SIMULATION OF RAINFALL-RUNOFF EVENT USING HEC-HMS MODEL FOR REL SUB-BASIN, GUJARAT, INDIA

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Abstract: Hydrological modeling is a tool to estimate the basin's hydrological response. In this study, HEC-HMS model is used to simulate the rainfall-runoff process in Rel watershed of Gujarat, India. Rel basin is a sub-basin of Lower Luni basin. SCS curve number and SCS unit hydrograph methods were used to compute runoff and peak runoff rate. Rainfall-runoff simulation is conducted using data of one recent rainstorm event (July 2017). Initial results showed that there is a large difference between observed and simulated peak flows. Therefore, model calibration with optimization method and sensitivity analysis has been done. The results showed that lag time is a sensitive parameter. Model validation using optimized lag time parameter showed the reasonable difference in peak flow. It can be concluded that model developed can be used with a reasonable approximation for hydrologic simulation in Rel watershed to predict runoff from a rainfall event.

Keywords: Hydrologic modeling, Rainfall-Runoff simulation, HEC-HMS, SCS-CN method, Rel Basin.

1. INTRODUCTION

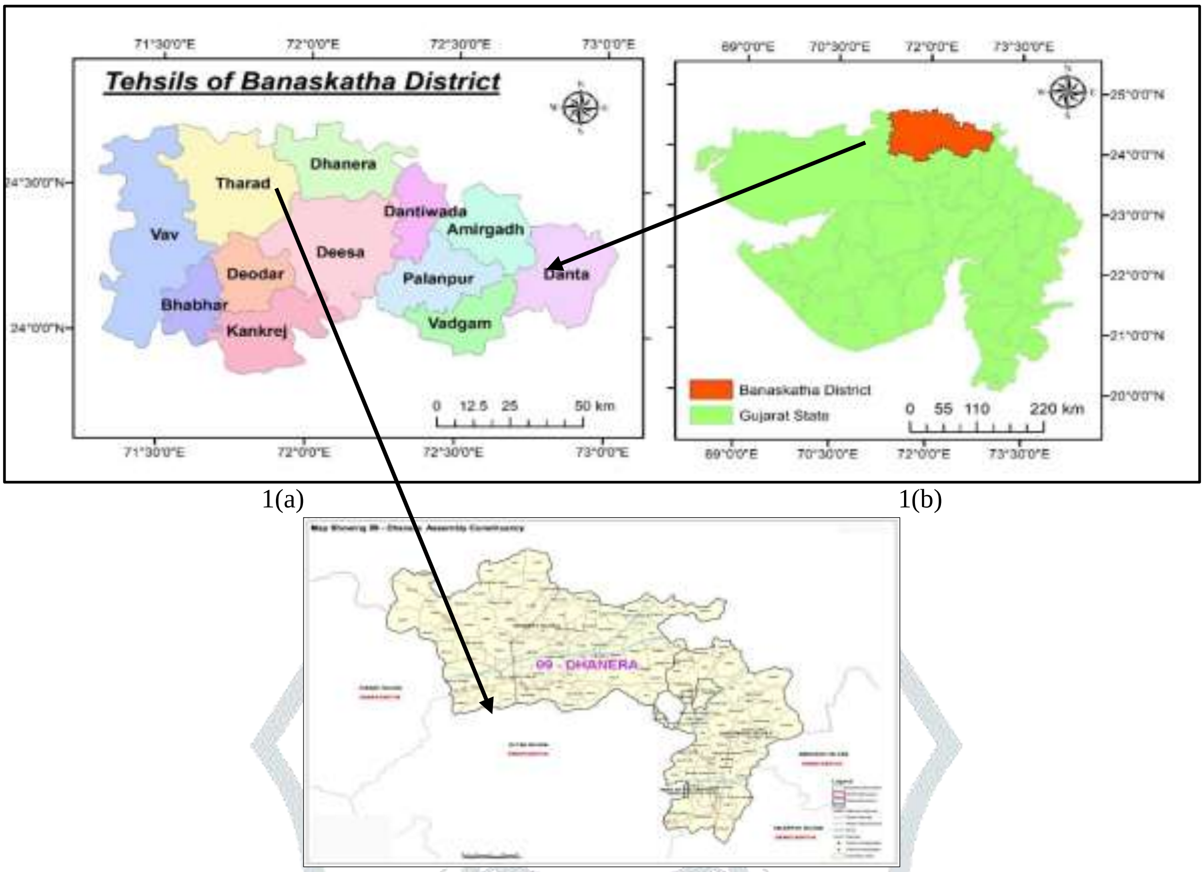
The two vital natural resources required for the agricultural production of any country are soil and water. The net productivity of crops depends on the proper management and utilization of these two resources. Out of these two resources, water is very important. To meet the industrial and urbanization demands, water is becoming a scarce resource for agricultural production in almost all places across the globe. To overcome the water-related problems, extensive care should be taken in the operation and management of reservoirs and watersheds. But in many cases, poor land-use planning and land management practices due to rapid development reduction of land cover, loss of plant nutrients, deterioration of river water quality and an increase of impervious surface area have adversely affected the surface runoff quantity and quality. The accurate prediction of catchment runoff responses to rainfall events remains a major challenge (McColl and Aggett, 2006). Numerous researchers have used different methods to simulate, assess, and predict the effects of urbanization on hydrological response of the watersheds. Watershed management implies the judicious use of all land and water resources. Decision support tools can help in better options for people to manage water and land resources. One viable answer and approach to this challenge is the use of suitable hydrologic models for the efficient management of watersheds and ecosystems (Yener et al., 2012).

