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TEMPORAL ANALYSIS OF RAINFALL-RUNOFF MODELS USING HEC-HMS IN SEMI ARID REGION: A CASE OF THE SHETRUNJI RIVER SUB-BASIN, INDIA

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Abstract: In water resources and more specifically in hydrology, the application of mathematical models to represent the hydrological cycle process is crucial. This is the reason why the hydrological concepts are expressed in mathematical language to represent the corresponding behavior observed in nature. The current research targeted to development of a hydrological model using the HEC-HMS model for runoff estimation in Shetrunji River sub-Basin, India. The Soil Conservation Service-Curve Number (SCS-CN) Method was adopted to estimate the rainfall losses while the Soil Conservation Service-Curve Number (SCS-CN) Method was used to transform the excess rainfall into a direct runoff hydrograph. Muskingum Model was adopted for routing the total runoff from the outlet of the sub-basin to the outlet of the total basin. Model performance was achieved using different sets of data in which the data used was for Ten years (2013 to 2023). The regression analysis has been carried out for the comparison of modeled and observed datasets. The result of this research will help the global community in dealing with open-source data. It will enhance the decision-making system for un-gauged basins at a small scale level.

Keywords: HEC-HMS, Rainfall-Runoff Modelling, Shetrunji River Sub-basin, Regression Analysis

I. INTRODUCTION

The most common material in the natural world is water, which is also the source of all life. Since we can only view a small fraction of the planet's surface, it can be challenging to understand that 70% of it is made of water. Earth's water content is not distributed evenly. In comparison to other places, some receive significantly more rainfall. This might be attributed to a variety of factors, including the location of the mountains and the strongest winds. Some of the variances in vegetation and the reasons why certain places are deserts and others are rainforests can be partially explained by this distribution of rainfall.

There are three states of water: liquid, solid, and vapour that is invisible. It creates the lakes, rivers, seas, oceans, and subterranean waterways that are present in the uppermost soil and crust layers of the planet. In polar and alpine locations, it exists as snow and ice cover in a solid condition. The various minerals that make up the earth's crust and core contain enormous amounts of water.

A Hydrological Cycle

The journey that water takes to move from the earth to the sky and back again is known as the hydrological cycle. The heat from the sun releases energy that causes water in lakes, oceans, and other surfaces of the earth to evaporate. Transpiration is the term for the loss of water by plants to the atmosphere. Eventually, the water vapor condenses and forms microscopic droplets in the clouds.

Water returns to the land (or sea) as precipitation (rain, sleet, or snow) is produced when cool air from above meets clouds. A portion of the rainwater seeps into the earth. Groundwater is the portion of subterranean water that is trapped between layers of rock or clay. However, the majority of the water runs off—either above or below ground—and eventually returns to the seas as somewhat salted water.

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The Stages of the Hydrological Cycle:- Evaporation, Transpiration, Condensation, Precipitation, Groundwater, Run-off

II. STUDY AREA AND DATA COLLECTION

The Shetrunji stream has its source in the Gir Jungle and meets the Khombhat Bay. It has a 227 km length.The second-largest river in the Saurashtra region, the Shetrunji flows eastward and empties into the Gulf of Cambay. It flows through the cities of Bhavnagar, Amreli, and Junagadh, which have respective total areas of 53.44%, 45.21%, and 1.35%.The basin lies roughly between latitudes 210 00' and 210 47' in the north and between longitudes 700 50' and 720 10' in the east. There are nine of the tributaries are longer than 15 km. Four of the tributaries, Safara, Shel, Kharai, and Talaji, are on the right bank, and the remaining five, Stali, Thebu, Gagadia, Rajawal, and Kharo, are on the left bank.

The current study region is located upstream of the Shetrunji dam, which is in Gujarat's Amreli district's, Liliya taluka (N 21° 32' 24.0792", E 71° 23’ 0”) ,Sanaliya village.

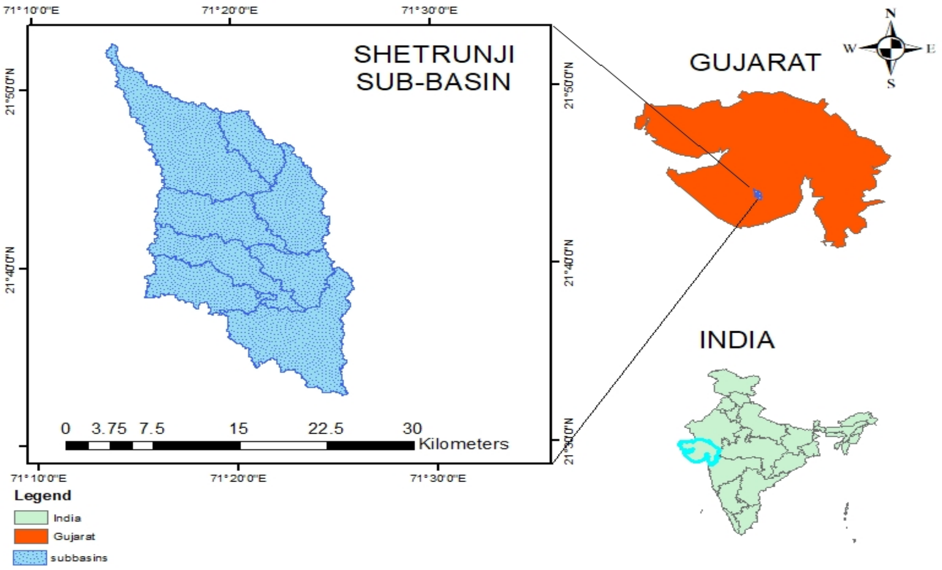

Fig. 1 Study Area

B Rainfall Characteristics

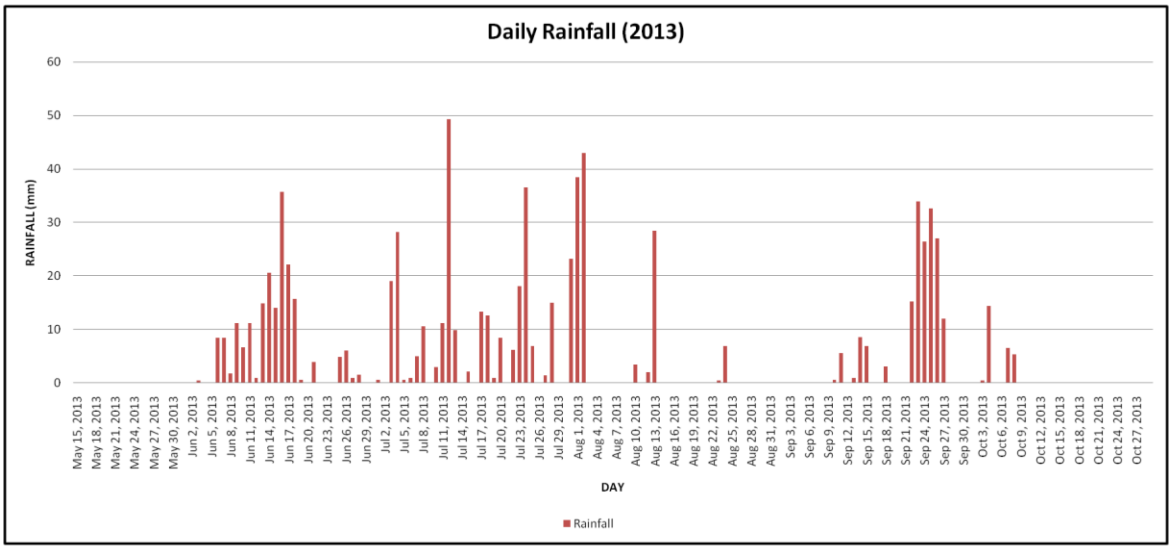

Fig. 2 Daily Rainfall (2013)

