Estimation of Runoff in Data Scare Watershed of Middle Gujarat, India Using HEC-HMS Model

Abstract

The accurate estimation of the hydrologic response in water resources planning and development is crucial. In this study, the rainfall-runoff relationship and hydrologic response of the Devgadh Baria watershed in the Panam river catchment were investigated. Due to limited availability and accuracy of runoff data, Clark UH, and SCS UH models were explored for runoff estimation. Remote sensing and GIS techniques were integrated to assess the ungauged watershed in the Middle Gujarat region.

Rainfall and discharge data, Sentinel-2 data, 12.5m ALOS PALSAR DEM, base maps, and soil maps were collected from various sources. The study area's five different events were randomly selected, and a Thiessen map was prepared to calculate weighted rainfall. Geomorphological parameters and Horton's ratios were estimated using remote sensing and GIS software ILWIS.

The composite curve number (CN) for the watershed was found to be 77.69. Excess-rainfall hyetographs were separated using the SCS-loss method, and the time to peak estimated by the models matched well with observed data, except for a one-day delay in the HEC-HMS based Clark UH model.

Four performance indices, namely NSE, PBIAS, RMSE, and d, were used to compare model performance. The SCS UH model demonstrated the highest NSE value (-0.28) for event-1, while the HEC-HMS based SCS UH model showed the lowest NSE value (-0.28) for event-1. The SCS model outperformed the other models based on performance indicators NSE, RMSE, and d. Overall, the SCS UH approach provided the best estimation of peak discharge and time to peak discharge. The direct surface runoff hydrographs estimated using.

Keywords: HEC-HMS, Clark UH, SCS UH, GIS, ArcGIS, DSRO, rainfall-runoff, Ungauged Catchment.

1. Introduction

Assessing water resources is a crucial task that involves observing hydrological processes and utilizing hydrological modeling. However, the current hydrological monitoring network is limited, with only a few stations representing vast areas. This lack of monitoring results in insufficient discharge data for many small watersheds, making water resource assessment challenging for those areas (Amisigo et al., 2008; Taylor et al., 2006). Rainfall-runoff processes in surface hydrology are complex and involve various factors such as climate, topography, soil, land use etc.

“The rainfall-runoff model is commonly categorized into three main types: empirical, conceptual, and physical models. The empirical model, often referred to as a data-driven model, relies on a smaller set of parameters. These parameters can be calibrated and determined based on field measurements or established through empirical procedures” (Ntoanidis et al. 2013; Gebre 2015; Gull & Shah 2020). “Conceptual models are predominantly employed in small, homogeneous areas by employing spatial lumping techniques and substituting various components of the hydrological cycle with conceptual storage elements” (Song et al. 2011; Khaddor et al. 2017; Pichuka et al. 2017; Winarta et al. 2019). “The physical model is founded on a comprehensive understanding of hydrological processes and pertains to catchment parameters. It is a distributed model that encompasses both spatial and temporal variability of all the parameters involved. Being the most intricate model, it necessitates a substantial amount of distributed data encompassing topography, land use/land cover (LULC), soil distribution, and other relevant factors. The dissimilarities in characteristics among these models have an impact on their applicability, accuracy, and reliability in simulating runoff response to extreme rainfall events or predicting runoff in catchments. Among the natural environmental factors, catchment morphology holds great importance as it greatly influences hydrological processes. Studies conducted on HEC-HMS have demonstrated its capacity to simulate and forecast stream flow utilizing diverse datasets and different types of catchments, particularly for smaller catchments. HEC-HMS is a software designed to simulate the complex rainfall-runoff processes in river basin systems. It offers a versatile range of applications and can be utilized to address various hydrological problems. The HEC-HMS model can be employed for conducting studies related to water availability, urban drainage analysis, flow forecasting, simulating flood events, assessing the impact of future urbanization, flood damage reduction strategies, wetland hydrology investigations, reservoir spillway design, floodplain regulation, and system operation optimization" (Bennett & Peters, 2000; Al-Abed et al., 2005; Oleyiblo & Li 2010;Ashish et al. 2012; Gautam et al. 2013; Shrestha et al. 2014; Sok & Oeurng 2016; Pichuka et al. 2017; Azmat et al., 2017; Derdour et al., 2018; Kazezyilmaz-Alhan et al. 2021).

"The classification of rainfall-runoff models includes empirical, conceptual, and physical models. The empirical model, alternatively known as a data-driven model, relies on a smaller number of parameters that can be calibrated and measured using field properties or determined through an empirical procedure" (Ntoanidis et al. 2013; Gebre 2015; Gull & Shah 2020). "Conceptual models are primarily utilized in small, homogeneous areas through the process of spatial lumping. They involve replacing different components of the hydrological cycle with conceptual storage elements" (Song et al. 2011; Khaddor et al. 2017; Pichuka et al. 2017; Winarta et al. 2019). The physical model of hydrology is grounded in a comprehensive understanding of hydrological processes and their relationship to catchment parameters. It is a distributed model that considers the spatial and temporal variability of all the relevant parameters. However, it is also the most complex model, demanding extensive data regarding topography, land use/land cover (LULC), soil distribution, and other factors. These variations in model characteristics significantly influence the applicability, accuracy, and reliability of the model's predictions for runoff response during extreme rainfall events or the estimation of runoff in catchments. Catchment morphology plays a crucial role as one of the key natural environmental factors that have a significant impact on hydrological processes. Studies conducted on HEC-HMS have demonstrated its capability to effectively simulate and forecast stream flow using diverse datasets and different catchment types, particularly in the context of small catchments. However, while the HEC-HMS model has been widely used worldwide, there have been limited investigations conducted specifically on Indian region catchments.

The study aims to fill the knowledge gap by estimating runoff in previously unaddressed watersheds. By estimating excess rainfall resulting from intense storms and implementing watershed interventions, it is possible to mitigate water scarcity. Water scarcity is a critical issue in the selected semi-arid region, and effective water resource planning and management are essential. Hence, this study was conducted in the Middle Gujarat region, a data scare was selected to analyse the rainfall-runoff relationship using HEC-HMS and remote sensing and GIS techniques. The objective of the study was to estimate runoff using the HEC-HMS based SCS UH and Clark model and compare the results of these transformation methods.\

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2. Study Area

The area selected for present study is a Devgadh Baria watershed of Middle Gujarat presented in Fig. 1. The Devgadh Baria watershed is a sub-catchment of Panam river up to Devgadh Baria taluka of Dahod District located in the middle Gujarat region of India and lies between 22º41'22" to 22º54'00" N latitude and 73º35' to 73º49'1" E longitude. The Panam rises near Bhabra in Jhabua district of Madhya Pradesh joining Mahi from left in Panchmahals district of Gujarat (NRSC & CWC, 2014). Devgadh Baria watershed has catchment area of 598.89 km^2, approximately rectangular in shape with a minimum elevation of 114 m at the outlet and a maximum of 597 m above mean sea level at the upstream end of the catchment. Average annual rainfall in the catchment area is 980 mm. About 80% of the rainfall occurs during July and August whereas 20% is distributed over the remaining months of the year.

2.1 Data used

Hydro-meteorological data play a significant role in runoff estimation as it gives an indication of the rainfall depth within the simulation period which directly affect the amount of runoff generated. The daily rainfall and runoff data of the watershed have been collected from were collected from the State Water Data Centre Gandhinagar for the year 2019. Three different isolated storms are selected for the study. The remote sensing information like sentinel 2 data was downloaded from Copernicus Open access hub. The DEM is a crucial dataset used to generate the morphometric characteristics of the watershed needed in hydrological modelling. ALOS PALSAR 12.5 m digital elevation model was used for elevation data. This is the basic data that will be used for watershed delineation, generation of the stream network. It is the basic input for HEC-HMS, to find the longest flow path, basin slope, basin elevation etc. These parameters will be used to calculate loss parameters, transform parameters like, time of concentration. The topographical map, drainage network, watershed boundary etc. for the watershed were extracted using Survey of India maps Ahmedabad. The soil data was obtained from the FAO (Food and Agricultural Organisation). ArcGIS(v10.0) is used to create the basin model input for HEC-HMS. The software used for the present study is HEC-HMS (v4.7) available in public domain on USACE website.