Hydrological modeling is a commonly used tool to estimate the hydrological response of a basin to a precipitation. It allows to predict the hydrologic response to various watershed management practices and gives a better understanding of the impacts of these practices (Kadam, 2011). It is evident from the extensive review of the literature that the studies on comparative assessment of watershed models for hydrologic simulations are very much limited in developing countries including India (Kumar and Bhattacharya, 2011; Putty and Prasad, 2000).There is urgent necessity to undertake study on hydrologic simulation through development of a suitable watershed model. The Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) is a popularly used and freely available watershed model to simulate the rainfall-runoff process.

Several studies have been conducted using the HEC-HMS model in different regions under different soil and climatic conditions. Chu and Steinman (2009) used HEC-HMS model for both, discrete and continuous, hydrological modeling in Monalack watershed in West Michigan. HEC-HMS model has been also used to simulate rainfall-runoff process with geo-informatics and atmospheric models for flood forecasting and early warnings in different regions of the world (Abed et al., 2005; Anderson et al., 2002; Clay et al., 2005; Hu et al., 2006; Knebl et al., 2005; McColl and Aggett, 2006; Yusop et al., 2007; Yener et al., 2012; Arekhi, 2012; Majidi and Shahedi, 2012; Halwatura and Najjim, 2013; Majidi and Vagharfard, 2013; Ali et al., 2011; Dzubakova, 2010). It was also used for watershed management in different parts of India (Putty and Prasad, 2000; Shrestha, 2006; Kumar and Bhattacharya, 2011; Bhatt et al., 2012; Kadam, 2011). The model was found accurate in spatially and temporally predicting watershed response in event-based and continuous simulation as well in simulating various scenarios in flood forecasting and early warnings.A number of watershed development and management programs are now going on in Banaskantha (Gujarat), India. However, a review of the literature reveals that not much work has been done on simulation of the rainfall-runoff process using any watershed model Banaskantha (Gujarat), India. The objective of the present study is to simulate the rainfall-runoff process using HEC-HMS hydrological model in the Rel watershed of Banaskantha (Gujarat), India to prevent flood damage in the basin

2. STUDY AREA

The present study was undertaken for Rel watershed of Banaskantha district of Gujarat, India. The latitude, longitude, and altitude of the watershed area are 24.5064 N, 72.0258 W and 128 m above the mean sea level respectively. Fig. 1 and 2 show the location of the study area. The area falls under the semi-arid climatic condition in the western part of the country. The area is characterized by hot summer, wet monsoon and cold winter. The average annual rainfall of the watershed is 520 mm. Average maximum and minimum temperatures are 41.35℃ and 9.79 ℃, respectively. Relative humidity ranges from 33 to 77%. The watershed has a total area of 611 km^2. Dhanera has suffered a lot in floods, in 1977 and recently two again affected by flood in 2015 and 2017. Recent flood of 23/07/2017 came with major damage. The land use and land cover of Rel Basin are shown in Fig.3.