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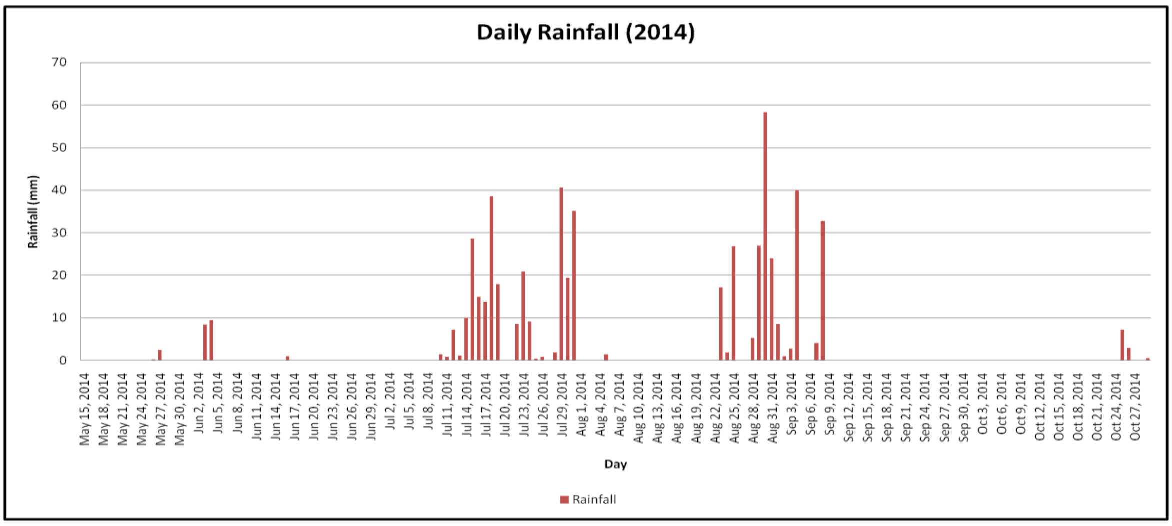

Fig. 3 Daily Rainfall (2014)

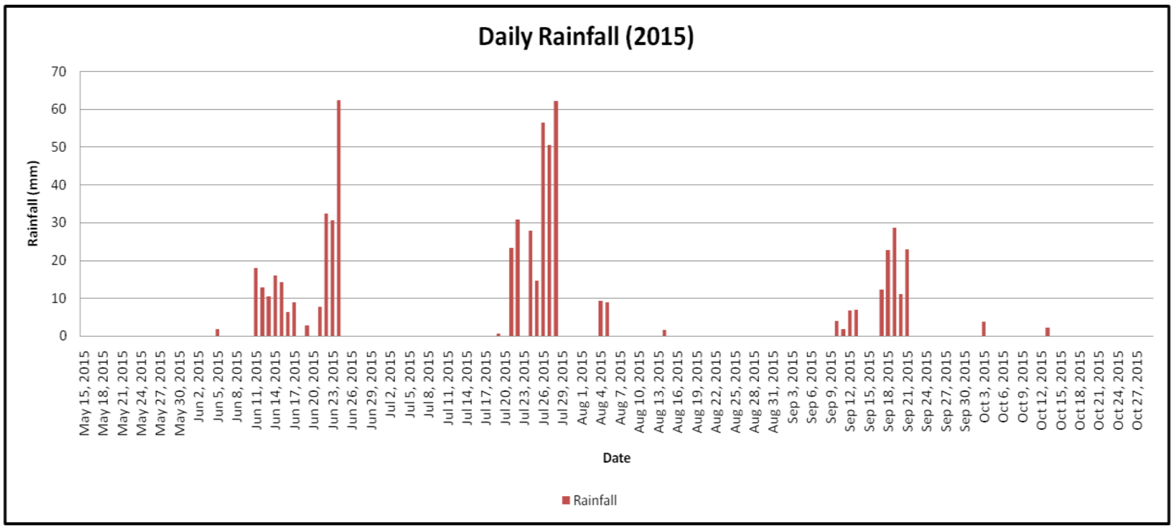

Fig. 4 Daily Rainfall (2015)

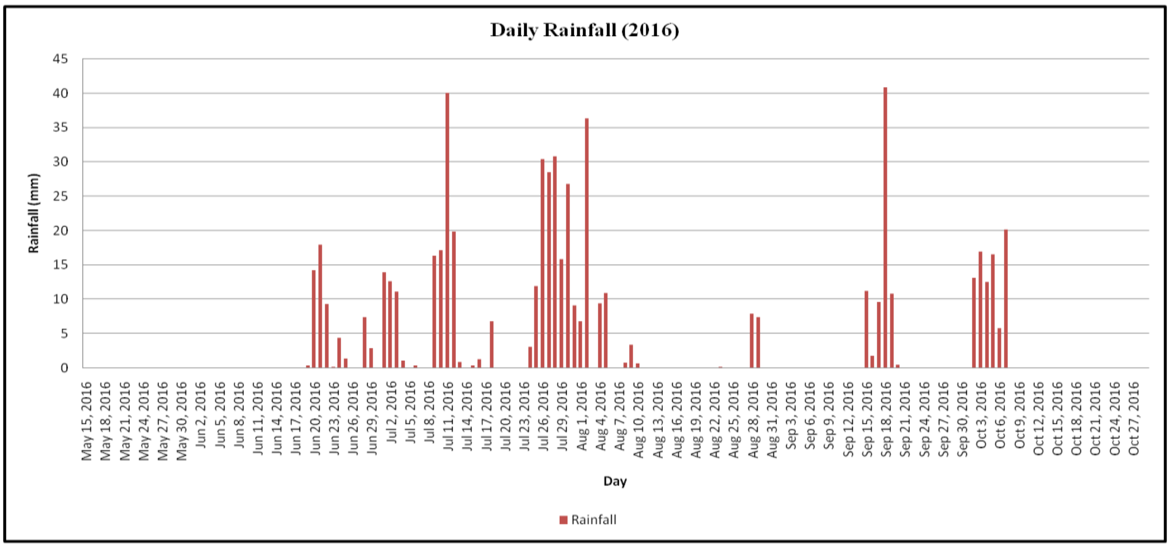

Fig. 5 Daily Rainfall (2016)

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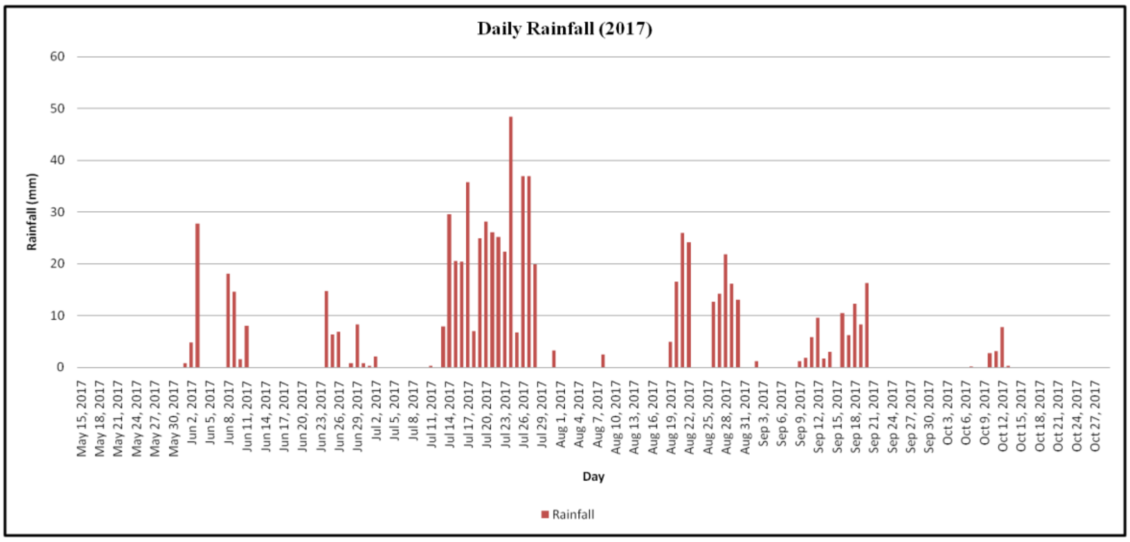