3. METHODOLOGY

3.1. GIS database development

Elevation plays a crucial role in hydrological studies of any catchment, and it is essential to have a Digital Elevation Model (DEM) for such analysis. DEM is utilized to acquire vital geographical, morphological, and topographical characteristics of the basin (Coulibaly et al. 2005; Young & Liu 2015). Various physical parameters of the basin, including slopes, centroid, longest flow paths, elevation information, river flow direction, stream orders, and drainage patterns, have been obtained. These data have been utilized to generate slope and topographic elevation maps for the basin, incorporating contour lines.

3.2. Basin delineation

HEC-HMS is characterized as a semi-distributed model, where the data can exhibit heterogeneity within the basin but remains homogeneous within sub-basins (Beven 2012). The delineation of the basin for a specific river portion has been performed using ArcGIS, considering the physical properties of the study area, such as land use/land cover (LULC) and soil distribution. The resulting basin boundaries are depicted in Fig. 2.

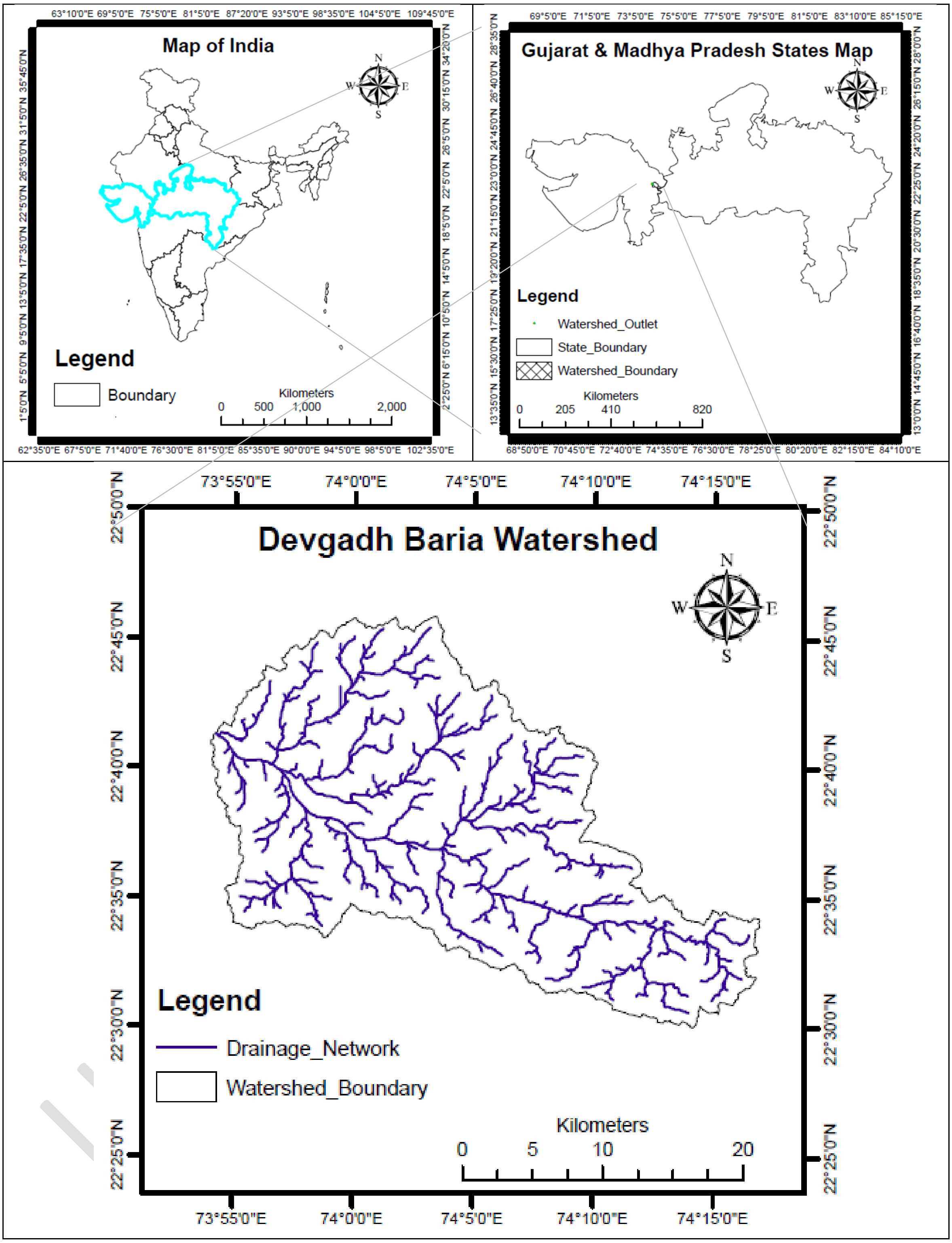

Fig. 1: Location map of Devgadh Baria watershed

3.3. Preparation of LULC and soil map

"Supervised classification techniques have been employed to generate the land use/land cover (LULC) map of the basin. Additionally, hydrologic soil groups (HSGs) are commonly categorized into four groups: A, B, C, and D. These groups are determined based on factors such as rainfall patterns, runoff characteristics, and infiltration properties" (Rodell

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et al., 2009; Roy et al., 2013; Derdour et al., 2018; Efthimiou 2018; Frappart & Ramillien 2018). In hydrologic soil group classification, Group A indicates soils with high infiltration rates and low runoff capacity. Group B represents silt loam soils, characterized by moderate infiltration rates and moderately coarse textures. Group C corresponds to clay loam soils, which exhibit slow infiltration rates and moderately fine textures. Clay loam soils are generally considered suitable for various plant growth. Group C soils possess a moderate water transmission rate, while Group D soils display low infiltration rates and high runoff potential. The soil map of the Devgadh Baria watershed was obtained from the World Soil Database. The dominant soil type in the Devgadh Baria watershed and the hydrologic soil group (HSG) is determined based on the classification system established by the Food and Agriculture Organization (FAO).

3.4. Curve number map of punpun river basin

The Curve Number (CN) is influenced by factors such as soil type, slope, and land use within the study area. Its value typically ranges from 0 to 100, with lower values indicating a lower runoff coefficient and higher values indicating a higher runoff coefficient. To generate a CN map, soil and land use maps are required in addition to a slope map. The slope map is prepared by identifying the contour lines of the basin using ArcGIS. In ArcGIS, the CN is generated by integrating the land use, soil map, slope map, and Digital Elevation Model (DEM) of the basin. The average CN for each sub-basin was computed using the equation given below:

$$(CN)_{avg} = \frac{(CN)_i \, A_i}{A_{\ Total}}$$

where, i is the number of sub-basin, A_i is the area of the particular sub-basin and A_{Total} is the total area of the basin.

3.4 Mean Precipitation using Thiessen-mean Method

The rain gauges represent only point sampling of the areal distribution of a storm. In practice, however, hydrological analysis requires a knowledge of the rainfall over an area, such as over a catchment. To convert the point rainfall values at various stations into an average value over a catchment, the Thiessen-polygon method is used in this study to convert rainfall values into an average value over the catchment. “This method attempts to allow for non-uniform distribution of gauges by providing a weighting factor for each gauge. The results obtained are usually more accurate than those obtained by simple arithmetic averaging. The gauges should be properly located over the catchment to get regular shaped polygons. However, one of the serious limitations of the Thiessen method is its non-flexibility since a new Thiessen diagram to be constructed every time if there is a change in the rain gauge network”. (Raghunath, 2006).

3.5. Hydrological modeling using HEC-HMS model

The hydrological characteristics of the basin have been calculated by utilizing the physical properties of all the subbasins for simulation purposes. In order to compute rainfall losses, the SCS-CN (Soil Conservation Service - Curve Number) loss method has been employed. This method was selected based on the data availability for the region and its relatively straightforward nature, which reduces complexity in the modeling process (Song et al., 2011; Hoseini et al., 2017; Yu et al., 2018; Tassew et al., 2019). To estimate infiltration using the CN (Curve Number) method, it is necessary to determine the CN value for each sub-basin.

