International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
www.chemijournal.com
IJCS 2021; 9(1): 3476-3482
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Received: 14-11-2020
Accepted: 23-12-2020

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Modelling of rainfall and runoff using HEC-HMS in Oghani Micro-watershed of Azamgarh District Uttar Pradesh

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DOI: https://doi.org/10.22271/chemi.2021.v9.i1aw.11772

Abstract
The present study was conducted using HEC-HMS, based on the SCS Curve Number method, Muskinghum method and Unit Hydrograph method, with the primary objective of developing a hydrological simulation model to forecast rainfall and runoff in the Oghani micro-watershed of Azamgarh district of Uttar Pradesh. Ten years rainfall-runoff peak events were used for this study purpose. Out of these ten events six events were selected for calibration and the rest of four events were used for validation. An initial calibration parameter was extracted from the data using geomorphological characteristics. The final parameter of validation was obtained from the optimization methodology and called the model's global values. For these rainfall-runoff events, the total surface runoff hydrograph was computed using the SCS unit hydrograph method that was compared with the hydrographs observed. For these rainfall-runoff occurrences, the cumulative surface runoff hydrograph was determined using the SCS unit hydrograph system that was correlated with the hydrographs observed. Error functions were measured using HEC-HMS for expected values and associations were also determined between observed and predicted values. Error functions include root mean square error (RMSE), mean absolute relative error (RMSE), and mean absolute relative error (MARE). The HEC-HMS model used for rainfall-runoff simulation in the selected watershed shows various errors within the permissible limits (RMSE -1.47, MARE - 0.0035, RMSE - 1.965 and MARE - 0.00595) which indicates the satisfactory performance of HEC-HMS model in predicting runoff. Comparison of the computed peak runoff discharge with measured values shows good result despite limited data availability.

Keywords: HEC-HMS, hydrologic modelling, rainfall, runoff, geomorphic characteristics

Introduction

The global climate is continuously changing in recent years and causing extremity weather condition like drought and floods which more frequently affecting agriculture and natural resources very significantly and impacting overall ecosystem and livelihood in any area. Rainfall and runoff are the two most important component of the hydrological cycle and also affects the hydrologic and hydraulic design of structures to be erected to conserve the discharge and to develop the strategies for the future use. Precise estimation of runoff discharge and volume in any watershed is the most important aspects in engineering planning and environmental impact assessment, flood forecasting and water conservation calculation (Balvanshi and Tiwari 2014) [3]. The operation and management of reservoirs and watersheds should be given extensive care to solve water-related problems. In many cases, however, inadequate land-use planning and land management practise having adversely affected surface runoff quantities and quality during rapid growth by decreasing land cover, Loss of plant nutrients, degradation in the consistency of river water and a rise in the area of the impermeable soil. The precise estimation of catchment runoff responses to rainfall events is a major problem that persists (McColl and Aggett, 2006) [12]. A viable solution and approach to this challenge is the use of effective hydrological models to manage watersheds and ecosystems effectively (Yener *et al*., 2012) [17]. It helps the hydrological response to various watershed management practices to be forecast and a clearer understanding of the impacts of those practices (Kadam, 2011) [9]. It is evident from the comprehensive analysis of the literature that in developing countries, including India, studies on a comparative assessment of hydrological simulation models are very poor (Kumar and Bhattacharya, 2011; Putty and

Prasad, 2000) [10]. Our water resources have now entered an era of scarcity. It is estimated that thirty years from now, approximately one-third of our population will suffer from chronic water shortages. Indicators of water stress and scarcity are generally used to reflect the overall water availability in a country or a region. When the annual per capita of renewable fresh water in a country or a region falls below 1,700 cubic meters, it is held to be the situation of water stress. If the availability is below 1,000 cubic meters, the situation is labelled as that of water scarcity Efforts have been made to collect water by building dams and reservoirs and creating groundwater structures such as wells. (Pachauri and sridhan 2017). Watershed management requires wise use of both land and water resources. The precise estimation of catchment runoff reactions to rainfall events remains a major problem (McColl and Aggett, 2006) [12]. The effects of urbanization on the hydrological response of the watersheds have been simulated, assessed, and predicted by numerous researchers. Hydrological modelling is a widely used method for estimating the hydrological response of the basin due to precipitation. Model selection is based on the watershed characteristics and comparative comprehensive evaluation-based studies are therefore required to evaluate the watershed characteristics as well as to provide a basis for determining a model input that will perform adequately in a specific procedure (Johnson *et al.,* 2003) [7].

