Original Research Article

Application of HEC-HMS model for modelling flood in sub basin of Meenachil river, Kerala, India

Abstract: Meenachil river basin, located in southern part of Kerala, is frequently liable to flood. It is an area predominant with agricultural land and falls under tropical humid zone. Hence, water resources planning & management and understanding of rainfall-runoff relationship along with its land characteristics, is necessary for irrigation scheduling, flood control and design of various engineering structures. HEC-HMS which is a widely used rainfall-runoff model was chosen for the simulation of watershed responses and generation of flood hydrographs. The performance parameters NSE and R^2 values were obtained above 0.7. The Error in Peak Flow (%) and Volume (%) were figured below 20. All these values indicated satisfactory performance of the model simulation both in the calibration (2013-2016) and validation (2017-2018) period. Curve number, Initial abstraction and Lag time were found to be the most sensitive parameters of the model. Simulated and observed stream flow values indicated that the model was able to predict and present credible results for the sub basin.

Keywords:*HEC-HMS; Hydrologic modelling; Meenachil River; Flood.*

1. INTRODUCTION

The wise utilization and sound management of water resources is very important for sustainable development of a country. Watershed is the most basic unit for any water resources development and management in the area. Runoff is one of the most important hydrologic parameters considered for watershed development and management. The estimation runoff process in a watershed is extremely complicated, nonlinear and dynamic in nature. The assessment of runoff process in a watershed depends on many factors like meteorology, topography, geology, soil and land use pattern. Numerous methods are available for estimation of runoff based on the above factors (Subramanya, 2014). Nowadays GIS in conjunction with hydrological models is being used for estimation of runoff. Several models have been developed by different researchers in order to simulate the rainfall- runoff process of a watershed. Even though a variety of rainfall-runoff models are available, selection of an appropriate rainfall-runoff model for a given watershed is essential to ensure efficient planning and management of a watershed. The HEC-HMS model, which is a GUI-based user-friendly model available in the public domain has been found to be a useful tool for the hydrologists across the globe for flood modelling.

HEC-HMS (Hydrologic Engineering Centre Hydrologic Modelling System) is a widely used numerical model (computer programme) designed to simulate the rainfall-runoff processes in a watershed. It was established on the initiatives of US Army Corps of Engineers for simulating all hydrologic processes of a dendritic watershed system. The HEC-HMS model can be simply described as "physically based and conceptually semi-distributed model designed to simulate rainfall-runoff processes in a wide range of geographic areas, from large river basin water supplies and flood hydrology to small urban and natural watershed runoffs" (Tassew *et al.*, 2019). The model simulates various scenarios both spatially and temporally, in flood forecasting and early flood warning system. This model encompasses losses, runoff transform, open channel routing, parameter estimation and analysis of meteorological data and rainfall-runoff simulation. The software contains an absolutely integrated work environment comprising a database, data entry utilities, computation engine. In addition, it confronts multiple options to simulate base flow, interflow and channel flow. A model of the watershed is constructed by separating the hydrologic cycle into manageable pieces and constructing boundaries around the watershed of interest in the software (USACE, 2000). Finally, "the software gives output as hydrographs that can be used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation and systems operation" (Scharffenberg and Harris, 2008). HEC-HMS is chosen by several modellers due to its easy operation, handling, availability and better technical advantage and support from its developers. Hence, HEC-HMS model is used in this study to simulate rainfall-runoff process in the subbasin.

Kerala was affected severely during the 2018 flood. The Meenachil River flowing through the southern part of Kerala played a significant role in contributing the 2018 Kerala flood which resulted in largest loss of life in human history. Moreover, this river is frequently overflown every monsoon period with a flood causing enormous damage to the nearby livelihood. Therefore, a study was conducted to calibrate and validate HEC-HMS model for Meenachil subbasin and to generate long term flow data to determine the peak discharge rate of the river.

2. MATERIALS AND METHODS

2.1 Description of the Study areas

Meenachil River is one of the well-known rivers in central Kerala located in Kottayam district of Kerala which was formed by confluence of several streams originating from the Western Ghats at Araikunnumudi (elevation=1097m above MSL) and flows through Erattupetta, Palai, Ettumanoor and successively merges into the Vembanad Lake at Kavanattinkara, Kumarakom(CGWB, 2009).