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3.5.1 Loss Rate Method : SCS-CN

The SCS-CN method, developed by the USDA's Soil Conservation Service, estimates direct runoff from rainfall in small agricultural watersheds. It considers interception, storage, and infiltration volume, with an initial abstraction threshold before runoff occurs. Additional losses due to infiltration and increasing runoff with rainfall are incorporated. The method is widely used and described in the USDA-NRCS Technical Release 55: "Urban Hydrology for Small Watersheds." (Soil Conservation Service Engineering Division. (1986).

$$Q = \begin{cases} \dfrac{(P - I_a)^2}{P - I_a + S} & \text{P>I}_\text{a} \\ 0 & \text{P} \le \text{I}_\text{a} \end{cases} \qquad (3.30)$$

Where, *S* (mm) is potential maximum retention after runoff begins. I_a is all loss before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. I_a is highly variable but generally is correlated with soil and land cover parameters. To remove the necessity for an independent estimation of I_a, a linear relationship between I_a and *S* was suggested by Soil conservation service engineering division (1986) as: $I_a = S\lambda$, where λ is an initial abstraction ratio. The values of λ vary in the range of 0 to 0.3 and have been documented in a number of studies encompassing various geographic locations in the United States and other countries (Shrestha, 2003). Through studies of many small agricultural catchments, I_a was found to be approximated by empirical equations such as Ia= 0.2*S*.

By removing I_a as an independent parameter, a combination of *S* and *P* to produce a unique runoff amount can be approximated. Substituting I_a = 0.2S give

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (3.31)$$

The variable *S*, which varies with antecedent soil moisture and other variables, can be estimated as

$$S = \frac{25400}{CN} - 254 \qquad (3.32)$$

Where, *CN* is a dimensionless catchment parameter ranging from 0 to 100. A *CN* of 100 represents a limiting condition of a perfectly impermeable catchment with zero retention, in which all rainfall becomes runoff. A *CN* of zero conceptually represents the other extreme, with the catchment abstracting all rainfall and with no runoff regardless of the rainfall amount.

3.5.2 Unit Hydrograph Transforms Methods

When rainfall occurs, it satisfies all the basin requirement such as infiltration, initial abstraction, storage, etc. and the remaining portion is drained through the watershed outlet and is called as direct runoff. To calculate the direct runoff Clark's Unit Hydrograph Method and SCS Unit hydrograph Method equipped in HEC-HMS is used for this study.

3.5.2.1 SCS unit hydrograph

The Soil Conservation Service (SCS) proposed a parametric UH model; this model is included in HEC-HMS. The model is based upon averages of UH derived from gauged rainfall and runoff for many small agricultural watersheds throughout the US.

The SCS UH lag can be estimated via calibration for gauged headwater sub watersheds. For ungauged watersheds, the SCS suggests that the UH lag time may be related to time of concentration, t_C as:

$$t_{lag} = 0.6\, t_C$$

2.5.2.2 Clark unit hydrograph method

The Clark Unit Hydrograph Method requires a specified duration, the Clark Unit Hydrograph (CUH) was developed using a time-area method (Viessman and Lewis 2003). This method considers an instantaneous unit hydrograph, which is similar to a regular unit hydrograph except that it is assumed that effective precipitation is applied to a drainage basin in an infinitely short period of time.

Storage effect or attenuation is accounted for by a built-in storage coefficient. Many studies have found that the storage coefficient, divided by the sum of time of concentration and storage coefficient, is reasonably constant over a region (USACE-HEC, 2021) shows this relationship.

$$\frac{R}{R+T_C}$$

"The storage coefficient (R) measures the storage of rainfall in the watershed before it can drain to the outlet point. It is measured in units of time. The higher the storage coefficient in comparison to the time of concentration, the higher the storage within the watershed" (Sabol 1988).

2.5 PERFORMANCE INDICATORS

The performance of the HEC-HMS models was evaluated using five performance indices, namely: Nash-Sutcliffe efficiency (NSE), Percentage Bias (PBIAS), root mean square error (RMSE),) and Index of Agreement measure (d) as defined below (Moriasi *et al.*, 2015). The range of optimal values for these performance indicators are given in Table-1.

Table-1: Performance indicators (Moriasi *et al.*, 2015)

Sr. No.	Static	Formula	Range	Optimal Value
1	NSE	$E = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O}_i)^2}$	-∞ to 1.0	1.0
2	PBIAS	$PBIAS = \frac{\sum_{i=1}^{n}(O_i - O'_i) * 100}{\sum_{i=1}^{n}(O_i)}$	-∞ to ∞	0.0
3	RMSE	$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - P_i)^2}$	0.0 to ∞	0.0
4	d	$1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(\lvert P_i - \bar{O}\rvert + \lvert O_i - \bar{O}\rvert)^2}$	0.0 to 1.0	1.0

Where, O_i is observed data, P_i is predicted/computed values at time i and n is the number of the observations, and $\bar{O}_i$ is the mean of observed discharge values at time/place i.

3 RESULTS AND DISCUSSION

3.1 DEM Processing and Watershed Delineation

The 12.5 m ALOS PALSAR DEM was used to delineate the Devgadh Baria watershed using ArcGIS software. The DEM map of Devgadh Baria watershed imported in ArcGIS software to delineate watershed using different steps such as fill, flow direction, flow accumulation, stream definition, stream segmentation, catchment grid delineation, catchment polygon processing, drainage line processing, catchment merging etc. The stream ordering map of the catchment is shown in Fig. 2 and the river is found to be 5th order according to the Strahler stream ordering definition.

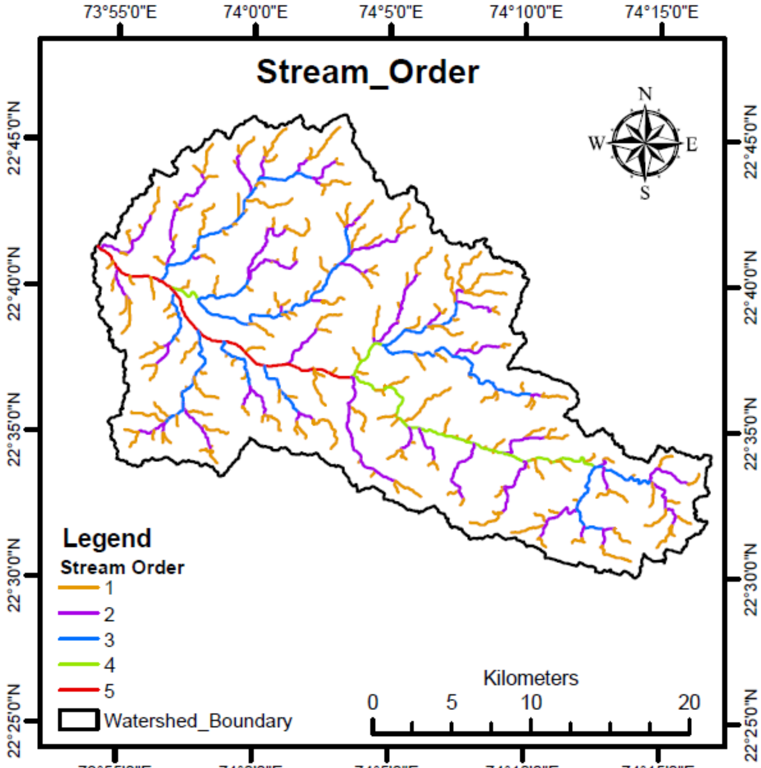

Fig. 2: Stream Order map

3.2 Thiessen polygon

The Thiessen polygon map for weighted rainfall is prepared using ArcGIS software is shown in Fig. 3. The watershed area covered by Devgadh Baria, Devhat and Rangpur rain gauges are found to be 405.24, 108.40 and 85.25 km^2 respectively. Therefore, the weightage factor of Devgadh Baria, Devhat and Rangpur rain gauges are found to be 0.68, 0.18 and 0.14 respectively.