Hydrographs developed by the program use directly or in conjunction with other software for extreme precipitation conversion to runoff, base-flow estimation, area routing, urban drainage studies, water quality, the potential effect of urbanization, flow forecasting, flood damage mitigation, floodplain management and operation of systems. There are various methods for simulating surface runoff in HEC-HMS, and these methods have different results (Elham Rafiei Sardoii *et al*., 2012) [14]. The model was found to be effective in predicting the hydrological behaviour with space and time. In the case-based study and continuous simulation, watershed response, as well as simulation of different Flood forecasting scenarios and early warnings, may be predicted.

Methodology

Study area

The *Oghani* watershed located in the south-western district of Azamgarh, Uttar Pradesh between 5°49'22" to 25°41'42" latitude and 83°9'49" to 83°2'14" longitude at an altitude of 77.65 m above the mean sea level (MSL). The total watershed area is 750.00 ha. The average annual precipitation is 680 mm and covers an average of 62 wet days. Over the year, the temperature differs by 17.3° C. The difference in the temperature ranges from 43 in May/June to 5 in December/January

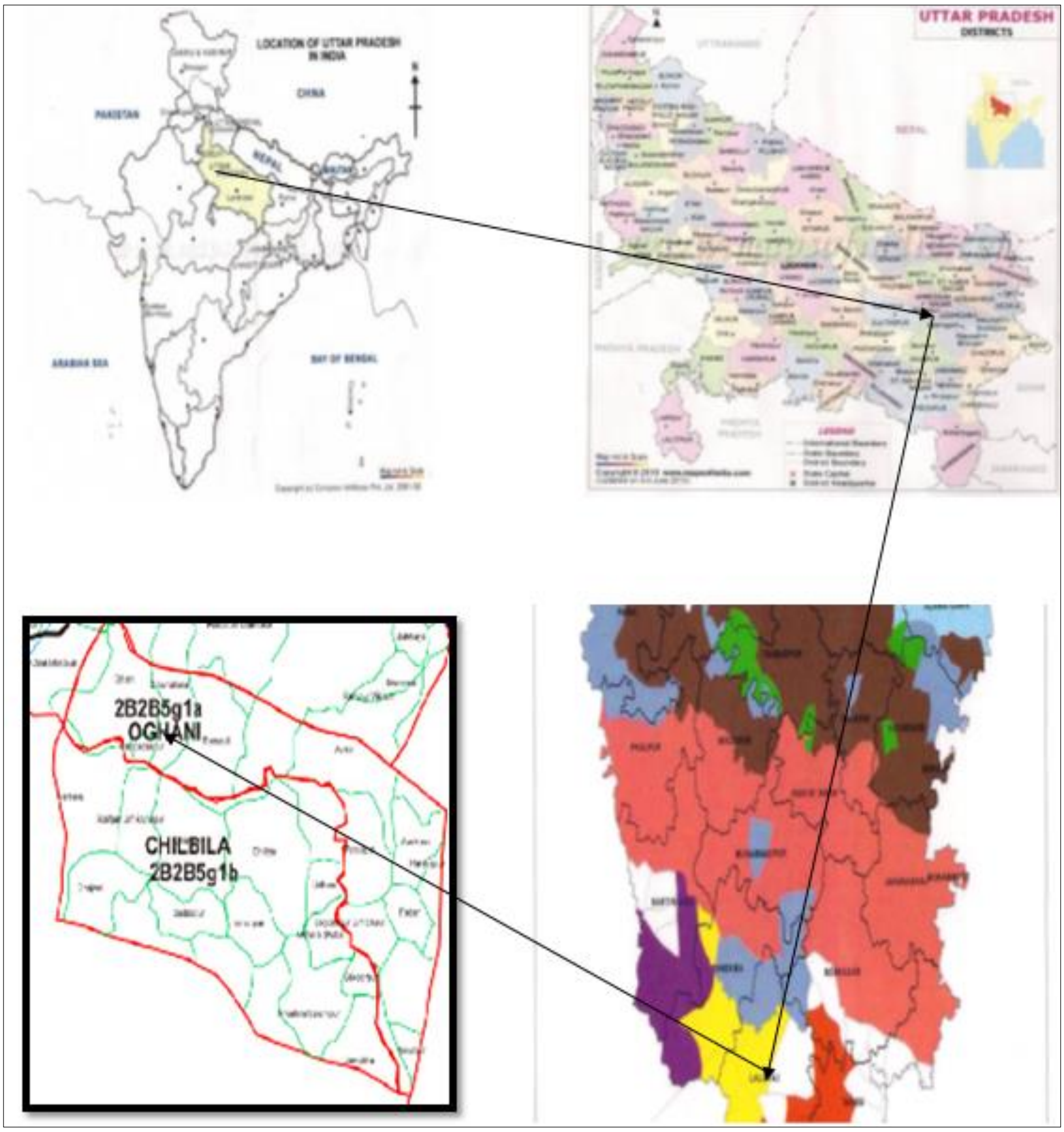


Fig 1: Location map of study area

The Ghaghara River separates the soil from the district's study area, mostly clay; much of the land is small, and there are abundant marshes and lakes. The type of loamy soil covers a significant portion of the district. The surface soil is yellow to brown with the sub-soil being brownish-yellow. Its water retention capacity is low due to the light and open texture of the soil, but it can be made capable of producing good crops if irrigation facilities are provided.