Fig. 6 Daily Rainfall (2017)

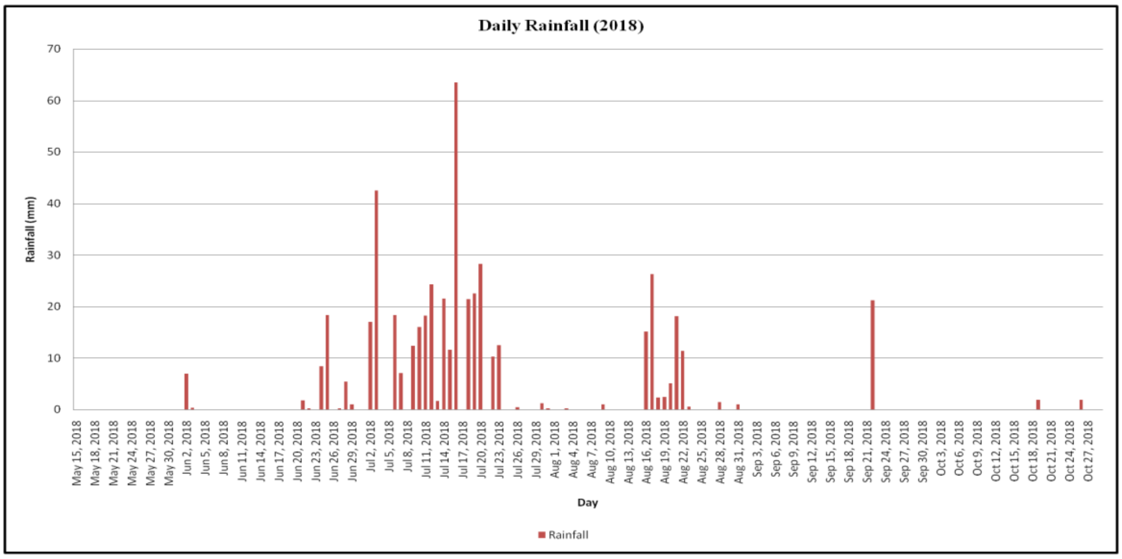

Fig. 7 Daily Rainfall (2018)

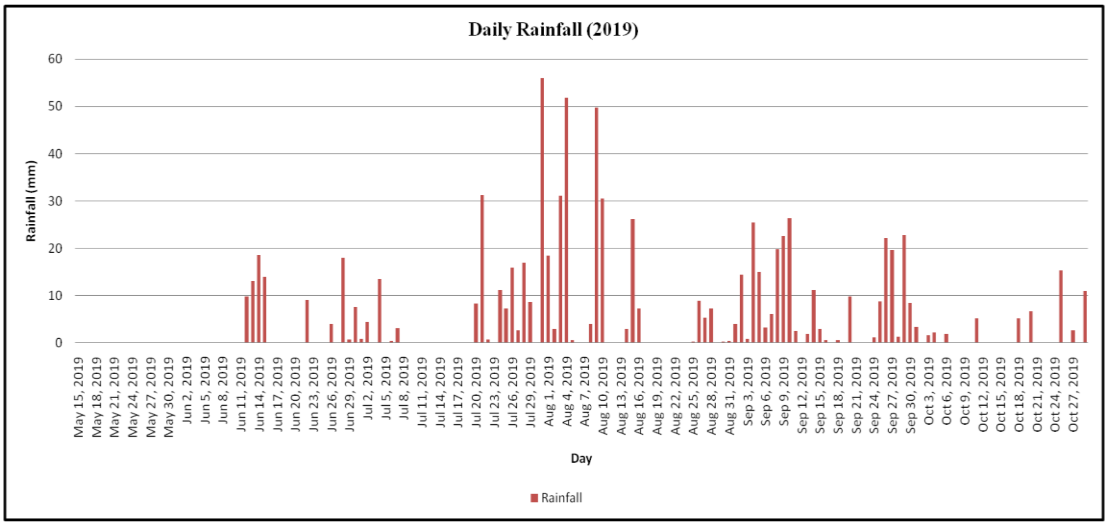

fig. 8 Daily Rainfall (2019)

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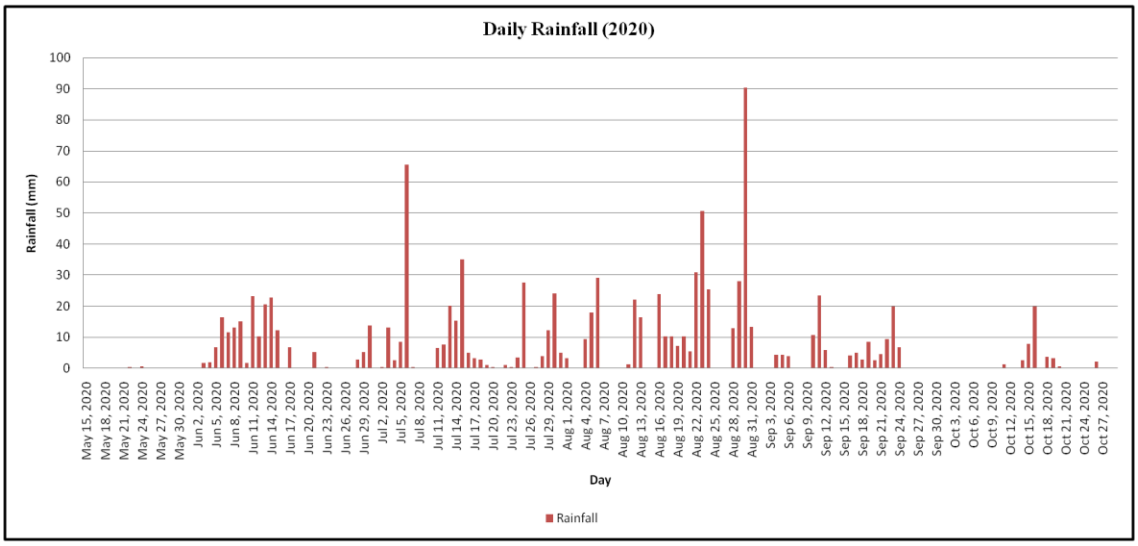

Fig. 9 Daily Rainfall (2020)

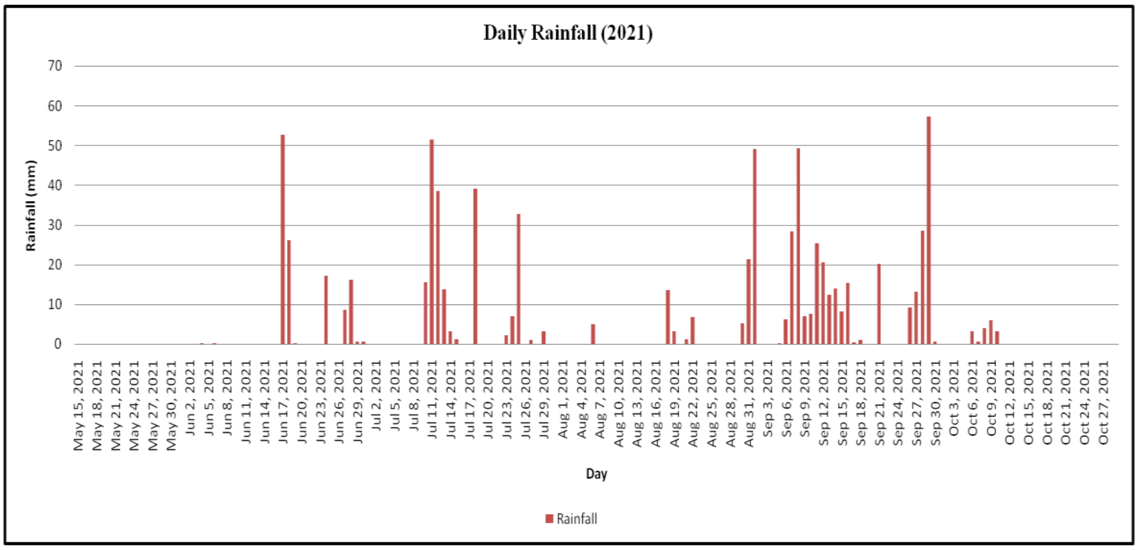

Fig. 10 Daily Rainfall (2021)