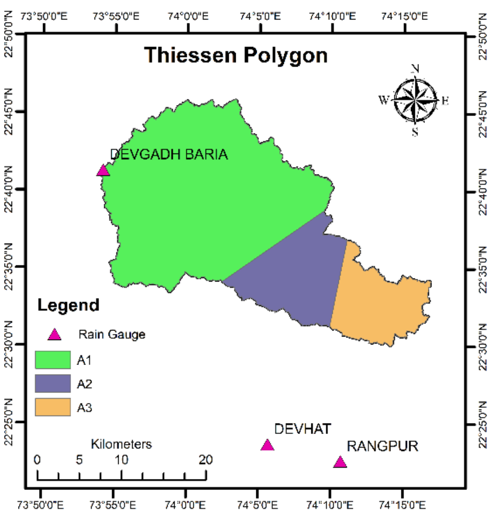

Fig. 3: Thiessen polygon map

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3.3 Curve Number (CN) Generation

The SCS has developed standard Tables of curve number values as functions of catchment land use/cover conditions and HSG (hydrologic soil group). Land use/cover map and HSG map for watershed is prepared details are below:

3.3.1 Land use map

Land use is one of the most important parameters affecting the surface runoff generation process. To incorporate the effect of land use, the watershed is classified into five dominant land use land cover categories viz. Agriculture, Bare land, Built up Forest, and Water. To prepare land use maps remote sensing image Sentinel-2 is obtained from Copernicus website for the year 2019, this image is classified using supervised classification. ArcGIS is used to classify these remote sensing images into different land use categories. The overall accuracy of the classification is found as 0.91 for the Sentinel-2 of year 2019. The land use map and the area under different land use types are shown in Fig. 4 and Table-2, respectively.

Table-2: Land use/land cover in watershed

Land use class	Area (km^2)	Area (%)
Agriculture	252.34	42.13
Bare land	0.14	0.03
Built up	18.47	3.08
Forest	320.69	53.55
Water	7.25	1.21
Total	598.89	100

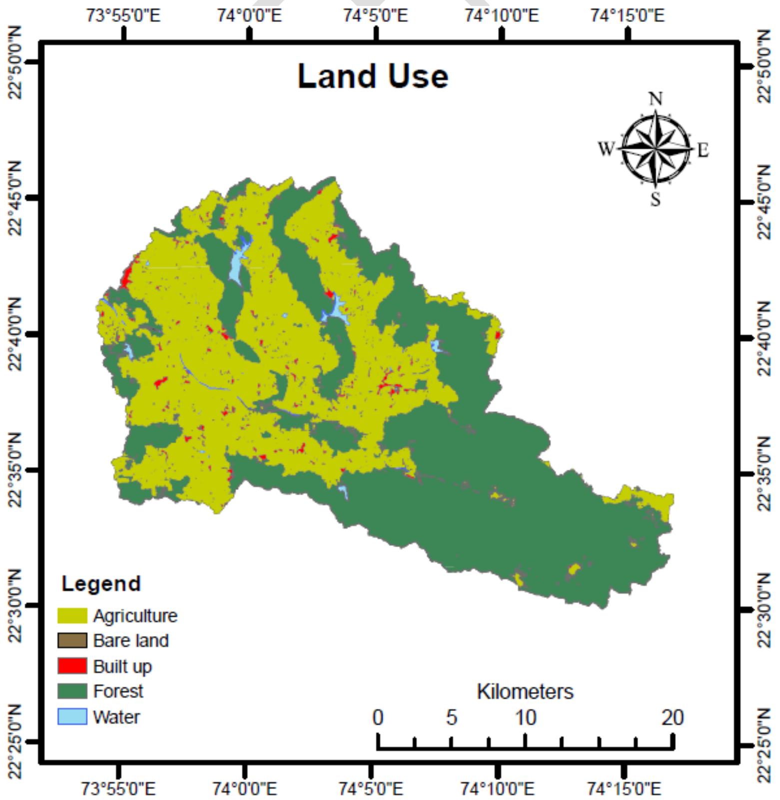

Fig. 4 (a): Land Use Map

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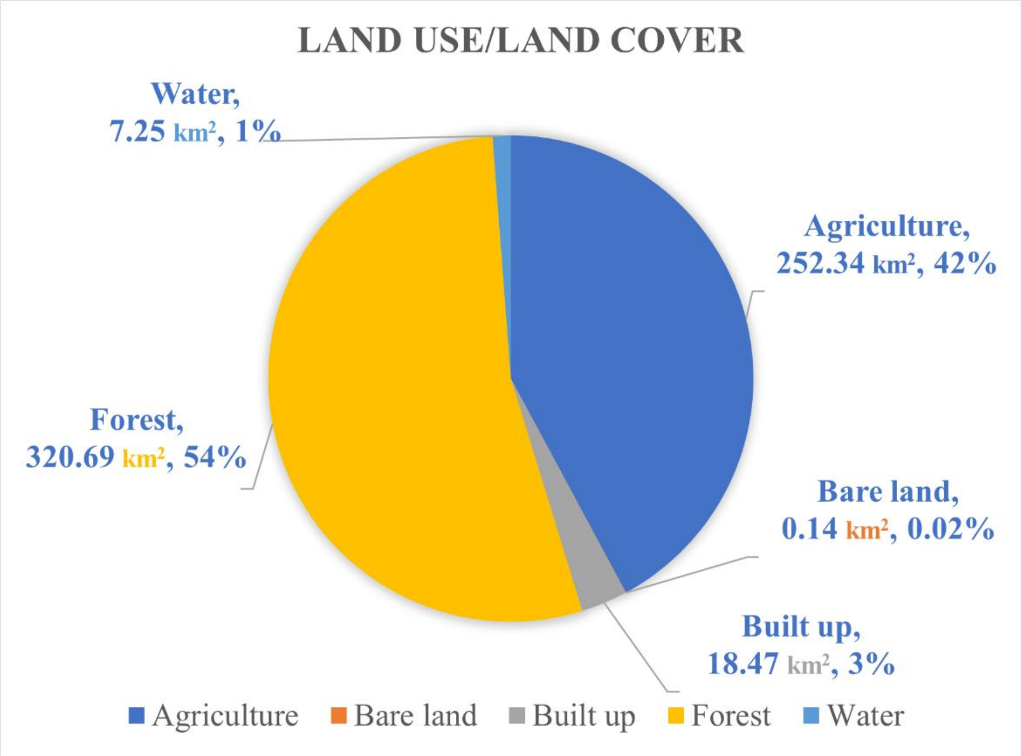

Fig. 4 (b): Land Use distribution in watershed

3.3.2 Soil map

Soil texture in the watershed is another factor affecting the conversion of rainfall into runoff. Soil series map at 1:250,000 scale for watershed downloaded from FAO website, is used as the source of soil database and soil grid in this study. After pre-processing of soil maps using GIS the soil types obtained for the study area are clayey and loamy soil. In which the clayey and loamy soil cover an area of 51.90 and 546.99 km^2, respectively. The soil map and the area under different soil types are shown in Fig. 5 and Table-3, respectively.