1(a) 1(b)

1(c)

Figure 1 Dhanera City in Banaskantha District, Gujarat, India

Figure 2 Satelite Image of Rel Basin

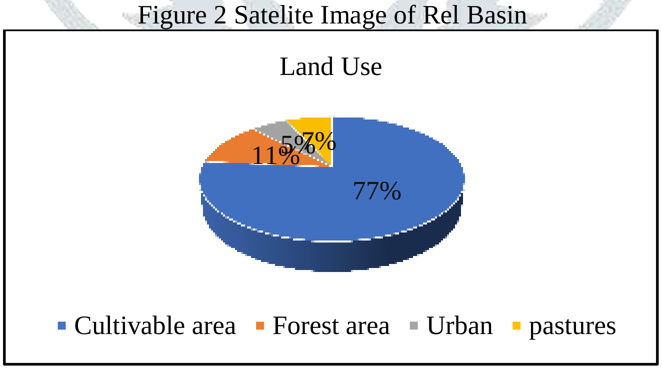


Figure 3 Land Use And Land Cover of Rel River Basin

3. DATA COLLECTION

The continuous daily record of rainfall and other meteorological data of the watershed for the year 2017 were collected from the agro-met observatory center, Irrigation Department, Deesa which is located near the watershed. The daily continuous runoff data of the watershed measured using automatic water level stage recorder was also collected for the year 2017. The topographical map, soil map, land use/pattern map, drainage network, watershed boundary etc. for the watershed were extracted using Survey of India maps and GIS model which is used to create the basin model input for HEC-HMS. The software used for the present study is HEC-HMS (v4.2.1) available in public domain on USACE website.

4. METHODOLOGY

Model Approach

The model approach used to determine the runoff volume is the SCS-CN method. With this method, the precipitation excess is a function of cumulative precipitation, soil type, land use/cover and antecedent moisture. Considering the initial loss and the potential maximum retention, the precipitation excess can be calculated; the maximum retention and the basin characteristics are related through the curve number. The standard SCS curve number method is based on the following relationship between rainfall depth, P, and runoff depth, Q;

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} \text{ for } P > 0.2S; \text{ otherwise } Q = 0 \quad (1)$$

$$S = \frac{25400}{CN} - 254 \text{ (in mm)} \quad (2)$$

$$I_a = 0.2S \quad (3)$$

Where: Q is the surface runoff (mm), P is the precipitation (mm), S is the soil retention (mm), I_a is the initial loss (mm), and CN is the curve number.

To obtain volumes, P and Q (in mm) must be multiplied by the basin area. The potential maximum retention (*S*) represents an upper limit for the amount of water that can enter the basin through surface storage, infiltration, and other hydrologic losses. For convenience, *S* is expressed in terms of a CN, which is a dimensionless basin parameter ranging from 0 to 100. A CN of 100 represents zero retention, where all the rainfall becomes runoff. A CN of zero conceptually represents the other extreme, with the basin trapping all the rainfall with no runoff regardless of the rainfall amount. The basin parameter CN can be determined from empirical information. The SCS has developed tables of initial curve number (CN) values as a function of the basin soil type and the land cover/use/condition. The hydrologic soil groups are defined in accordance to the standard SCS soil classification procedures, which establish a range from classification A for sand and aggregated silts with high infiltration rates, to classification D for soils that swell significantly when wet and have low infiltration rates. On the basis of the soil information for Rel basin and the visible ground coverage, a CN of 77 was chosen. A potential retention (*S*) was computed by applying Equation 2. The initial loss (I_a) was estimated from Equation 3. These values were used in the model for the Rel Basin.

To determine how the runoff is distributed over time, a time-dependent factor must be introduced. The time of concentration (t_c) is used in the SCS methods. The t_c is most often defined as the time required for a particle of water to travel from the most hydrological remote point in the basin to the point of collection. There are several methods available for calculating t_c, one of them is the SCS Lag Method with,

$$t_L = \frac{L^{0.8}[(\frac{1000}{CN})-9)^{0.7}}{1900S^{0.5}} \quad (4)$$

and $$t_c = 1.67t_L \quad (5)$$

Where, t_c is the time of concentration (minutes); t_L is the watershed lag time (minutes); *L* is the length of the longest watercourse (km); *S* is the mean slope of the basin (%); and CN is the curve number.

Input Data for HEC-HMS Basin Model

The methodology adopted to find runoff for Rel Basin is shown in Figure 4. The first step is preparing a Digital Elevation Model (DEM). In order to generate the DEM for the study area, a contour map in scale 1:50,000 was used to digitize the 50 m contour interval. With the aid of Arc Map GIS 10.1, these digitized contours were converted to a DEM with 90 m cell size. Such DEMs include pits or ponds that should be removed before being used in hydrological modeling. These are cells where water would accumulate when drainage patterns are being extracted. Pits are a sign of errors in the DEM arising from interpolation. These pits were removed by an algorithm known as SINK filling.