Watershed area lies in the southern districts of Kerala, India, and is hedged within 9°5’2’’N and 9°56’10’’N (latitudes), and 76°19’19’’E and 77°11’24’’E (longitudes). On the western side is the Arabian Sea coast, and on the eastern side is the area enclosed by the Western Ghats. The river has a catchment area of 1208.1km² and is composed of 47 sub watersheds and 114 micro watersheds. Meenachil River is a 7th order river, consisting of 38 tributaries including major and minor ones. The major tributaries involve Kadapuzha, Kalathukadavu, Kurisumalai, Trikkoil, Punjar and Meenadom (CGWB, 2009). The location map of the sub-basin which is situated at the upstream of Meenachil river basin selected for this study is shown in Fig.1.This subbasin consists an area of 444.12 km² which is about 35% of the total area of Meenachil river basin and is gauged at ‘Palai’ station.

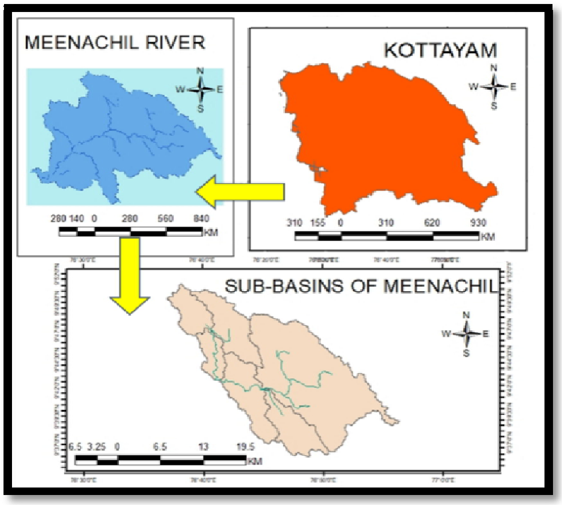

Fig. 1 Location map of the study area

2.2 Data acquisition

The different input data collected for the hydrological modelling in HEC-HMS are shown inTable1.

Table 1 Hydro-meteorological and remote sensing data used and their source

Sl. no.	Datatype	Description	Source
1	NASA DEM (NASA SRTM3 SRTMGL1) (30 m resolution)	Remote sensing data for terrain processing	U.S.G. S
2	Landsat 8 OLI/TIRS C1 (Level 1) (15-30m resolution)	Remote sensing data for preparing LULC	U.S.G. S
3	Soil data	For preparing soil map to determine the curve number	Department of Soil Survey and Soil Conservation, Trivandrum
4	Rainfall data during 2013-2018 at Erattupetta, Kozha and Kidangoor gauging station	For HEC-HMS model input and simulation	a) IDRB (Irrigation Design & Research Board), Trivandrum b) CWC (Central Water Commission)
5	Discharge data during 2013-2018 at Palai	For calibration and validation of HEC-	IDRB, Trivandrum

	gauging station	HMS model	

3METHODOLOGY

Main objective of this research was to examine the rainfall-runoff relationship in Meenachil sub-basin using HEC_HMS model. The methodology is based on meteorological and physical data processing in the geospatial environment and data editing using remote sensing and GIS techniques. The various procedures included are DEM processing, defining stream network, topography and watershed characteristics using the HEC-GeoHMS tools in ArcMap, defining geological and soil characteristics of the watershed using HSG (hydrologic soil group)map and LULC map to compute the runoff curve number (CN), importing the catchment physical characteristics data to HEC-HMS model, run the rainfall/runoff simulation and comparison of computed and observed flows and finally the calibration and validation of the model. The HEC-HMS flowchart adopted in this study is as shown Fig. 2.