Table-3: Soil type in watershed

Soil Type	Area (km^2)	Area (%)
Loamy	546.99	91.33
Clayey	51.90	8.67
Total	598.89	100.00

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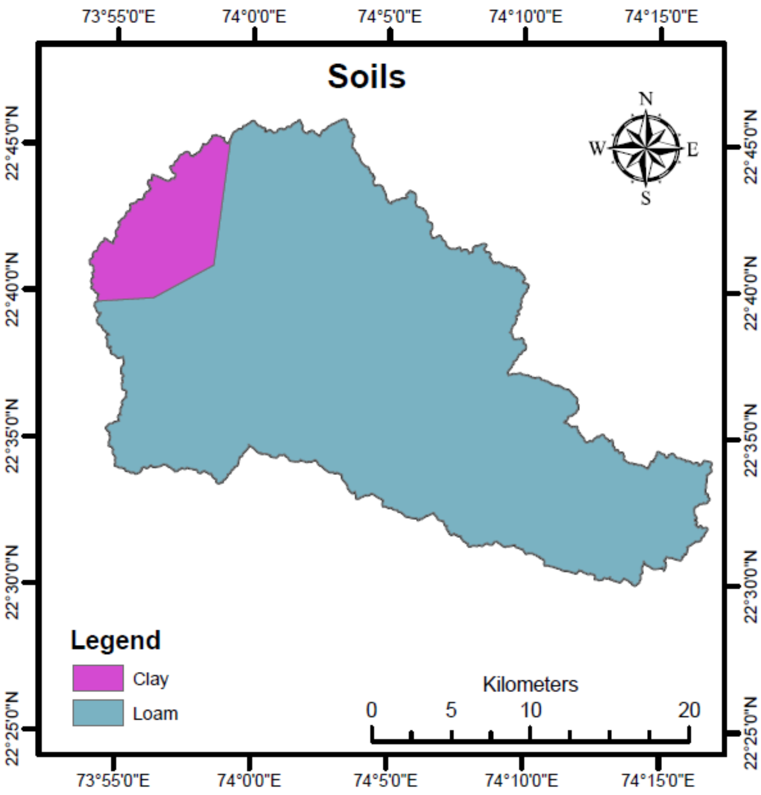


Fig. 5 (a): Soil map

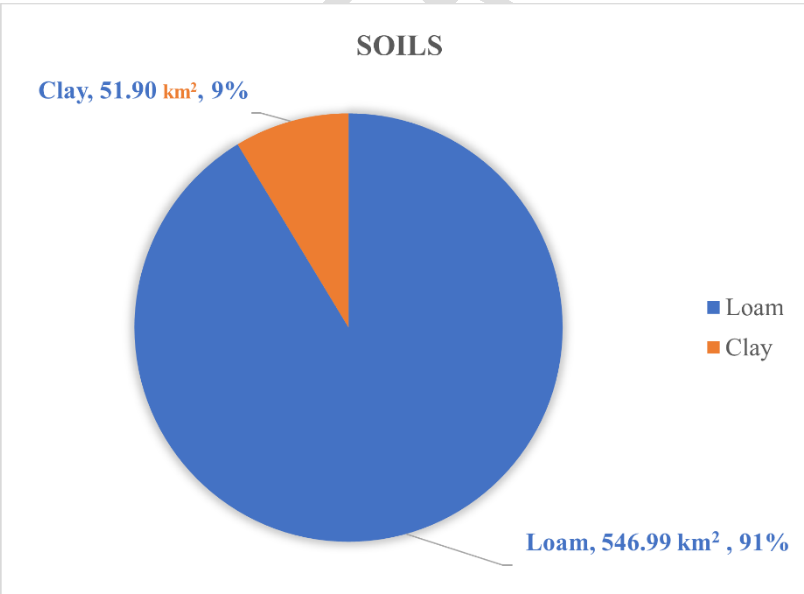


Fig. 5 (b): Soil distribution in watershed

3.3.3 Curve Number (CN) generation

CN is used for loss model in HEC-HMS model. Primarily it is prepared from the combination of land use and soil map. The CN grid map of year 2019 is presented in Fig. 6 and CN values are presented in Table-4. The following steps are done to get a Curve Number grid for the area of interest from land use and soil maps:

- Vectorization of both the land use and soil maps.

- Table or vector operation (Union) to get polygons of unique combination of both the maps in Arc-GIS.
- CN value generation from unique polygons by query operation in Arc-GIS and create the gridMap.
- CN value determination polygon of watershed.

Table-4: Composite Curve Number Calculation

Curve Number (CN)	Area, km^2	$CN_i \times Area_i$	Composite CN = $(CN_i \times Area_i)$/ Total Area
70	309.28	21649.60	77.69
77	11.42	879.34	
85	215.97	18357.45	
88	0.14	12.32	
89	36.35	3235.15	
90	14.95	1345.50	
92	3.53	324.76	
100	7.25	725.00	
Total	598.89	46529.12	