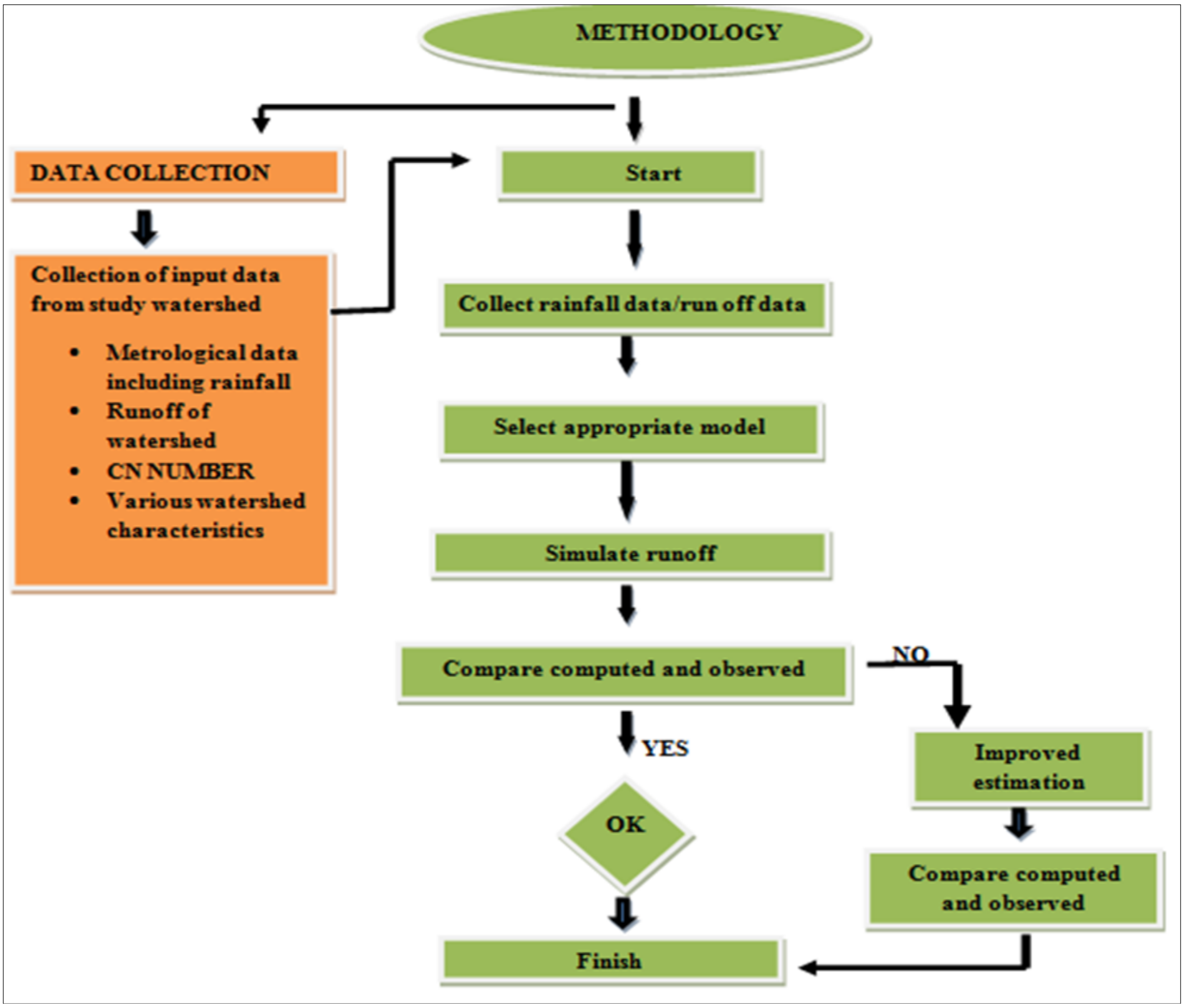


Fig 2: Flow chart of methodology

Data acquisition

For the event-based simulation of a selected run-off event, the agro-methodical observatory, the agricultural department, Azamgarh and also the Indian Meteorological Department (IMD) Lucknow data for rainfall depth were analyzed. Precipitation and other meteorological statistics were gathered for 2009 (Rainfall Assessed with a Self-recording Rain Gauge). In addition to precipitation and other meteorological statistics, the automated water level outlet obtained daily runoff data for 2009-18.