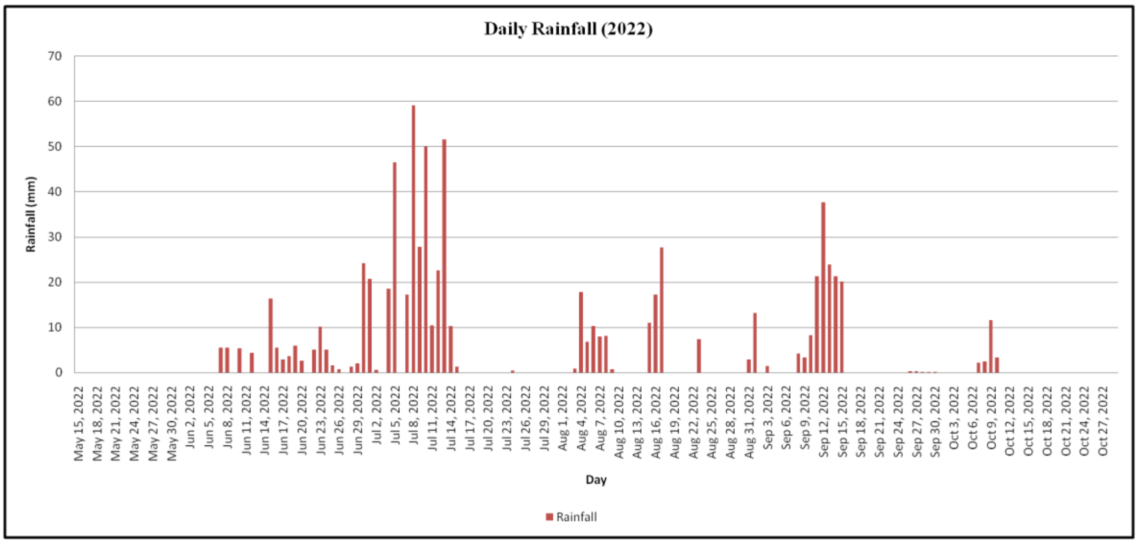

Fig. 11 Daily Rainfall (2022)

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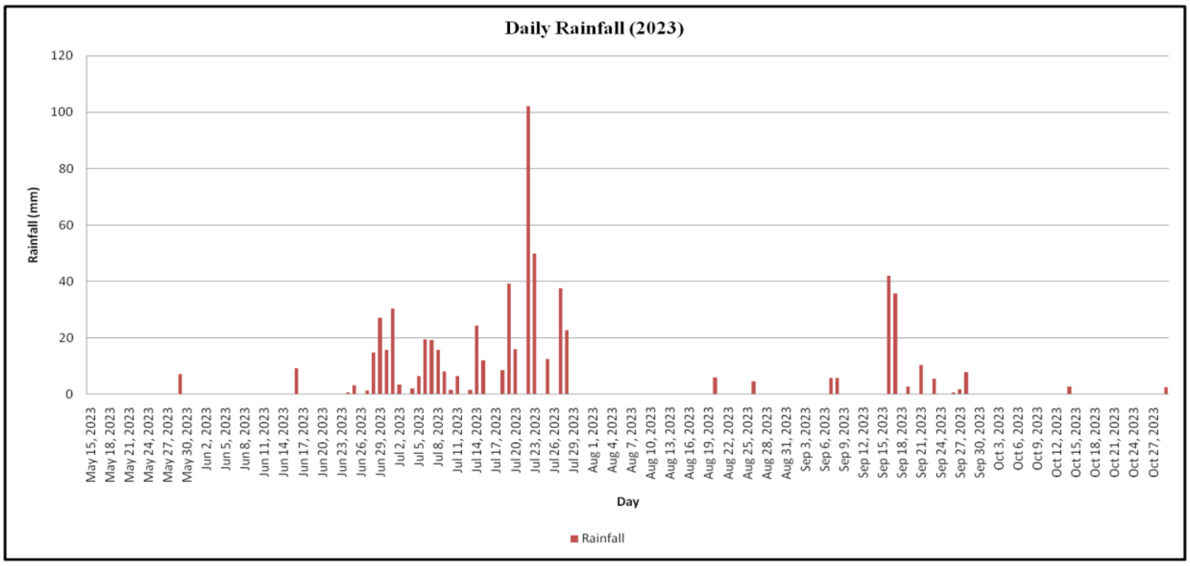

Fig. 12 Daily Rainfall (2023)

TABLE I DATA COLLECTION

Type of data	Details	Source of data	Use in study
DEM	30m SRTM	USGS earth explorer	Terrain file creation
Rainfall	2013 to 2023 Daily	CHIRPS (Climate Hazards Group Infrared Precipitation with Station Data)	Input parameter of HEC-HMS
Runoff	2013 to 2023 Daily	SWDC (State Water Data Centre)	Comparative analysis
Curve number	250m spatial resolution	Global curve number map	Input parameter of HEC-HMS

III. METHODOLOGY

Rainfall modeling is paramount in water resource assessment. This will help to solve the growing demand for water and energy. Surface runoff is the largest source of accumulated water in water bodies. Proper modeling of the flow with appropriate factors is necessary to investigate the different mechanisms of surface flow generation.

Hydrologic modeling techniques are employed within HEC-HMS, such as the SCS-CN method, the Unit Hydrograph method. These methods help estimate runoff volumes and flow rates based on rainfall characteristics and basin properties.

This study focuses on investigating the influence of factors affecting surface water runoff in the Shetrunji stream sub-basin. After analyzing the influence of the factors, the rainfall-flow relationship was modeled using HEC-HMS models.

A Overview of HEC-HMS Software

HEC-HMS is tailored to replicate the entirety of hydrologic process within dendritic watershed system. It incorporates numerous conventional hydrological analysis methods, including event infiltration, unit hydrographs, and hydrologic routing.

The HEC-HMS is considered to replicate the rainfall-runoff dynamics of dendritic drainage basin. Its scope extends to diverse geographical settings, catering to a wide spectrum of practical challenges. This encompasses managing water provide and flood risks in expansive stream basins, as well as addressing runoff issues in both urban and natural small-scale watershed.

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A mathematical model can then be used to represent any mass or strength flux in the cycle. Generally, each flux can be represented by a variety of model options. Every mathematical mannequin included in the application is suitable for certain settings and circumstances.