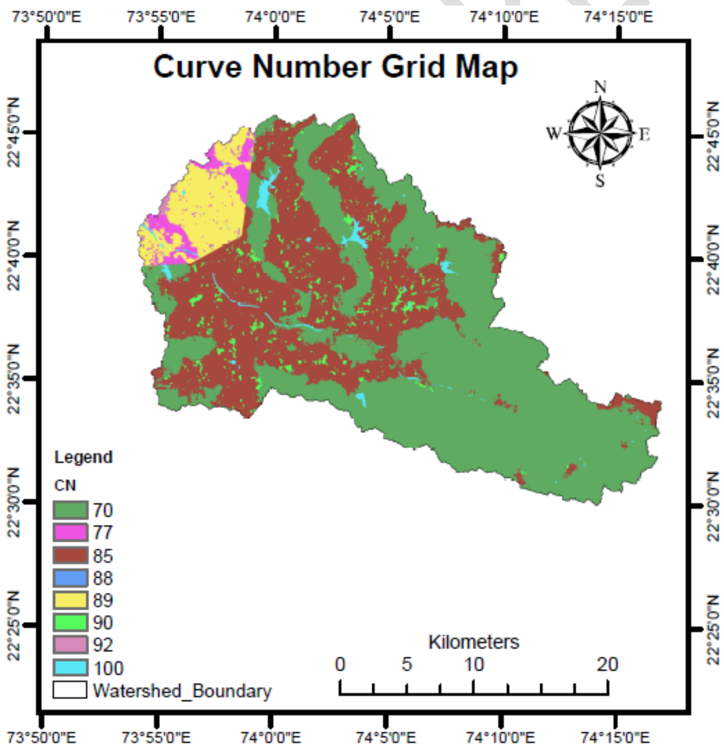


Fig. 6 (a): Curve Number grid map

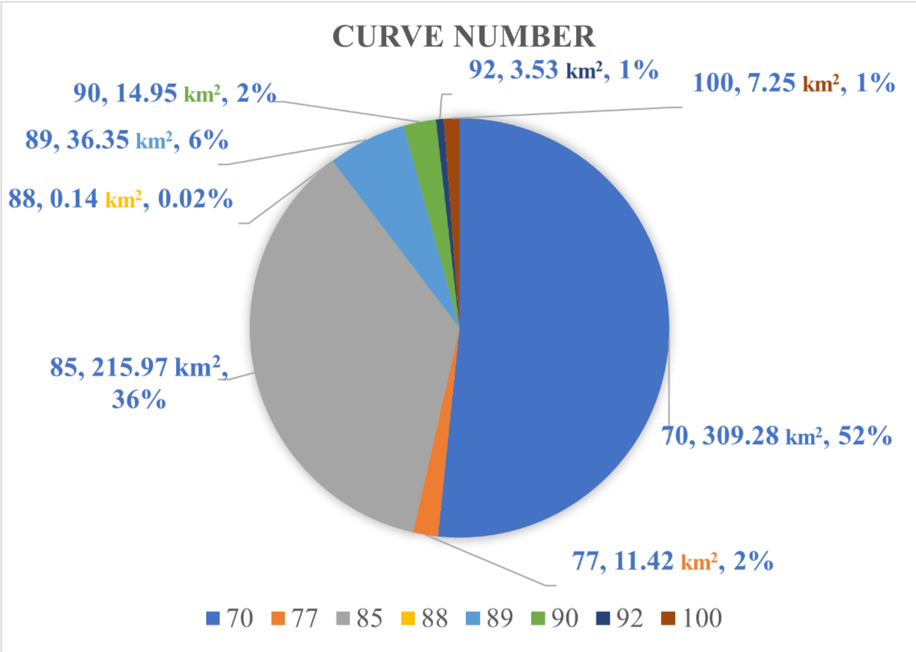


Fig. 6 (b): Curve Number distribution in watershed

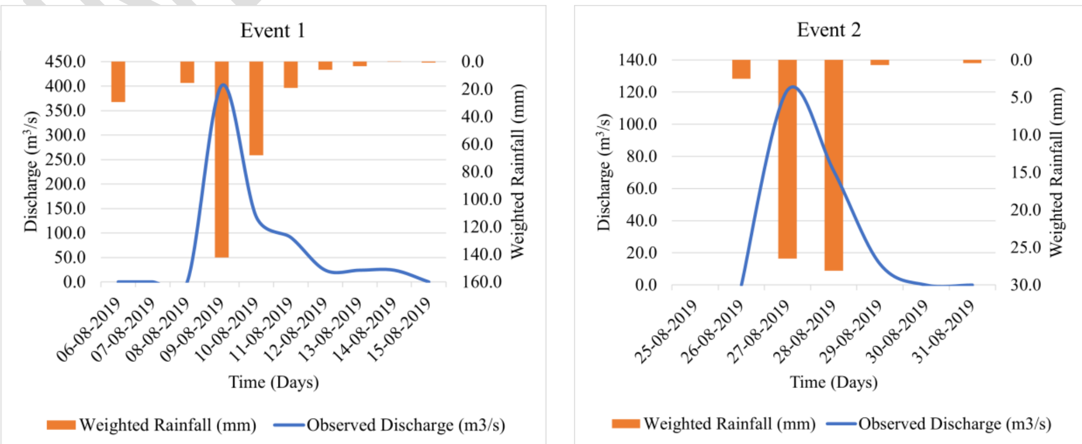
3.4 Selected Events

The discharge/runoff data and corresponding rainfall storm data were collected from the State Water Data Centre, Gandhinagar. The single peaked different five events were selected randomly from the data of the study area and details of the event is given in Table-5.

Table-5: - Different events selected for study

Event No.	Date	
	From	To
1	05-08-2019	17-08-2019
2	24-08-2019	02-09-2019
3	11-09-2019	20-09-2019

The observed direct surface runoff data have been used for the comparison purpose of the runoff hydrographs computed by using HEC-HMS based Clark and SCS model. The weighted rainfall and observed discharge are shown in Fig. 7 (a) to (c) along with the direct surface runoff hydrographs computed by the proposed models.



(a) (b)

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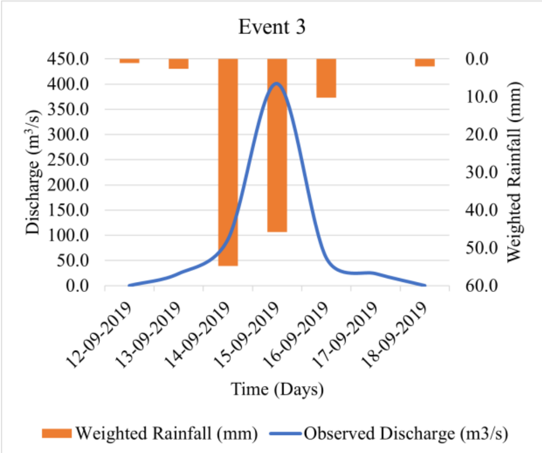

(c)

Fig. 7 (a) to (c): Presentation of Discharge and rainfall of selected events

3.5 MODEL APPLICATION

The HEC-HMS software was utilized to develop a model for simulating daily hydrological processes in the Devgadh Baria Watershed. The model was calibrated using rainfall and observed flow data from event-1 to event-2 in the year 2019, and subsequently validated using data from event-3 in the same year.

A daily flow model was developed based on daily rainfall and observed stream flow data collected at the Devgadh Baria gauging site on the Panam river. The calibration and validation results of the daily model are illustrated in Fig. 8 and 10, respectively. The simulated stream flow closely aligns with the observed flow data during both the calibration and validation periods, with a few exceptions in peak flow values and peak time with Clark UH. In the validation phase, the simulated stream flow was slightly lower than the observed values in the last event-3. Overall, the simulated stream flow exhibited a good agreement with the observed flow pattern.

The DSRO hydrographs computed using the HEC-HMS package Clark and SCS UH models for the five events are shown in Fig. 8 to 10. The maximum discharge (Qp in m^3/s) and time to peak (tp in days) values of observed and simulated are presented in the Table-6.

Table-6: Peak discharge and time to peak of the observed and computed DSRO hydrographs

Event. No.	Observed		SCS UH		Clark UH	
	Q_p (m^3/s)	t_p (days)	Q_p (m^3/s)	t_p (days)	Q_p (m^3/s)	t_p (days)
1	400.90	2	495.70	2	316.80	3
2	96.29	3	75.10	3	36.80	4
3	150.90	3	195.30	3	112.50	4

Table-6 shows the peak discharge and time to peak of the observed and the computed DSRO hydrographs. The time to peak discharge of the observed hydrograph is upto three events and that of the, SCS UH, and Clark UH DSRO hydrographs varies from 2 to 5, and 3 to 6. The observed DSRO hydrographs and the computed DSRO hydrographs using the four models are shown in Fig. 8 to 10. It can be observed from the Fig. 8 to 10 and from Table-6

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that the time to peak estimated by the models are found same as the as compared to the observed hydrograph except that of the Clark's UH model.