After filling the DEM sinks, a flow direction map was computed by calculating the steepest slope and by encoding into each cell the eight possible flow directions towards the surrounding cells. Flow direction is then used to generate the flow accumulation map. The flow accumulation, generated by addressing each cell of the DEM, counts how many upstream cells contribute to flow through the given cell. Flow direction and accumulation maps are then used to delineate the stream network. The stream network can be divided into segments, which will determine the outlets of the basin. The generated stream network has a dendritic shape of the third order.

The last step is the basin delineation process, which depends on the generated flow direction and accumulation map. Furthermore, it also depends on a user-specified number known as a threshold. This threshold determines the minimum number of pixels within each delineated sub-basin. A value of 27778 was chosen to delineate the basin because the basin area is small and Rel basin has no further sub-basins as Rel Basin is itself a sub-basin of Lower Luni Basin.

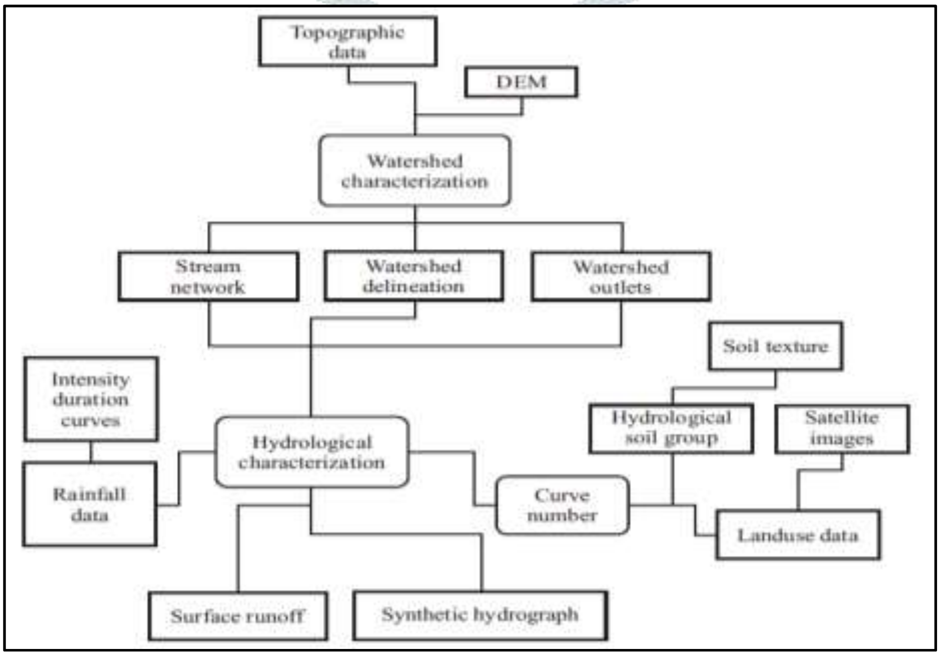


Figure 4 Flow Chart of Methodology

Computation of Hydrologic Parameters

The basin parameters (area, lag-time, and average curve number) were calculated as described above. Other parameters, needed for estimating the lag-time, such as length and slope of the longest flow path, were also calculated and stored in the basin attribute table. These files, when opened in HEC-HMS, automatically create a topologically correct schematic network of basins and reaches with hydrologic parameters.

To construct the rainfall-runoff model for the Rel basin, a schematic representation of the Rel network was created by dragging and dropping icons, that represent hydrological elements, and connections between them were established. The hydrologic parameters for each basin were entered using HEC-HMS sub-basin editor; required data consist of sub-basin area, loss rate method (SCS-CN method was used), transform method (SCS Unit Hydrograph method was used), and base flow method (base flow was set to zero for Rel). Here the time span of the storm event as short, and hourly or daily data of temperature and evapotranspiration is not available so for entire simulation it was taken as an average from India water portal. The evapotranspiration was 6.38 mm and the temperature was 30.28℃.

A precipitation model is the next component of the HEC-HMS model. The intensity of rainfall was obtained from the Intensity-Duration-Frequency (IDF) curve of Bapla rainfall station. Location of Bapla is shown in Figure 2. Bapla is a Village in Dhanera Taluka in Banaskantha District of Gujarat State. For each time duration, the corresponding precipitation depth was computed as the product of intensity and duration. Finally, the control specifications for a 7 day simulation period (from the 23 July 2017 to the 29 July 2017) were selected with 1 hour time interval. Similarly, evapotranspiration and temperature models were formed.