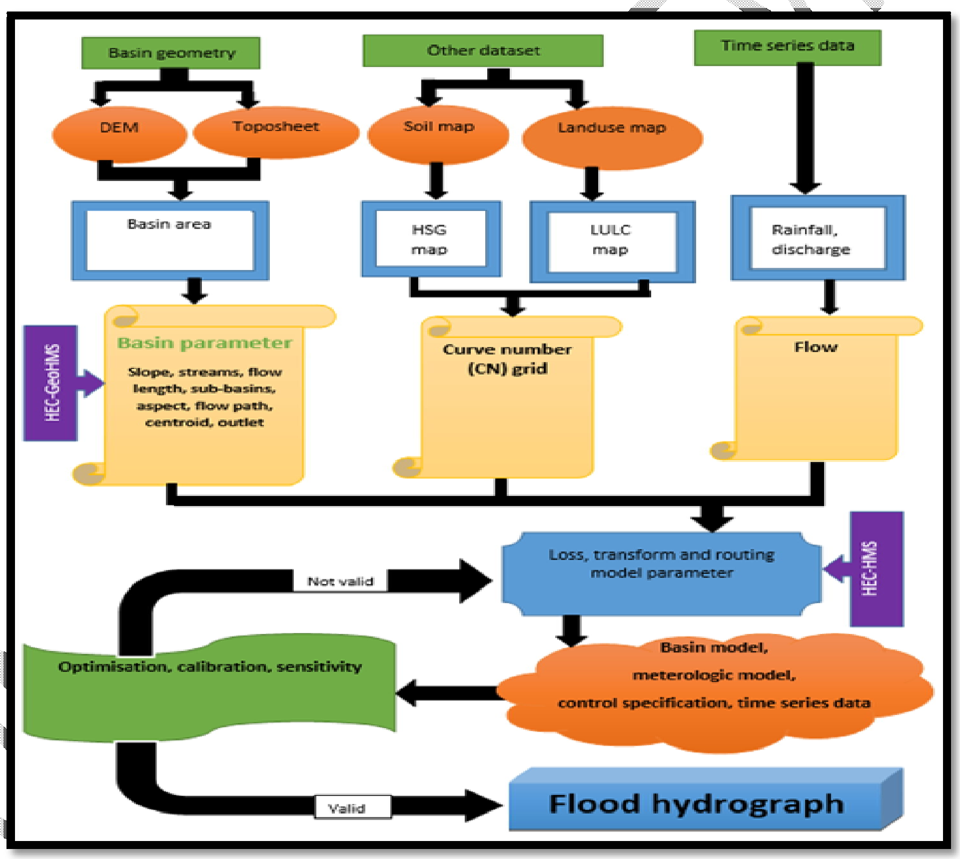

Fig. 2 HEC-HMS Flow Chart

Following are the significant steps of HEC-HMS methodology adopted in the present study:

- River basin was extracted from the DEM using HEC-GeoHMS tool in Arc-GIS.
- Metrological Model was created from rainfall data using HEC-GeoHMS
- Basin and metrological models are integrated in HEC-HMS

- Time-series rainfall data (precipitation) was inserted in HEC-HMS model
- Control specification to provide simulation data was then specified
- Simulation run of the model was performed by assimilating basin model, metrological model and control specification

3.1 HEC-HMS Model

3.1.1 Data processing

DEMs were generated from the data provided by the U. S. Geological Survey (USGS) website. The hydrologic models were generated with the help of HEC-GeoHMS software using DEM of the study area. The software assisted in creating the HEC-HMS basin model, meteorological model, control specification model, time series data file and background map file, which were done precursor to HEC-HMS model (Maidment and Djokic, 2000).Curve number for the loss model was obtained basically from the combination of Land Use and Land Cover(LULC) map and soil map in HEC-GeoHMS.

3.1.2 Model Setup

"HEC-HMS version 4.3 developed by the US Army Corps of Engineers was used to model the hydrologic processes for the watershed. Generally, the model contains a basin model, meteorological model, control specifications and time-series input data. The basin model depicted in Fig.3 represents the physical watershed with hydrological elements such as subbasins, junctions, reservoir and reaches" (U.S. Army Corps of Engineers, 2008).