HEC-HMS hydrological model

HEC-HMS is a hydrological simulation program developed by the Hydrologic Engineering Center (HEC) of the US Army Corps of Engineers, a physically and conceptually semi-distributed model designed to simulate rainfall-runoff processes in a wide variety of geographic areas, such as the supply of water to major river basins and flood hydrology to small urban and natural runoff watersheds. The system encompasses losses, runoff transform, open channel routing, Analysis of meteorological data, rainfall-runoff simulation and parameter estimation. To represent each part of the runoff phase, HEC-HMS uses different models, including models that compute runoff length, direct runoff models, and base flow models. Each model run combines a basin model, meteorological model and control specifications with run options to obtain results. For each component of the runoff phase, the following methods were chosen, such as runoff depth, In event-based hydrologic modelling, direct runoff and channel routing. These methods are chosen on the basis of each method's applicability and limitations, data availability, suitability for the same hydrological situation, well-established, stable, generally appropriate, advice from the researcher, etc.

SCS Curve Number (CN) method

In SCS-CN method, accumulated precipitation excess is estimated as a function of cumulative precipitation, soil cover, land use and antecedent moisture and equation is (Singh, 1994):

$$P_e = \frac{(P-I_a)^2}{(P-I_a+S)} \quad \text{.................... (1)}$$

P_e = Accumulated precipitation excess at time t

P = Accumulated rainfall depth at time t

Ia = The initial abstraction (initial loss through interception, evaporation, detention, infiltration before runoff starts) and

S = potential maximum retention (ability of a watershed to abstract and retain storm Precipitation
I_a and S is calculated from following equation

$$Ia = 0.2s \quad \text{...............} (2)$$

$$S = \frac{25400-254CN}{CN} \quad \text{................} (3)$$

For a watershed that consists of several soil types and land uses, a composite CN is calculated as suggested by panigrahi (2013) [13]

SCS unit hydrograph method
SCS unit hydrograph is applied for estimation direct runoff. The basin lag (T_{lag}) is the parameter of SCS UH model is which is 0.6 times the time of concentration (T_c), value of T_c is computed as suggested by Panigrahi (2013) [13]

$$T_{lag} = .6t_p \quad \text{................} (4)$$

Where
T_{lag} = Lag time (min)

SCS UH Model for Direct Runoff

$$T_C = 0.02L^{.77}S^{-.385} \quad \text{................} (5)$$

Where,
L = Main channel length (m),
S = Average slope of the channel reach (m/m),
Tc = Time of concentration (min).

Muskingum method
The Muskingum channel routing method is selected. In this procedure, parameters X and K must be used. Technically, the K parameter is the time the wave travels in the duration of the range, and the X parameter is the constant coefficient that ranges from 0-0.5. With the aid of observed inflow and outflow hydrographs, this can be calculated. Parameter K is estimated as the distance between identical inflow and outflow hydrograph points. Once K is approximate, X by trial and error can be approximate (USACE-HEC, 2008) [16].

$$\left(\frac{I_{t-1}+I_t}{2}\right) - \left(\frac{O_{t-1}O_t}{2}\right) = \left(\frac{S_t+S_{t-1}}{\Delta t}\right)$$

Statistical Analysis
Root Mean Square Error (RMSE) of peak discharge =

$$\sqrt{\frac{\sum_{i=1}^{m}(Qoi-Qci)^2}{m}} \quad \text{................} (6)$$

Mean Absolute Relative Error (MARE) peak

$$\text{discharge} = \frac{\sum_{i=1}^{m}\left|\frac{Qop-Qcp}{Qop}\right|}{m} \quad \text{................} (7)$$

Root Mean Square Error (RMSE) of runoff depth

$$= \sqrt{\frac{\sum_{i=1}^{m}(Roi-Rci)^2}{m}} \quad \text{................} (8)$$

Mean Absolute Relative Error (MARE) of runoff

$$\text{depth} = \frac{\sum_{i=1}^{n}\left|\frac{(R_0-R_C)}{R_0}\right|}{n} \quad \text{................} (9)$$

Results and Discussion
For modelling with HEC-HMS, ten years of daily rainfall and runoff data was used to predict the runoff in the study watershed. All the rainfall events were methodically scrutinized and the events were randomly selected from the data gathered. In order to cover a wide spectrum of durations and peaks, flood events of different durations and various peak flows were selected. The details of the flood events selected are given in table 1.