5. MODEL CALIBRATION AND VALIDATION

Model calibration is an essential process needed to ensure that the simulation outputs are close to real observations. Once the model is developed and simulated for the initial parameter estimates, it was calibrated against known runoff rates measured at the Dhanera station during a storm event that occurred between the 23 July 2017 to the 29 July 2017. The model calibration was done by adjusting the curve number values until the results matched the field data. The process was completed by trial and error by repeatedly adjusting the parameters and inspecting the goodness of fit between the computed and observed hydrographs. The process can also be done automatically by using the iterative calibration procedure called optimization. The measure of the goodness of fit is the objective function. HEC-HMS allows the user to calibrate the model to the best-fit condition by selecting various objective functions to provide the best calibration results. The objective function measures the variation between computed and observed hydrographs and is equal to zero when the hydrographs are identical. The automated calibration was used to adjust initial losses, curve number and lag time to minimize the objective function value and to find optimal parameters. When manual validation of the observed and simulated hydrograph was not acceptable, initial parameters were adjusted to provide a better optimization target value for the optimization process.

A calibrated model should be validated before it is recommended for use. For validation, the simulated data as predicted by the model must be computed with the observed data and statistical tests of error functions must be carried out. If the values of error functions are very small and within an acceptable range of accuracy then the model is validated.

6. RESULTS

Each component of HEC-HMS, models an aspect of the precipitation-runoff process within a portion of the basin. Representation of a component requires a set of parameters that specify the particular characteristics of the component and mathematical relations that describe the physical processes. Fig. 5 shows the calibrated parameter values of each of the components represented in this model. Apart from the sub-areas, which are fixed, parameters were calibrated simultaneously through adjustment of their values until a good agreement between the observed and simulated hydrographs was achieved.

The calibration and validation graphs of catchments are shown in Fig. 5, 6, and 7. Table 1 shows observed and simulated discharge and percentage errors between them. Figure 6 show good agreement between observed and simulated values of discharge after calibration and validation. It can be seen in the graphs that the simulated and observed peak discharges occurred on the same day, and their maximum time difference was one hour, which is acceptable for flood forecasting. In Table 1, some simulated values have large difference compare to observed values due to taking average parameters of temperature and Evapotranspiration in the simulation process.