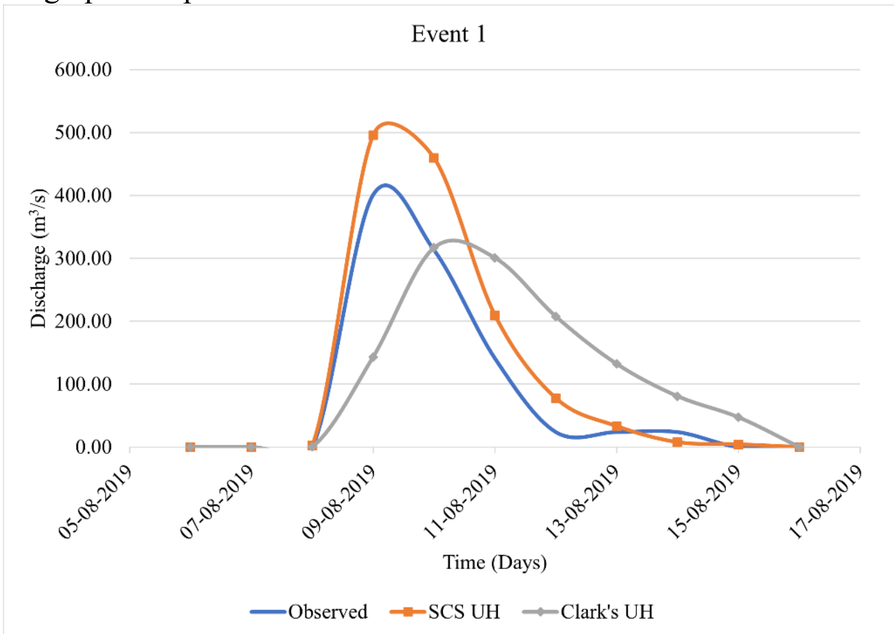

Fig. 8 (a): Comparisons of DSRO hydrographs of Event No. 01

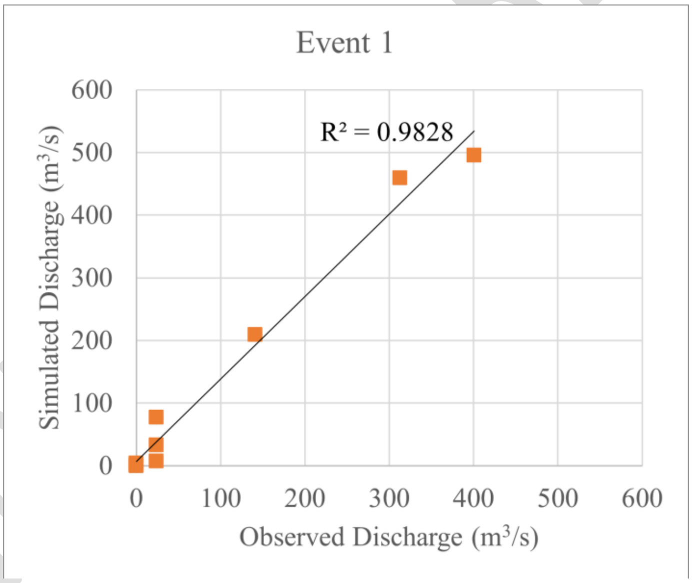

Fig. 8 (b): Scatter plot of Observed and SCS UH simulated runoff of Event No. 01

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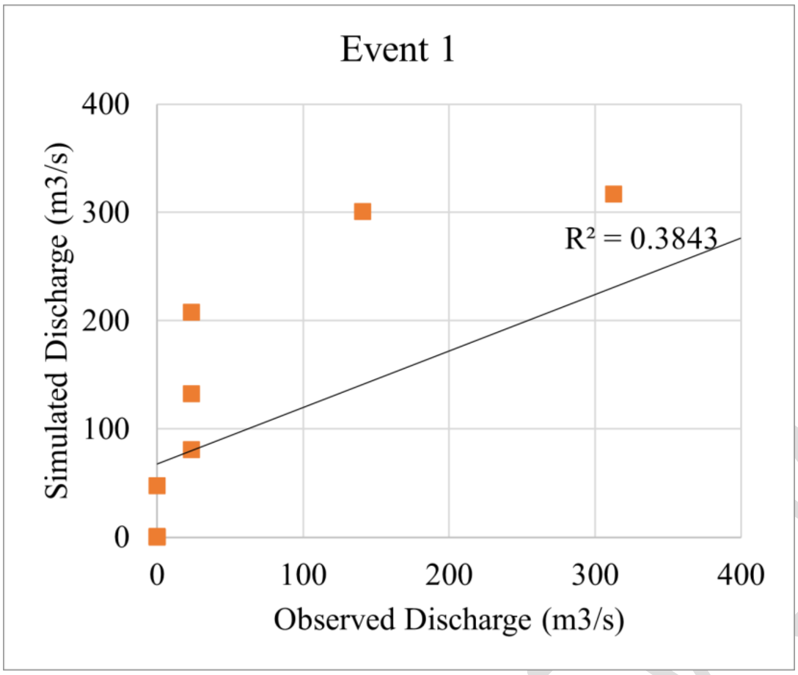

Fig. 8 (c): Scatter plot of Observed and Clark UH simulated runoff of Event No. 01

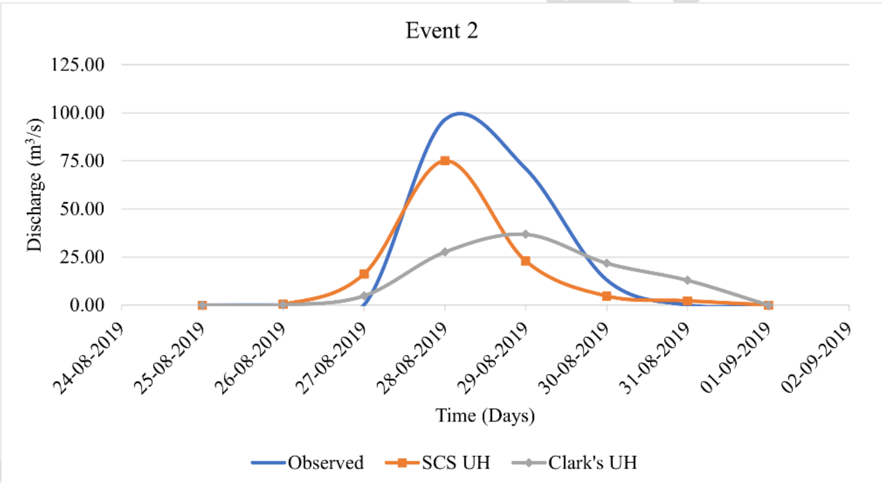

Fig. 9 (a): Comparisons of DSRO hydrographs of Event No. 02

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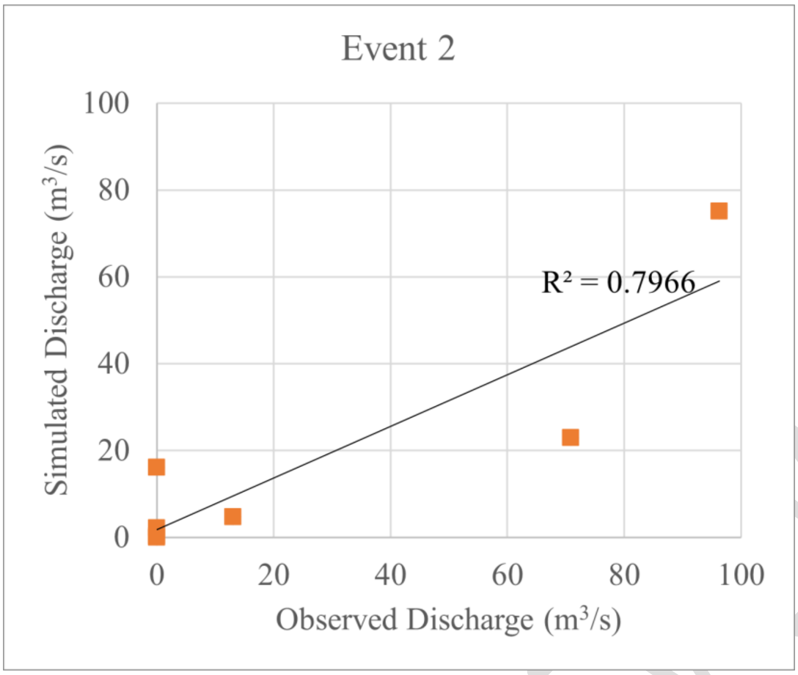

Fig. 9 (b): Scatter plot of Observed and SCS UH simulated runoff of Event No. 02

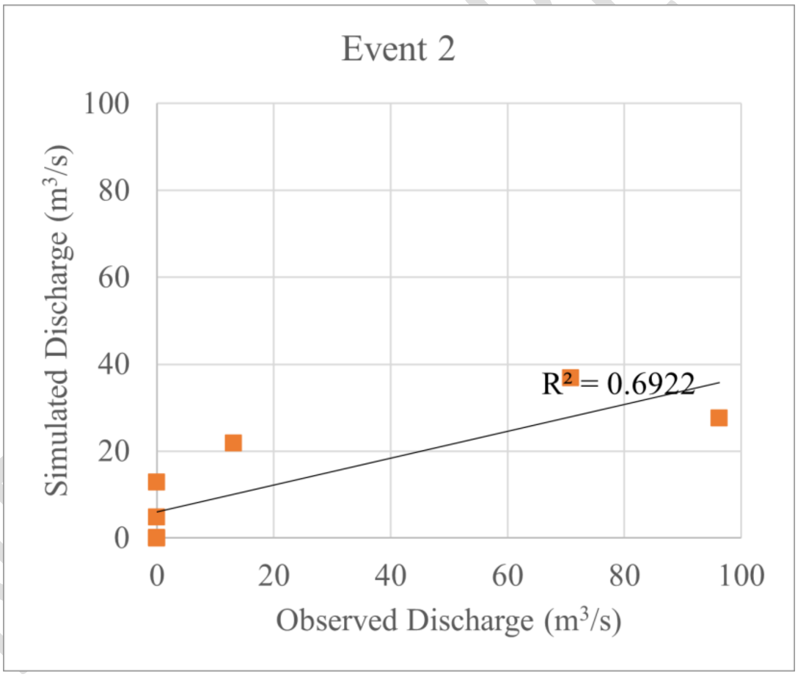

Fig. 9 (c): Scatter plot of Observed and Clark UH simulated runoff of Event No. 02

