-Dec-23	0.76

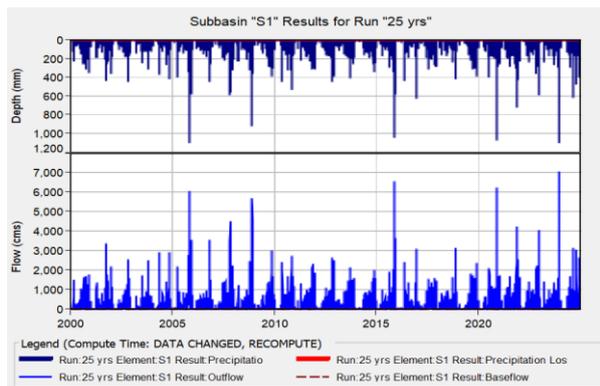


Figure 6 Flow and depth Hydrographs

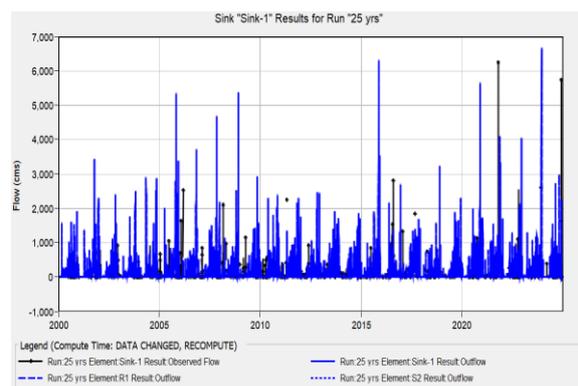


Figure 7 Flow validation Hydrograph

Table 6 Peak Discharge

25 Years	Hydrological Element	Peak Discharge (m ³ /s)	Time of Peak	Volume (mm ³)
2000-2024	Junction	7083.3	3 December 2023, 24:00	210949.42
2000-2024	Basin	7083.3	3 December 2023, 24:00	210949.42
2000-2024	Reach	6633.7	3 December 2023, 24:00	211470.96
2000-2024	Sink	6677	3 December 2023, 24:00	211467.79