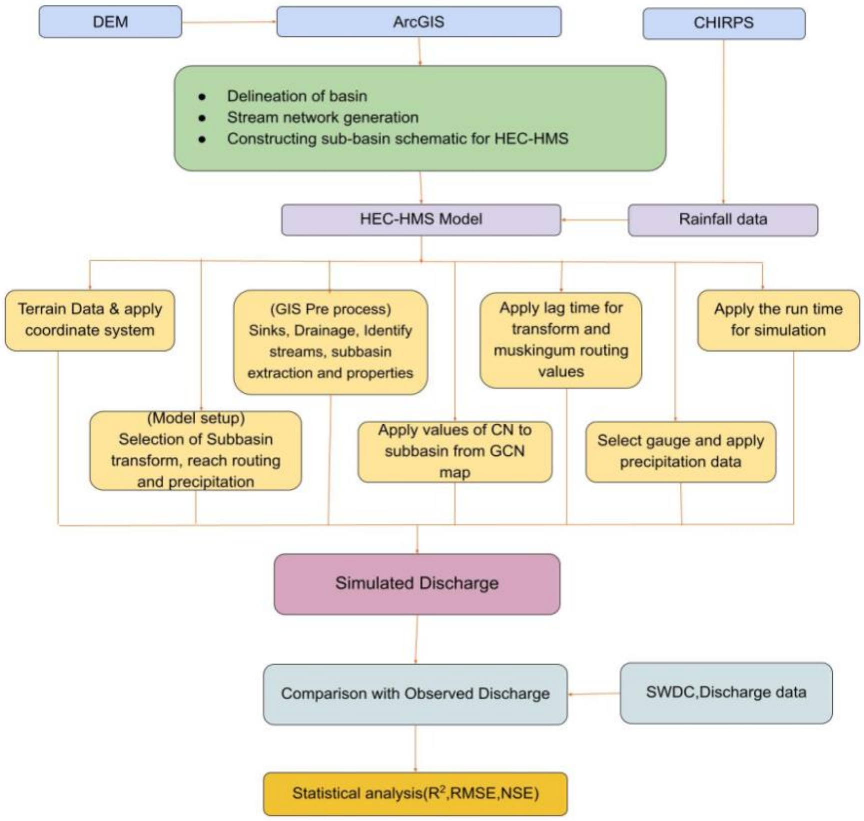

Fig. 13 Methodology Chart

B SCS CN Loss Method

The empirical relationship between the runoff characteristics of the watershed and the rainfall and preservation forms the basis of the curve number method.

The hydrological loss rate is ascertained by using this technique. The SCS-CN methodology for incremental losses is implemented through the SCS-CN method. The methodology's goal was to determine the overall amount of infiltration during the storm.

It calculates the excess precipitation as a purpose of land use, soil cover, and cumulative precipitation.

$$Q = \frac{(P - la)^2}{(P - la) + S}$$

Where, Q- Accumulated precipitation excess at time t;
P= Accumulated Rainfall depth at time t;
la= Initial Abtraction
S= Potential Maximum Retention
la = 0.2 S

Therefore,

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

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$$S = \frac{100}{CN} - 10$$

TABLE 2 CURVE NUMBER AND SLOPE

Subbasin	CN	Area (km^2)	Flow length	Basin slope	Slope	Slope(%)
Subbasin-1	78	84.898	28.8517	0.0408	2.8205	4.076
Subbasin-2	78	22.292	12.4284	0.0422	2.8205	4.219
Subbasin-5	78	43.052	15.4445	0.0446	2.8205	4.458
Subbasin-4	78	41.723	18.5346	0.0430	2.8205	4.297
Subbasin-8	78	35.693	17.2679	0.0425	2.8205	4.248
Subbasin-10	78	38.287	22.2675	0.0414	2.8205	4.136
Subbasin-7	78	27.632	13.5735	0.0429	2.8205	4.29
Subbasin-9	78	71.939	20.2671	0.0418	2.8205	4.177

C SCS UH Runoff Transform Method

It is used for calculating direct runoff from the exceeding Precipitation. Here for this purpose SCS UH method is used to perform simulation.

Basic Abstract of SCS UH method
SCS UH model is Dimensionless, single peak can be generate which is shown in fig q. as a ratio to the UH peak Discharge, q p, for any time t.

SCS suggest that UH peak and time of UH peak are related by:

$$q_p = \frac{CA}{Tp}$$

Where, A= Watershed Area

C= Conversion constant

The time of peak is related to the duration of unit excess precipitation as,

$$Tp = \frac{\Delta t}{2} + Tlag$$

Where, Δt = Excess precipitation duration,

T lag = The difference between the centre of mass of rainfall excess and peak of the UH

Estimating SCS UH Model Parameter

$$\mathrm{Tc} = 0.01947^{\mathrm{L}0.77}\mathrm{S}^{-0.385}$$

Where, Tc = Time of Concentration,
L = Length of Travel,
S = Slope of Catchment

$$T_L = 0.6T_C$$
$$T_L = \text{Lag min}$$

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TABLE 3 TIME OF CONCENTRATION & LAG TIME

Sub basin	Tc	Lag time (hr)	Lag time (min)
Subbasin-1	10.4395	6.2637	375.8209
Subbasin-2	5.2310	3.1386	188.3170
Subbasin-5	6.0549	3.6329	217.9767
Subbasin-4	7.1361	4.2817	256.9001
Subbasin-8	6.7820	4.0692	244.1520
Subbasin-10	8.4238	5.0543	303.2551
Subbasin-7	5.5665	3.3399	200.3946
Subbasin-9	7.7743	4.6646	279.8738

IV. RESULT

Hydrological modeling is currently carried out in HEC-HMS with Arc-GIS. Using Arc-GIS, watershed A map of delineation was created. The Shetrunji sub-basin is being event-based modeled using HEC-HMS model. Runoff Volume is computed using SCS CN loss method. There are ten subbasins within the Shetrunji sub-basin. The HEC-HMS model has been used to simulate a variety of rainfall events, and the models that produce the most appropriate outcomes are examined here.

The simulation and observation of discharge data are crucial for understanding and managing water resources effectively. The HEC-HMS is a widely used tool for simulating hydrological processes and predicting stream flow.

Several statistical metrics can be used to quantify the agreement between simulated and observed discharge data, such as R^2, NSE, and RMSE. These metrics provide purpose measures of model performance and help hydrologists assess the reliability of simulation results. Simulated and observed discharge data (2013 to 2023) are shown in the below figures.

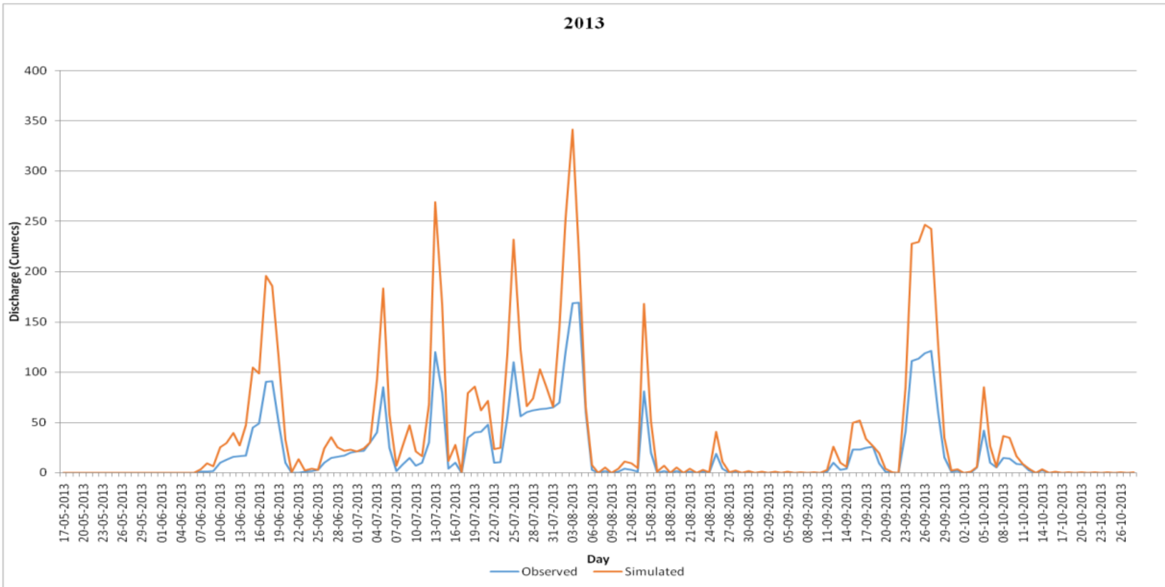

Fig. 14 Simulated and Observed Discharge Data (2013)