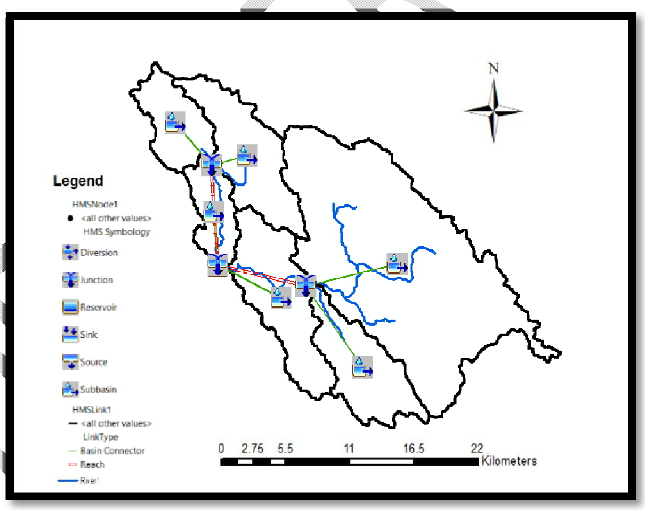

Fig. 3 HEC-HMS schematics of Meenachil sub basin

The basin model comprises 6 subbasins, 3 reaches, 3 junctions and 1 outlet. "The 30-m DEM was employed to calculate basin slope, drainage area and delineation of the watershed. The Soil Conservation Service (SCS) Curve Number method was used as the loss model in the study. The SCS Curve Number method can calculate the precipitation excess as a function of cumulative precipitation, soil cover, land use and antecedent moisture. The two parameters for the SCS Curve Number method required in the HEC-HMS model are the curve number and impervious percentages (%). The SCS Curve Number method implements the curve number methodology for incremental losses. The program calculates incremental rainfall during a storm by recalculating the infiltration at the end of each time interval"(U.S. Army Corps of Engineers, 2008). Hence SCS Unit hydrograph method was used to simulate transformation of rainfall to direct runoff as Soil Conservation Service (SCS) proposed this predominant, dimensionless, parametric single-peaked unit hydrograph for rainfall-runoff estimation. For reaches, the Muskingum method is employed as the routing method One of the most well-liked and user-friendly routing techniques is the Muskingum method, which is based on the conservation of mass and the diffusion representation of the conservation of momentum.

3.1.3 Model Calibration and Validation

The model calibration was attained by adjusting the parameter values until the results matched with the observed data. Calibration process helps in making the simulated discharge data in match with the observed discharge data in terms of peak value, shape of the curve and time of peak, while keeping modifications of the parameters in a reasonable range. The process was completed either by repeated manual adjustment of the parameters, computation and inspecting goodness of fit between the computed and observed hydrographs or automatically by using the iterative calibration procedure called optimization. Objective goal of optimization was minimisation of the difference between computed and observed discharge. ‘First lag auto correlation statistics’ was used to maintain this minimisation function of the analysis. Optimization trials were implemented to improve calibration results.

Peak-Weighted RMS Error and Simplex methods were used to reduce the objective function values. Nash–Sutcliffe model efficiency (E) was used to check how well the simulated hydrograph matched with the observed hydrograph. The value of E can range from $-\infty$ to 1. If E is equal to 1, the simulated hydrograph matches perfectly with the observed hydrograph (Nash and Sutcliffe, 1970). Moreover, peak streamflow, peak time, and flood volume are also examined to assess the calibration and validation results.

Daily rainfall and discharge(streamflow) data from year 2013 to 2016 were used for model calibration whereas the data from year 2017 to 2018 were used for validation. The same parameters, obtained after calibration, were used for validation and thus the flood hydrographs of the catchment were generated. Using the fine-tuned parameters in the calibration process, the model was validated. The overall simulation was started from 1^{st} Jan 2013 to 31^{st} Dec 2018 with a time interval of 24 hr, for the calibration and validation purpose. The floods in 2018 were the largest flood event among the various flood events in the streamflow record of 100 years from the discharge gauging station. The major flood events helped in examining the model performance as well in making the simulation more reliable one during high rainfall periods.

4. RESULTS AND DISCUSSION

4.1 HEC-HMS model input data preparation

The different input data for the HEC-HMS model setup for flood modelling study in the sub basin of Meenachil river included Digital Elevation Model (DEM), rainfall data, stream flow data, soil type and land use/land cover (LULC) data. The input data files were prepared using HEC-GeoHMS, ERDAS Imagine and ArcGIS 10.3. The spatial distribution of land use/ land cover of the watershed was prepared using Landsat 8 as shown in Fig. 4.