Table 1: Details of the selected flood events used for model development and calibration occurred in *Oghani* watershed between 2009 to 2018

Sl. No.	Flood Events	Occurred during	Event Date	Rainfall during the day (mm)	Calibration/Validation
1	Event 1	01 Jan -31 Dec, 2009	27th June	66.69	Calibration
2	Event 2	01 Jan -31 Dec, 2010	02nd July	65.33	Calibration
3	Event 3	01 Jan -31 Dec, 2011	29th July	46.71	Calibration
4	Event 4	01 Jan -31 Dec, 2012	16th July	52.71	Calibration
5	Event 5	01 Jan -31 Dec, 2013	28th June	114.13	Calibration
6	Event 6	01 Jan -31 Dec, 2014	08th Oct	76.85	Calibration
7	Event 7	01 Jan -31 Dec, 2015	25th July	66.39	Validation
8	Event 8	01 Jan -31 Dec, 2016	10th Aug	35.40	Validation
9	Events 9	01 Jan -31 Dec, 2017	10th July	61.74	Validation
10	Events 10	01 Jan -31 Dec, 2018	25th Aug	41.77	Validation

Calibration and validation of the model: The successful implementation of the hydrological watershed model depends on how well the model is tuned, which in turn depends on the technological expertise of the hydrological model as well as the accuracy of input data. The HEC-HMS watershed model is calibrated for event-based modeling.
The aims of the model calibration are to align the measured simulated quantities of runoff, runoff peak and hydrograph timing with the observed ones. The accessible hydro-meteorological data is split into two parts for model calibration and model validation. Of the ten activities selected, six were selected for model calibration and four for model validation. The initial values are given to the chosen model at the moment of calibration. At the time of calibration, the parameter values required for calibration were calculated and given to the selected model as initial values. To optimize these parameters, the optimization tools available in HEC-HMS were also used.

Table 2: Various initial and optimize parameter calculated from SCS-CN equations and Muskingum equation for *oghani* microwatershed

Sl. No.	Parameter		Initial Values	Optimize value
1	Loss rate parameter	Initial abstraction (Ia),	19.23	16.17
		Curve Number (CN)	70	67.50
		Impervious (%)	00	00

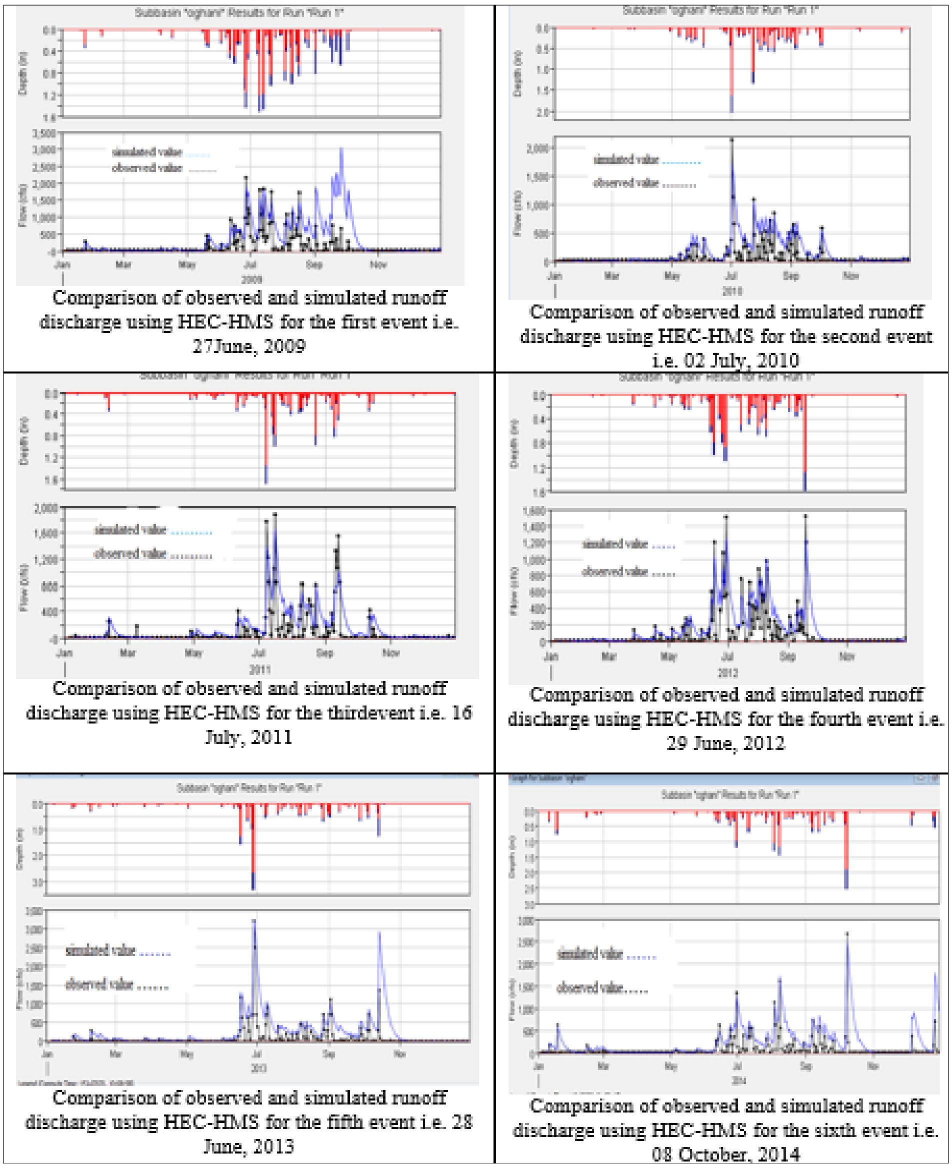
2	Transformation Parameter	Lag time	60	57.45
3	Muskingum Routing Method Constants	Muskingum (K), Hr	0.98	0.716
		Muskingum (X)	0.45	0.336