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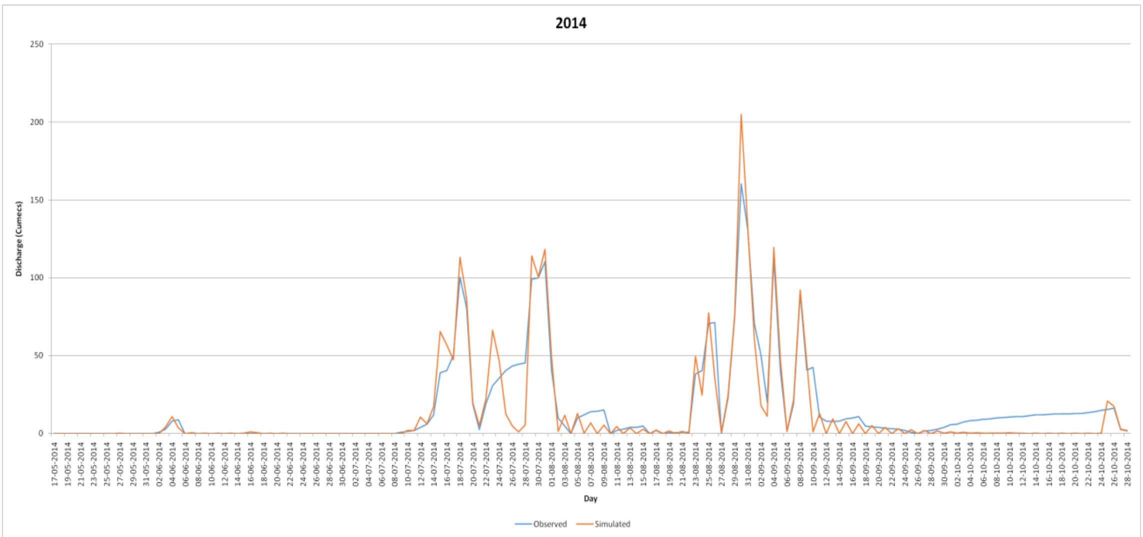

Fig. 15 Simulated and Observed Discharge Data (2014)

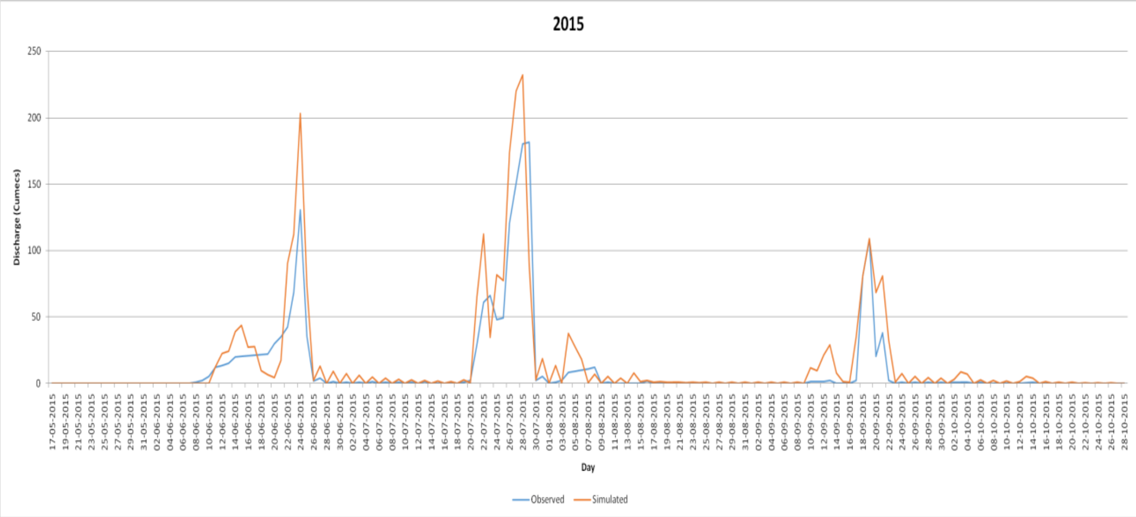

Fig. 16 Simulated and Observed Discharge Data (2015)

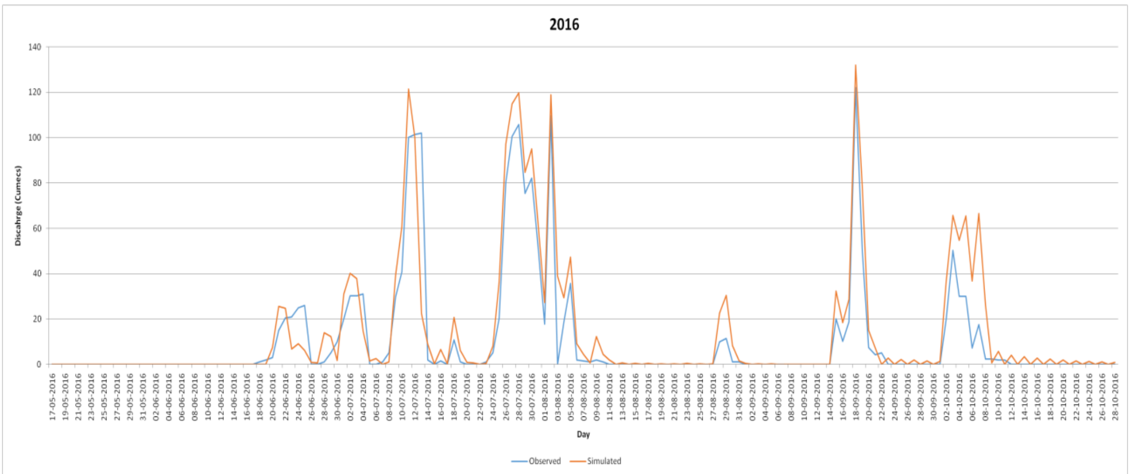

Fig. 17 Simulated and Observed Discharge Data (2016)

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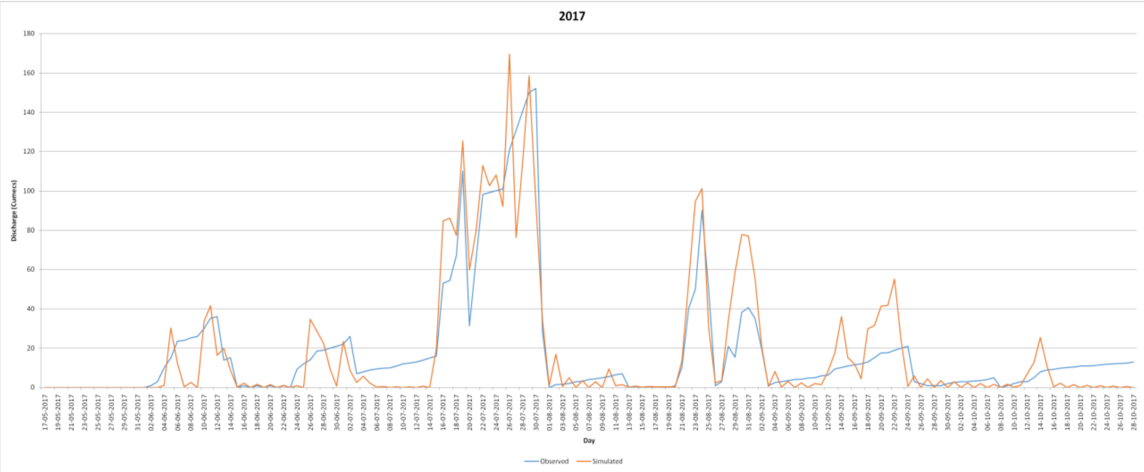