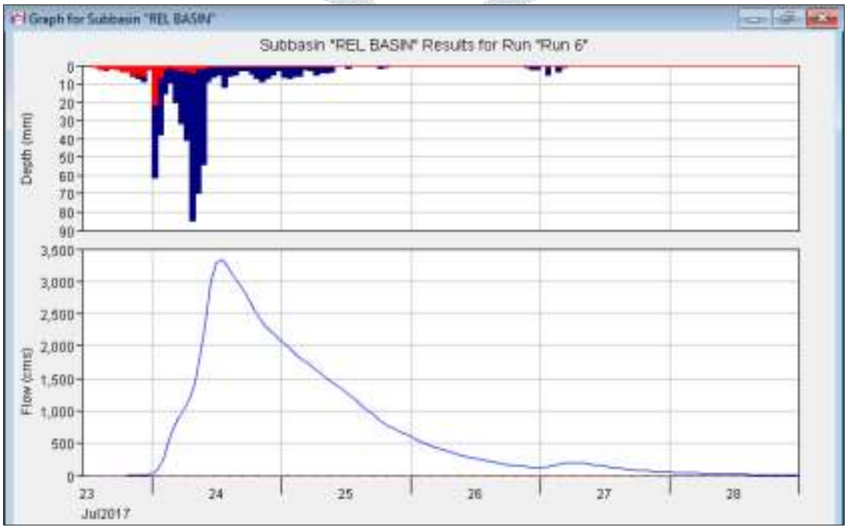


Figure 5 Outflow Hydrograph of Calibration

Table 1 Sample Comparison of Simulated and Observed Discharge

Date	Time	Observed Discharge (m^3/s)	Simulated Discharge (m^3/s)	Error (%)
23-07-2017	18:00	24.60	0	100
24-07-2017	00:00	22.57	75.4	234.07
24-07-2017	06:00	121.31	1174.5	868.18
24-07-2017	12:00	3177.32	3379.7	6.36
24-07-2017	18:00	1485.90	2596.6	74.74
25-07-2017	00:00	1295.84	2027.1	56.43
25-07-2017	06:00	1002.93	1619.2	61.44
25-07-2017	12:00	602.20	1238.9	105.72
25-07-2017	18:00	477.05	829.2	73.81
26-07-2017	00:00	333.72	567	69.90
26-07-2017	06:00	192.03	375.6	95.59
26-07-2017	12:00	302.55	247.5	18.19
26-07-2017	18:00	225.65	161.2	28.56
27-07-2017	00:00	174.00	137.6	20.91
27-07-2017	06:00	145.12	202.8	39.74
27-07-2017	12:00	102.34	130.7	27.71
27-07-2017	18:00	78.70	78.7	0
28-07-2017	00:00	78.70	50	36.46
28-07-2017	06:00	78.70	30.8	60.86
28-07-2017	12:00	107.62	18.9	82.43
28-07-2017	18:00	73.18	11.9	83.73
29-07-2017	00:00	60.91	7.6	87.52

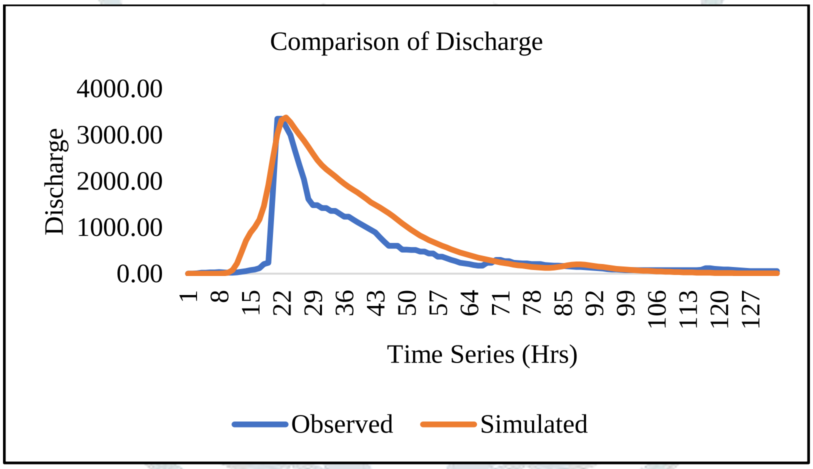


Figure 6 Comparison of Simulated and Observed Discharge for Validation

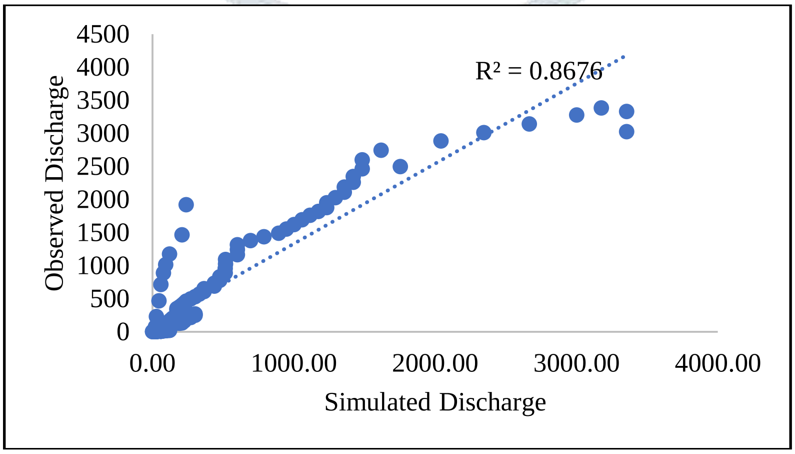


Figure 7 Correlation between Simulated and Observed Discharge

7. CONCLUSION

The drainage pattern of study area is third order dendrite. Simulation of the rainfall-runoff process is carried out in this study for Rel sub-basin using HEC-HMS model and SCS-CN methods. Due to difficulties to provide data requirements of SCS-CN method, its application is less than other loss calculation methods. The rainfall-runoff simulation was conducted with one recent event and initial results for event show differences between simulated and observed discharges. The model was calibrated to optimize the parameters. The model validation with optimized lag time values showed very small difference between observed and simulated discharges. This difference is in the range of

±20% which is an acceptable error. The comparison of observed and simulated hydrographs with high R^2 value (=0.86) shows the capability of the model to be used in hydrologic simulation in Rel watershed.

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