Various parameters of the direct surface runoff hydrographs observed were compared with those of the simulated runoff hydrographs, such as the values of runoff depth and peak discharge.

Table 3: Comparison of runoff depth and peak discharge of *Oghani* micro watershed before and after of Optimization

Events	Runoff Depth (mm)			Peak Discharge (m^3/s)		
	Before Optimization	**After Optimization**	**observed**	**Before Optimization**	**After Optimization**	**observed**
27June, 2009	36.56	37.89	38.90	60.02	60.45	60.88
02 July,2010	42.44	43.73	44.05	59.88	60.98	61.38
16July,2011	39.96	40.98	41.11	52.34	53.10	53.88
29 June,2012	41.33	42.34	43.18	41.45	42.63	42.90
28 June, 2013	74.83	75.96	76.2	89.98	90.75	90.78
08 Oct,2014	51.45	52.97	53.34	73.67	75.30	75.69

In the HEC-HMS model, the measured initial parameter values (Table 2) were first used for calibration and various parameters were simulated, such as runoff depth and peak discharge. These parameters were contrasted with the actual value (Table 3), and less discrepancies were noticed between the observed and the simulated values of all the parameters for all six calibration cases. Using the optimization function available in the HEC-HMS model, the original measured parameters were then optimized and the various optimized parameters are seen in table 3. The hydrograph parameters, such as the runoff depth and peak discharge, were simulated again with the aid of these optimized parameters (Table 3). Around the values of the various parameters of the hydrograph with the observed one. Optimization parameters are considered. Similar trends were noted for all other events used for calibration which are shown in fig.3



Comparison of observed and simulated runoff discharge using HEC-HMS for the first event i.e. 27June, 2009

Comparison of observed and simulated runoff discharge using HEC-HMS for the second event i.e. 02 July, 2010

Comparison of observed and simulated runoff discharge using HEC-HMS for the thirdevent i.e. 16 July, 2011

Comparison of observed and simulated runoff discharge using HEC-HMS for the fourth event i.e. 29 June, 2012

Comparison of observed and simulated runoff discharge using HEC-HMS for the fifth event i.e. 28 June, 2013

Comparison of observed and simulated runoff discharge using HEC-HMS for the sixth event i.e. 08 October, 2014

Fig 3: Comparison between daily observed and simulated runoff discharge using HEC-HMS during calibration (2009-2014)

Model validation

A calibrated model should be tested in order to be recommended for use. For validation, the simulation results as projected by the model must be calculated with the data observed and the statistical test error function must be performed. When the values of the error functions are very small, the model can be validated. Four activities were considered for validation of the model. These four randomly chosen occurrences are listed in Table 5.