Fig. 18 Simulated and Observed Discharge Data (2017)

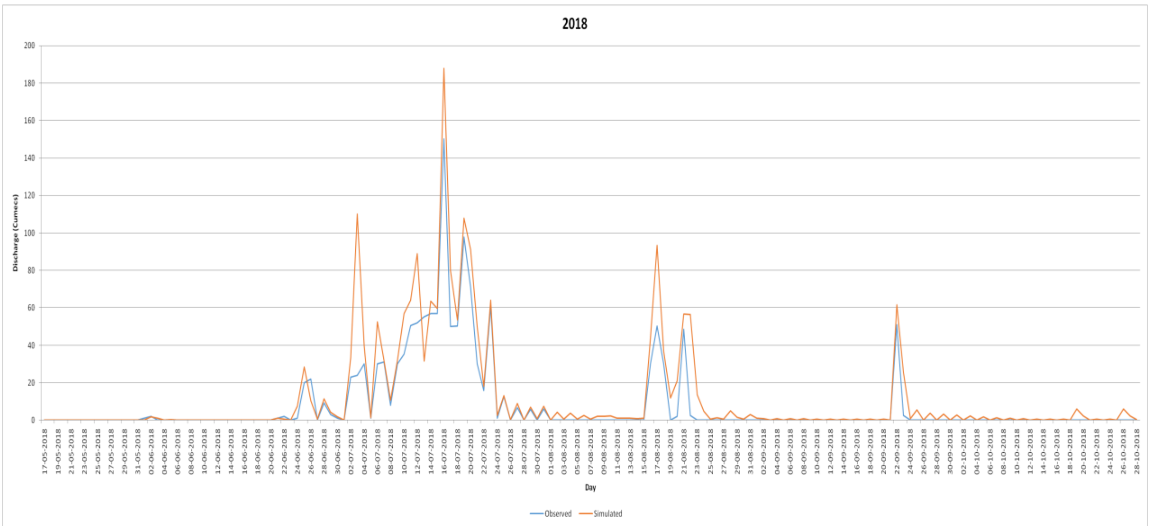

Fig. 19 Simulated and Observed Discharge Data (2018)

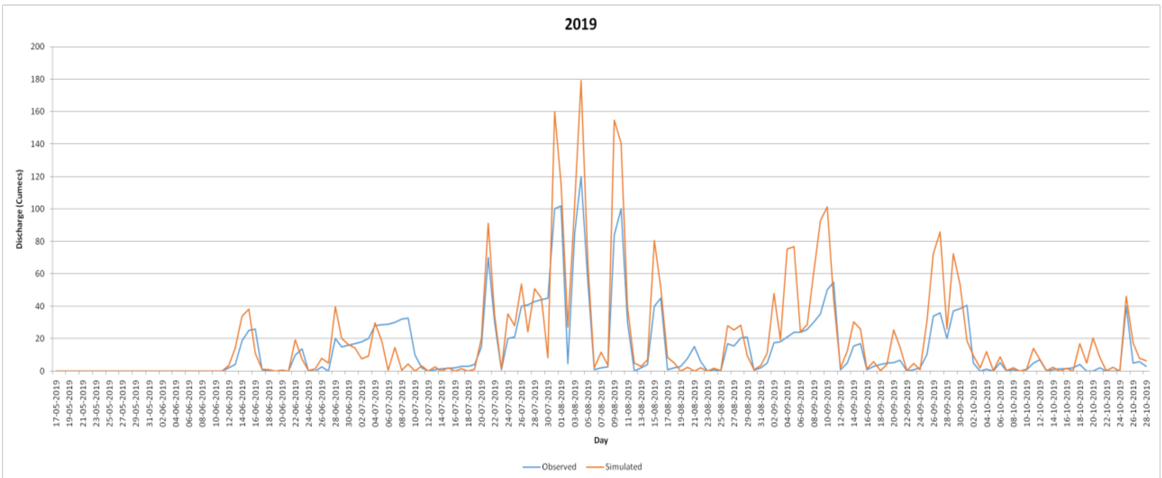

Fig. 20 Simulated and Observed Discharge Data (2019)

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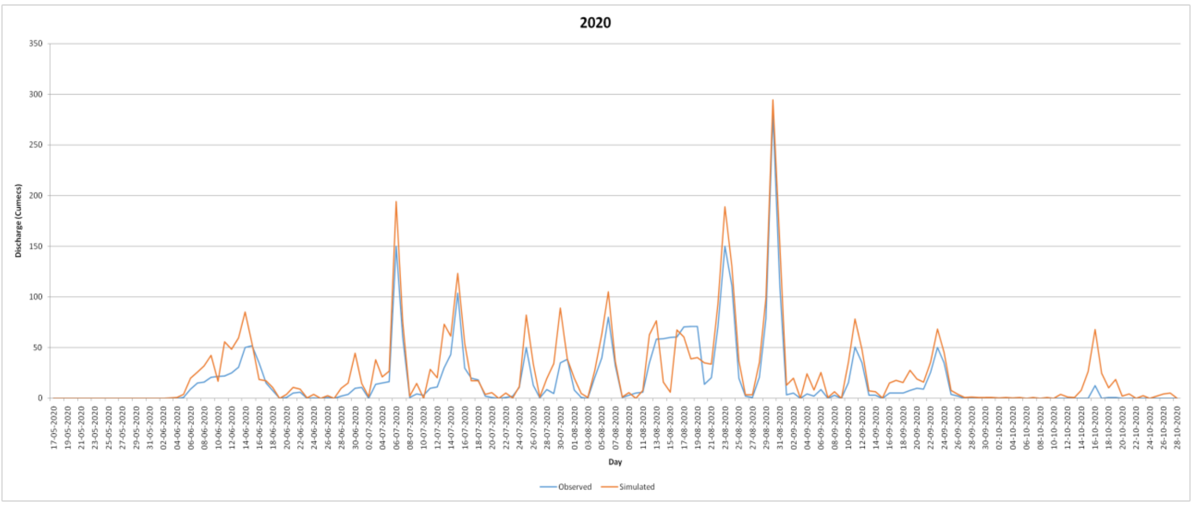

Fig. 21 Simulated and Observed Discharge Data (2020)

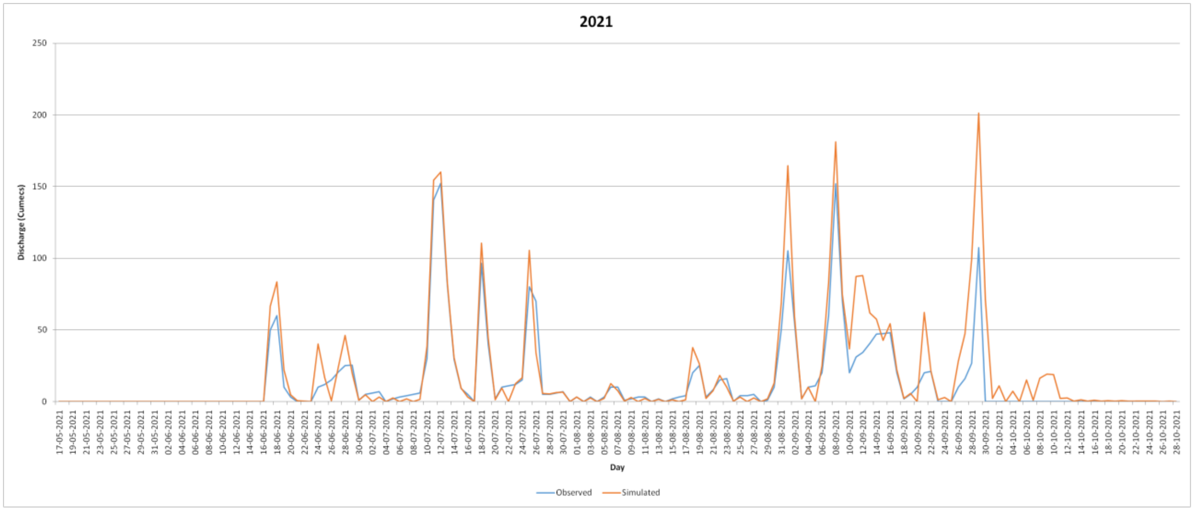

Fig. 22 Simulated and Observed Discharge Data (2021)