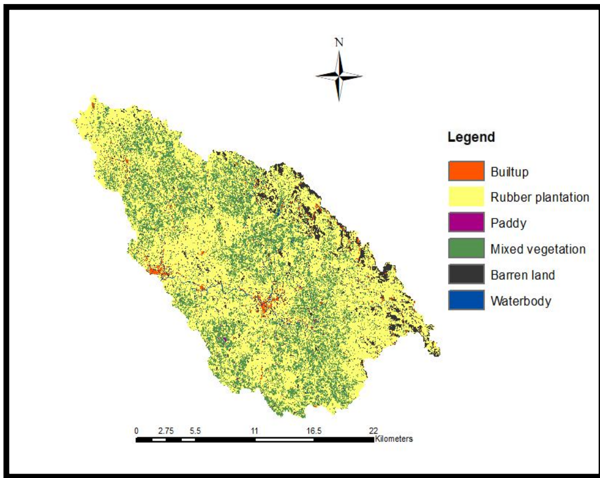

Fig. 4 Land use /land cover map of Meenachil sub basin

Hydrological elements, their connectivity and related geographical details were included in the basin model. It represents the physical watershed of Meenachil sub basin and is displayed in Fig. 5**.**

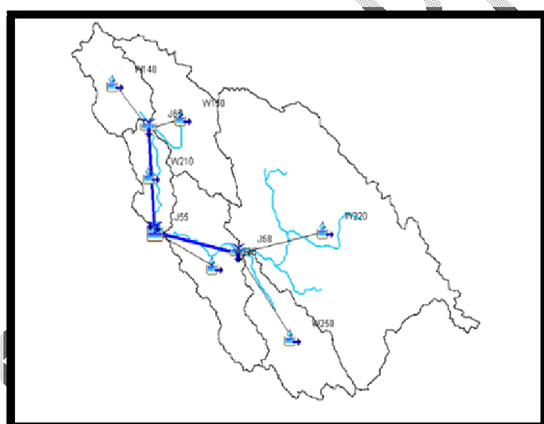

Fig. 5 Basin model of Meenachil sub basin in HEC-HMS

The various parameters of sub basin and reach elements such as initial abstraction (I_a), curve number (CN), lag time (LT), CN scale factor, I_a scale factor, Muskingum k and Muskingum x were estimated automatically using optimisation trials. The NSE values increased as expected when using the optimised parameters. It was seen that the optimised value produced a hydrograph that was nearly identical to the one that had been observed. As a result, optimum parameter values were used for accurate simulation and model calibration. The initial and optimized parameter values for different sub-watershed named W230, W220, W210, W150, W250 and W140 of Meenachil subbasin are shown in Table 2, where 'I' represents the initial parameter and 'O' represents the optimised parameter.

S.No	**Parameter**	**Sub-Watershed**											
		W230		**W220**		**W210**		**W150**		**W250**		**W140**	
		I	**O**	**I**	**O**	**I**	**O**	**I**	**O**	**I**	**O**	**I**	**O**

1	CN	75.88	79.93	61.46	65.73	68.93	66.28	69.98	64.84	71.46	74.10	78.70	71.46
2	I_a (mm)	16.00	16.15	11.86	31.87	12.89	22.89	11.70	21.79	10.29	20.29	13.75	13.75
3	LT (min)	1636.3	564.4	4456.2	3678.6	1446.5	1625.9	1832.8	1544.7	2964.3	307.8	1963.3	208.27
4	CN scale factor	0.24		0.24		0.24		0.24		0.24		0.24	
5	I_a scale factor (mm)	1.03		1.03		1.03		1.03		1.03		1.03	
6	Muskingum k (hr)	0.37		0.37		0.37		0.37		0.37		0.37	
7	Muskingum x	0.29		0.29		0.29		0.29		0.29		0.29	

Table 2 Initial and optimised parameter values for different sub-watersheds

Figure 6 displays the hydrograph plot of the observed flow and the simulated outflow during the calibration period. The graph demonstrated that the simulated and observed hydrographs trended quite similarly in all of the calibration period's years—2013, 2014, 2015, and 2016.