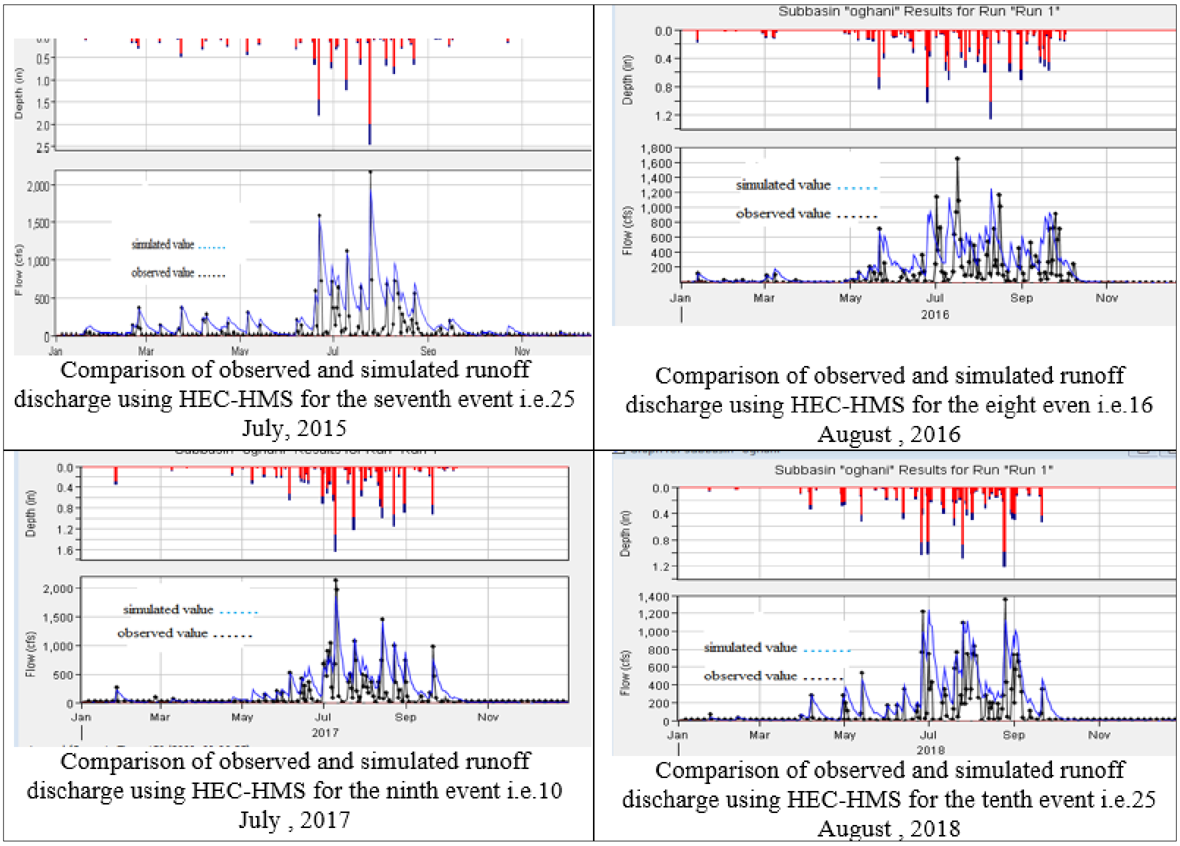
Table 4: Calibrated parameter values are used for validation calculated from SCS-CN equation and Muskingum equation of *Oghani* micro watershed

Sl. No.	Parameter		Value
1	Loss Rate Parameter	Initial Abstraction (I_a), mm	16.17
		Curve Number (CN)	67.50
2	Transform Parameter	Lag Time (T_{lag}), min	17.50
3	Routing Method Constants	Muskingum (K), Hr	0.716
		Muskingum (X)	0.336

The values of various runoff hydrographs, such as runoff depth and peak discharge, were simulated with optimized parameters in the tuned model and are shown in Table 5. The simulated values of these parameters are often found to be similar to the observed values for all cases (Table 5).

Table 5: Comparison of simulated and observed runoff depth, peak discharge and time to peak of *Oghani* micro watershed during validation

Events	Runoff Depth (mm)		Peak Discharge (m^3/s)		Peak time	
	Simulated	Observed	Simulated	Observed	Simulated	Observed
25 July,2015	52.26	53.54	60.12	61.28	12:00	1:00
16 August, 2016	36.56	35.87	45.66	46.49	2:00	4:00
10 July, 2017	43.18	44.09	59.89	60.19	9:00	11:30
25 August,2018	30.05	30.48	38.58	37.23	5:20	7:00



Comparison of observed and simulated runoff discharge using HEC-HMS for the seventh event i.e.25 July, 2015

Comparison of observed and simulated runoff discharge using HEC-HMS for the eight even i.e.16 August , 2016

Comparison of observed and simulated runoff discharge using HEC-HMS for the ninth event i.e.10 July , 2017

Comparison of observed and simulated runoff discharge using HEC-HMS for the tenth event i.e.25 August , 2018

Fig 4: Comparison between daily observed and simulated runoff discharge using HEC- HMS during Validation (2015-2018)

Statistical test of error function

The efficient calibration and validation efficiency of the model was analyzed following statistical error function tests. The values for the optimized and non-optimized values of these error functions are shown in Table 6. The statistical test of error functions (Eq. 5 to 8) gave MARE values of 0.573 mm and 0.017 m3/s respectively for runoff depth and peak discharge. Similarly, RMSE values between the data measured and simulated are obtained as 4.18 mm and 1.62 m3/s respectively for runoff depth and peak discharge. Optimized values are considered, however, and these values have been limited in series to 0.016 mm, 0.0067 m3/sec, 0.1.88 mm and 0.938 m3/sec (Table 3). For the simulation of runoff hydrographs in the HEC-HMS model, the optimized value should be considered after conducting different statistical tests.