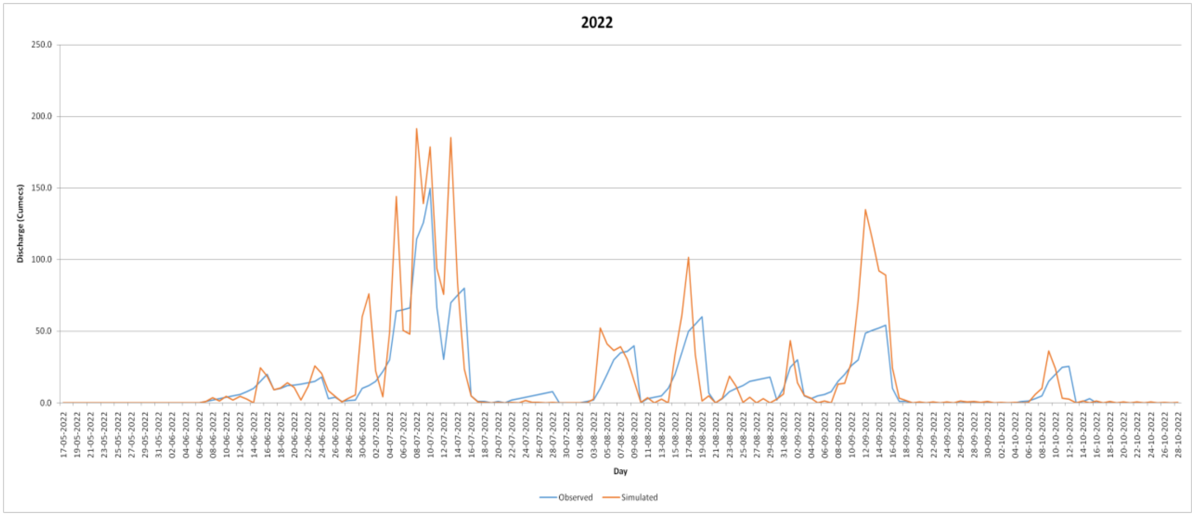

Fig. 23 Simulated and Observed Discharge Data (2022)

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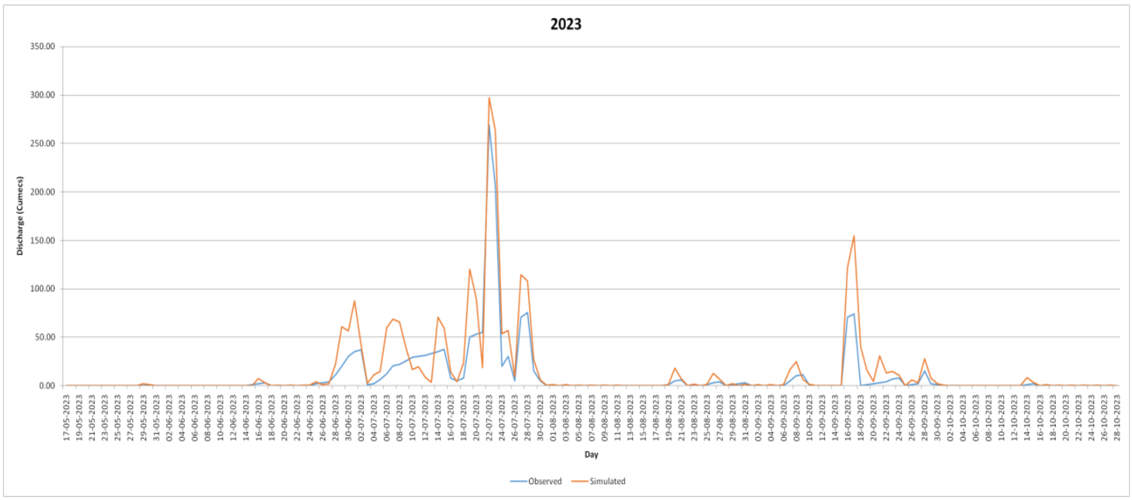

Fig. 24 Simulated and Observed Discharge Data (2023)

A REGRESSION ANALYSIS

Regression analysis involves examining the relationship between one or more independent variables and a dependent variable. In the context of hydrological modeling, regression analysis is often used to explore the relationship between model performance metrics such as R², NSE, and RMSE.

TABLE 4 REGRESSION ANALYSIS

Sr. No.	Year of Analysis	Statistics		
		R^2	RMSE	NSE
1	2013	0.8121	15.1218	0.8024
2	2014	0.8839	10.8707	0.8471
3	2015	0.8300	17.3121	0.7035
4	2016	0.8544	11.2660	0.8259
5	2017	0.8162	14.2497	0.8343
6	2018	0.8718	11.2589	0.7332
7	2019	0.8140	16.8518	0.7100
8	2020	0.8856	16.0471	0.8272
9	2021	0.8589	15.9384	0.7355
10	2022	0.7215	20.7968	0.7020
11	2023	0.8854	16.5372	0.7162
Average		0.8394	15.1137	0.7670

V. CONCLUSION

In conclusion, the utilization of the HEC-HMS model for rainfall runoff modeling has provided valuable insights into the hydrological processes within the Shetrunji river sub-basin. Through the application of rigorous statistical analysis, including the assessment of key performance metrics with the regression analysis for the effectiveness of the model in simulating runoff dynamics has been evaluated.

The R^2 serves as a measure of the proportion of variance in the observed data that is accounted for by the model. The high values of R² (0.8394) obtained in this study indicate a strong correlation between the simulated and observed runoff data, suggesting that the HEC-HMS model adequately captures the underlying hydrological processes within the watershed. Similarly, the NSE metric provides a measure of the model's ability to replicate the observed variability in runoff, considering both the mean and variability of the data. The NSE (15.1137) values obtained in this study indicate a satisfactory performance of the HEC-HMS model, with values close to or exceeding zero, indicating a good agreement between simulated and observed runoff patterns.

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Furthermore, the RMSE serves as a measure of the average deviation between the simulated and observed runoff values, providing insights into the overall accuracy of the model predictions. The low RMSE (0.7670) values obtained in this study indicate minimal discrepancies between the simulated and observed runoff data, indicating a good fit of the model to the observed hydrological conditions.

The model predicts regular and low runoff events precisely, while higher observed values don't properly match with the ground dataset.

In the HEC-HMS, a lot of options are available for simulations, whereas in this research, the Muskingum method has been employed. This method was selected using the trail-and-error method for better agreement with the observed dataset.

In rainfall-runoff modeling, the curve number (CN) plays a vital role in the modeling, which depends upon many factors like land use, land pattern, soil structure, and atmospheric moisture content. In this research, the global curve number map has been used for the curve number extraction, which outperforms this research.

In the SRTM DEMs used for this study, many DEMs are available for hydrological modeling, while many researches have shown that SRTM performs better as compared to other open-source DEMs and has makes close correlation with the observed dataset.

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