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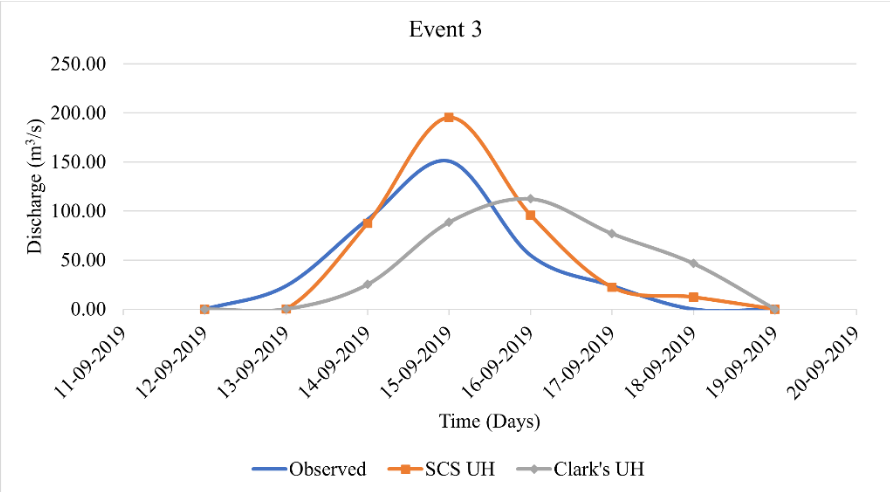

Fig. 10 (a): Comparisons of DSRO hydrographs of Event No. 03

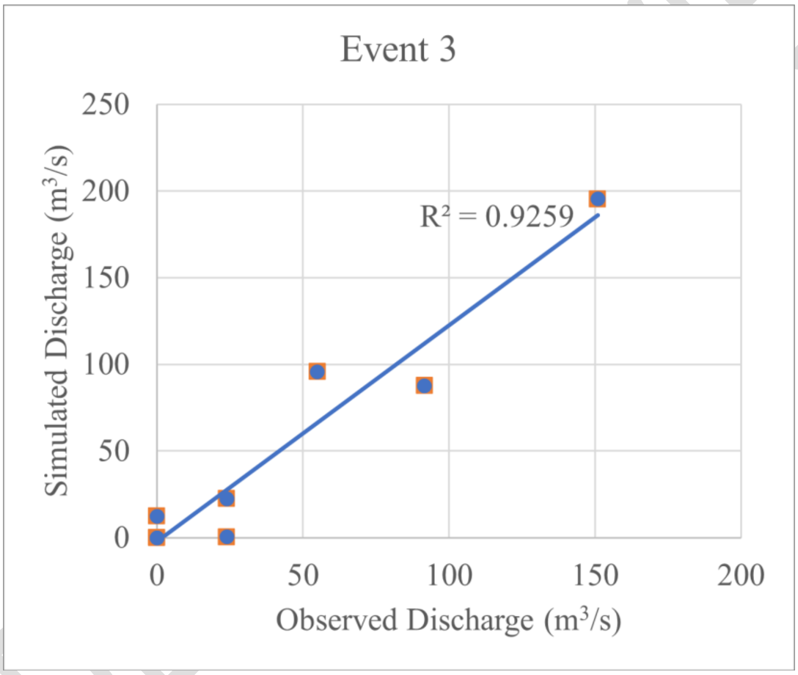

Fig. 10 (b): Scatter plot of Observed and SCS UH simulated runoff of Event No. 03

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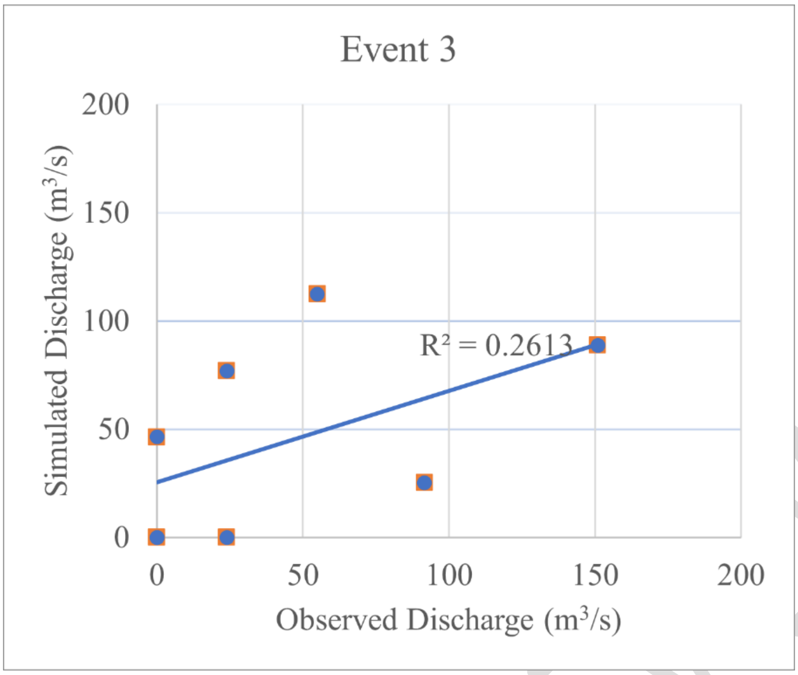

Fig. 10 (c): Scatter plot of Observed and Clark UH simulated runoff of Event No. 03

4.4. COMPARISON OF ERROR FUNCTIONS USED FOR EVALUATION

Table-7 shows the values of error functions computed to evaluate the DSRO hydrographs derived using the HEC-HMS based SCS and Clark model. These error functions are: (1) NSE, (2) PBIAS (3) Root mean square error (RMSE), and (4) Index of Agreement measure (d).

It can be observed from the Table- 7 that the values of NSE varies from -0.28 to 0.81 for SCS UH model; from -0.11 to 0.41 for Clark UH model. It can be observed from the Table-7 that the values of PBIAS varies from -32.65% to 108.76% for SCS UH model; from -42.30% to 77.89% for Clark UH model. It can be observed from the Table-7 that the values of RMSE varies from 19.64 to 59.1 for SCS UH model; from 19.79 to 113.9 for Clark UH model. It can be observed from the Table-7 that the value of d varies from 0.86 to 0.97 for SCS UH model; from 0.68 to 0.77 for Clark UH model.

Table-7: Error functions computed for DSRO hydrographs

Event No.	Methods	Error functions for DSRO hydrographs			
		NSE	**PBIAS**	**RMSE**	**d**
1	SCS UH	0.81	39.24%	59.10	0.97
	Clark UH	0.29	32.72%	113.93	0.76
2	SCS UH	0.70	-32.65%	19.64	0.89
	Clark UH	0.41	-42.30%	27.72	0.68
3	SCS UH	0.79	19.90%	23.36	0.96
	Clark UH	0.16	1.45%	46.26	0.71

5 CONCLUSIONS

The Land use and land cover in the watershed were classified into agriculture (42.13%), bare land (0.03%), built-up areas (3.08%), forest (53.55%), and water (1.21%). The predominant soil type in the watershed is loamy (91.33%), with some areas having clayey soil (8.67%). FAO soil data and Sentinel-2 remote sensing data in ArcGIS were used

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to create the soil map and land use map, respectively. The estimated Curve Number for the watershed was found to be 77.69. Weightage factors for calculating weighted rainfall using the Thiessen Polygon method were determined as 0.68, 0.18, and 0.14 for the Devgadh Baria, Devhat, and Rangpur rain gauges, respectively. The estimated time to peak using the HEC-HMS based SCS UH model matched well with observed data, while the HEC-HMS based Clark UH model showed a one-day delay in time to peak. The HEC-HMS based SCS UH model outperformed the HEC-HMS based Clark model based on performance indicators such as NSE, RMSE, and d.

A HEC-HMS-based rainfall-runoff model was developed using daily data for the Devgadh Baria watershed. The model underwent calibration using data from event-1 and event-2 and validation using data from event-3. The model's performance was evaluated using statistical parameters, including NSE, PBIAS, RSME and d.

Based on the values of NSE, PBIAS, RSME and d the SCS UH model demonstrated superior performance in both calibration and validation compared to the Clark UH model. Therefore, it can be concluded that the SCS UH model outperforms the daily models.

Furthermore, the study concludes that the HEC-HMS-based rainfall-runoff model is suitable for streamflow forecasting in the Devgadh Baria Watershed.

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