Table 6: Calculated error values for calibration events of study area *Oghani* micro watershed

RMSE				MARE			
Runoff Depth		Peak Discharge m^3/s		Runoff Depth		Peak Discharge m^3/s	
Calibration (a)							
Before Optimization	After Optim Ization	Before Optimization	After Optim Ization	Before Optimization	After Optim Ization	Before Optimization	After Optim Ization
4.16	1.88	1.62	0.938	.0573	.016	.017	.0067
Validation (b)							
…….	1.965	……..	1.47	……	0.00595	…….	0.0035

Summary and conclusion

The present study was conducted with the prime objective to develop a hydrological model to predict rainfall and runoff in oghani micro-watershed using HEC-HMS which is based on SCS Curve Number method, Muskinghum method and unit Hydrograph method. The results of the study show that HEC-HMS can be effectively used to predict the rainfall and runoff within the permissible limits of errors which may help to develop the strategies to manage and conserve the runoff water to be used effectively which is presently causing the flood situation in most of the watershed. It may also be helpful for the design of conservation structures as per the runoff discharge going waste on the watershed. HEC-HMS model can be effectively used for simulation of stream flow in oghani micro watershed. Ten years of rainfall-runoff events were selected for this study. Out of these ten events six events were selected for calibration and the rest of four events were used for validation. The initial calibration parameter was derived using geomorphological characteristics. By optimization technique, the final validation parameter was derived and considered as global values for the model. The total surface runoff hydrograph was computed for these rainfall-runoff events using the SCS unit hydrograph method which were compared with the observed hydrographs. The error functions were computed between observed and computed total runoff depth, direct surface runoff and time of peak discharge. The error functions include root mean square error (RMSE), mean absolute relative error (MARE) and mean absolute percentage error in runoff depth.

References

1. Abushandi E, Broder M. Modelling Rainfall Runoff Relations Using HEC-HMS and IHACRES Water Resources Management May 2013;27(7):2391-2409.
2. Anonymous. Watershed Data, Land and Water Resource Department, Azamgarh, UP 2019.
3. Balvanshiankit, Tiwariherendra. Effects of land use and land cover changes on surface runoff of a semi-urban catchment. Research gate Journal 2014.
4. Chavare, Shinde. Morphometric analysis of Urmodi basin, Maharashtra using geo-spatialbtechniques International Journal of Geomatics and Geosciences 2013.
5. Chavare Subhash. Analysis of relief of Kolhapur district using SRTM data and GIS techniques, Research analysis and evaluation, International referred research Journal 2011;3(26):12-13.
6. Chu X, Steinman A. Event and Continuous Hydrologic Modeling with HEC-HMS, Journal of Irrigation and Drainage Engineering, January-February 2009;135(1):119-124.
7. Gerry Johnson, Johnson *et al.*, Micro Strategy and Strategizing: Towards an Activity-Based View Journal of Management Studies 2003, 40(1).
8. Horton RE. Drainage Basins Hydro-Physical Approach to Quantitative Geomorphology Morphology, Bull. Geol. Soc. America 1945, 2(56).
9. Kadam AS. Event based rainfall-runoff simulation using HEC-HMS model, Unpublished P. G. thesis submitted to Department of Soil and water Conservation Engg., CAET, Dr. PDKV, Akola 2011.
10. Kumar D, Bhattacharya R. Distributed Rainfall Runoff Modeling. International Journal of Earth Sciences and Engineering 2011;4(6):270-275.
11. Majidi A, Shahedi K. Simulation of Rainfall-Runoff Process Using Green-Ampt Method and HEC-HMS Model (Case Study: Abnama Watershed, Iran), International Journal of Hydraulic Engineering 2012;1(1):5-9.
12. McColl C, Aggett G. Land-use forecasting and hydrologic model integration for improved land-use decision support, Journal of Environmental Management 2006;84(4):494-512 New Delhi, pp. 44-56.
13. Panigrahi B. Irrigation System Engineering, New Indian Publishing Agency 2013.
14. Elham Rafiei Sardoii. Calibration of loss estimation methods in HEC-HMS for simulation of surface runoff (case study: Amirkabir Dam Watershed, Iran) 2012.
15. Surendra Kumar Mishra, Vijay P Singh. Soil conservation service curve number methodology 1994, 1-83.
16. USACE-HEC. Hydrologic modeling system (HEC-HMS)- application guide, US Army Corps of Engineers, Hydrologic Engineering Center, Davis, Calif Using HEC-HMS Model (Case Study: Abnama Watershed, Iran), Current Advances in Environmental Science 2008;1(1):7-11.
17. Yener *et al.*, The Effect Of Ethical Climate On Work Engagement Procedia - Social and Behavioral Sciences 2012;58(2012):724-733.
18. Yusop Z, Chan CH, Katimon A. Runoff characteristics and application of HEC-HMS for modelling storm flow hydrograph in an oil palm catchment, Water Science and Technology 2007;56(8):41-48.