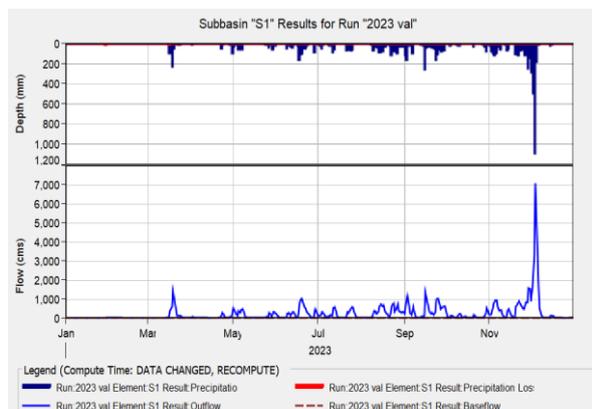


Figure 8 Peak Discharge Graph

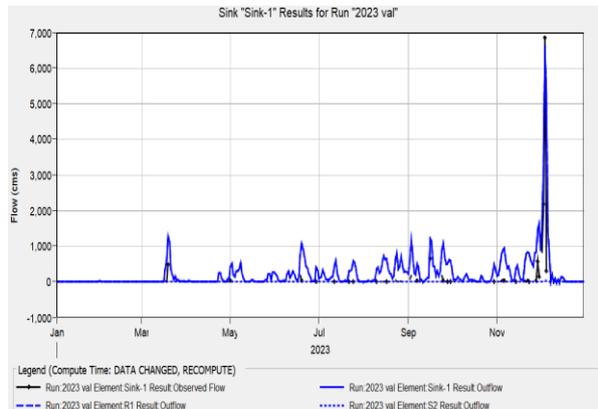


Figure 9 Validation for Peak discharge

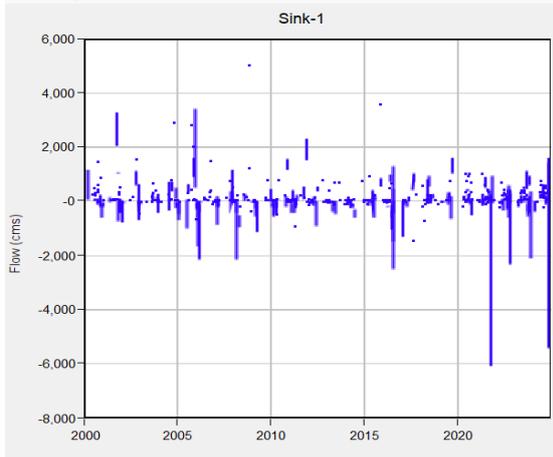


Figure 10 Residual Flow

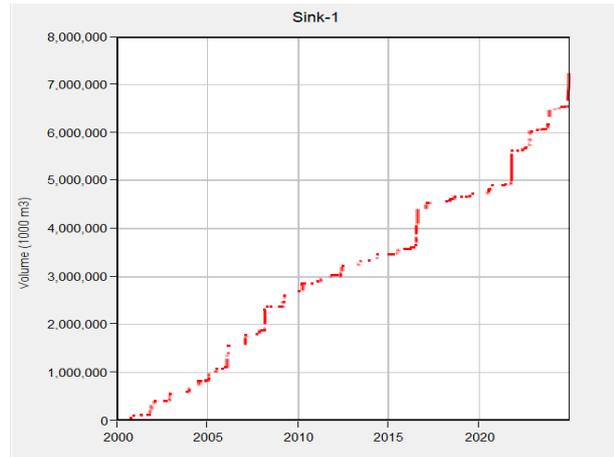


Figure 11 Cumulative Observed Flow

Table 7 Observed and Simulated Runoff

Period	Average Observed Runoff Volume (mm ³)	Average Simulated Runoff Volume (mm ³)	Error (%)
2000-2004	6954.65	7029.958	1.08
2005-2009	12835.34	12924.826	0.7
2010-2014	6767.69	6675.55	-1.36
2015-2019	11715.73	11388.118	-2.8
2020-2024	14209.31	14020.892	-1.33

Observed And Simulated Runoff With 5 Year Intervals

Table 6 presents a comparison of the simulated and observed runoff depths over intervals of five years. The simulated runoff depth is obtained using the HEC-HMS tool, whereas the observed runoff depth is the actual runoff that was recorded from the basin. To evaluate how well the model predicts runoff, the error percentage is computed.

Interpretation of Results

1. The observed and simulated runoff depths exhibit close agreement, indicating a well-calibrated hydrological model.
2. The error percentage varies between -2.80% and 1.08%, suggesting minor deviations due to model assumptions, input data uncertainty, and spatial variability in hydrological processes.

3. The highest deviation (-2.80%) occurs in the 2015-2019 period, which may be attributed to changes in land use, rainfall distribution, or errors in input data.
4. Increasing Runoff Trends: The observed runoff depth has increased over the years, especially in the 2020-2024 period, which may be attributed to changing rainfall patterns or alterations in land use.
5. The relatively low errors in other periods validate the model's reliability in simulating runoff patterns.

The Observed Average Rainfall and Runoff graph for the basin is drawn for the comparison of simulated Rainfall-Runoff model is shown in Figure 12.

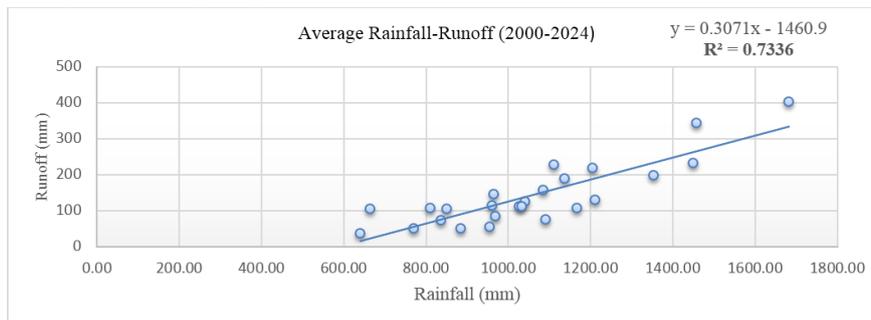


Figure 12 Runoff Graph for Swarnamukhi Basin with Initial Abstraction 0.2*S (Maximum Potential Retention)

HEC-HMS generates summary tables that outline key parameters for basins. Table 8 includes:

Table 8 Basin Summary

Basin	Area (sq.km)	CN Value	Lag Time (min)	Peak Flow (m ³ /s)
Swarnamukhi	919.96	88.5	455	7083.3

Calibration ensures that the model outputs align with observed data by adjusting parameters such as Curve Number (CN), Initial Abstraction, and Lag Time. Validation is performed using a separate dataset to confirm model accuracy. Table 8 provides values of statistical evaluation and model performance.

Table 9 Statistical Evaluation

Metric	Value
Nash-Sutcliffe Efficiency (NSE)	0.79
Coefficient of Determination (R ²)	0.7

To assess the reliability of the HEC-HMS model, statistical evaluation metrics such as Nash-Sutcliffe Efficiency (NSE), Coefficient of Determination (R²) were analyzed.

- NSE > 0.75 indicates good agreement between observed and simulated runoff.
- R² close to 1 suggests a strong correlation between model predictions and actual observations.

VIII. CONCLUSION

The HEC-HMS model performance was evaluated by comparing observed and simulated runoff data. The analysis showed that the model accurately predicted runoff values with only minor deviations. The highest deviation of 2.8% was recorded for the period 2015-2019, which could be attributed to land use changes and variations in rainfall patterns. For other periods, the error margins remained within an acceptable range, indicating good model accuracy. The Nash-Sutcliffe Efficiency (NSE) value for the model was found to be 0.79, confirming its reliability in simulating hydrological responses. The average coefficient of determination (R²) for simulation was 0.7%, and the (R²) for observed Rainfall and Runoff was 0.73%, further supporting the model's effectiveness in runoff estimation.

Peak flow analysis for the period 2020-2024 revealed that the highest peak discharge recorded at the basin outlet was 7083.3 m³/s on December 3, 2023. A sensitivity analysis of model parameters

highlighted that increasing the Curve Number (CN) value led to a significant increase in runoff, while adjustments in lag time, which was optimized to 455 minutes, improved peak flow simulation. It was also observed that soil moisture storage parameters played a crucial role in regulating runoff during consecutive rainfall events, confirming the importance of soil water balance in hydrological modeling.

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