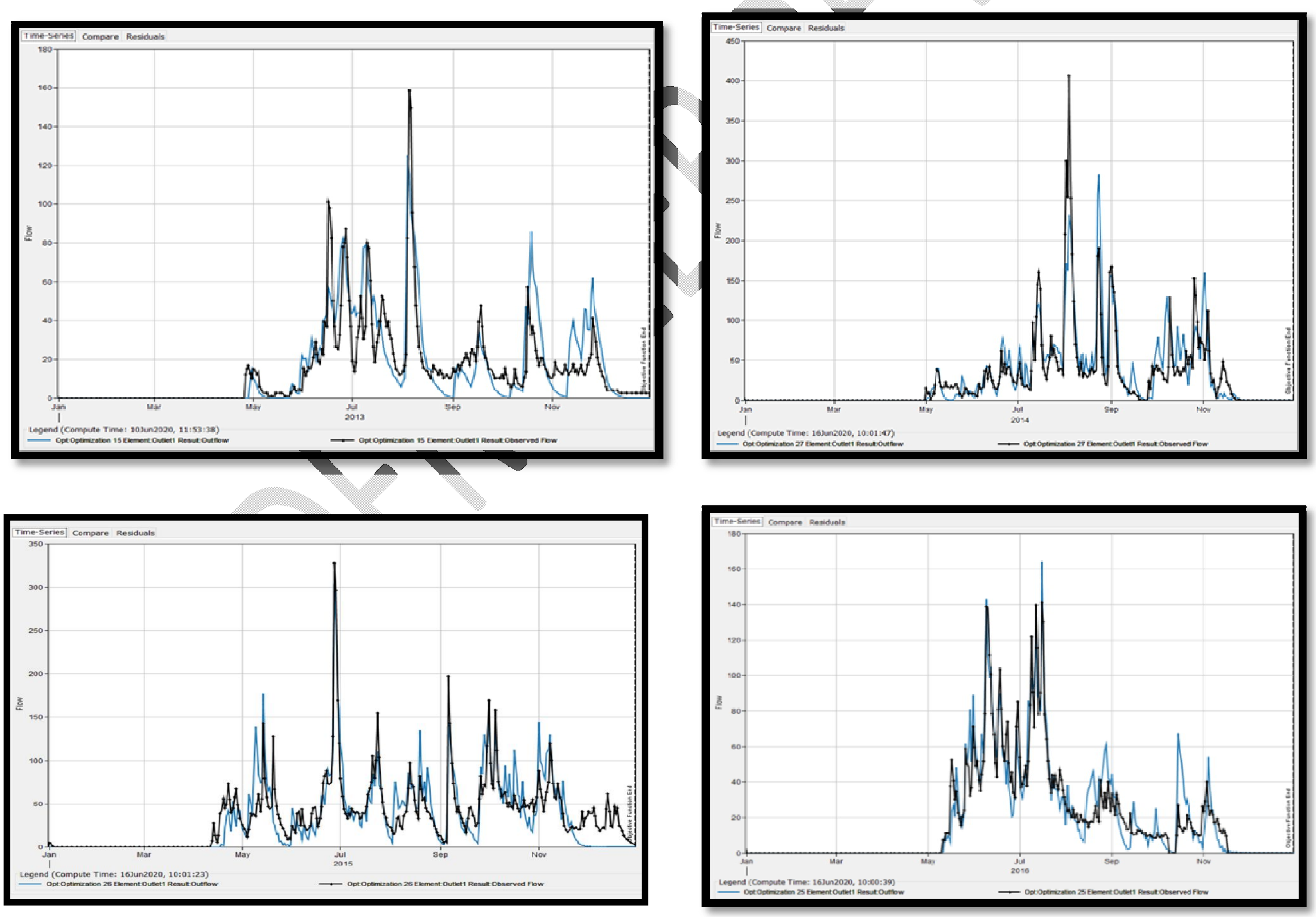

Fig. 6 Simulated and observed hydrograph during calibration period

The graphical comparison of simulated and observed hydrograph during the validation period (in the year 2017 and 2018) at the outlet is presented in Fig 7. There appeared a similarity in the trend of simulated and observed hydrograph for relatively longer duration of storms. It was also found that simulated values were near to observed value.

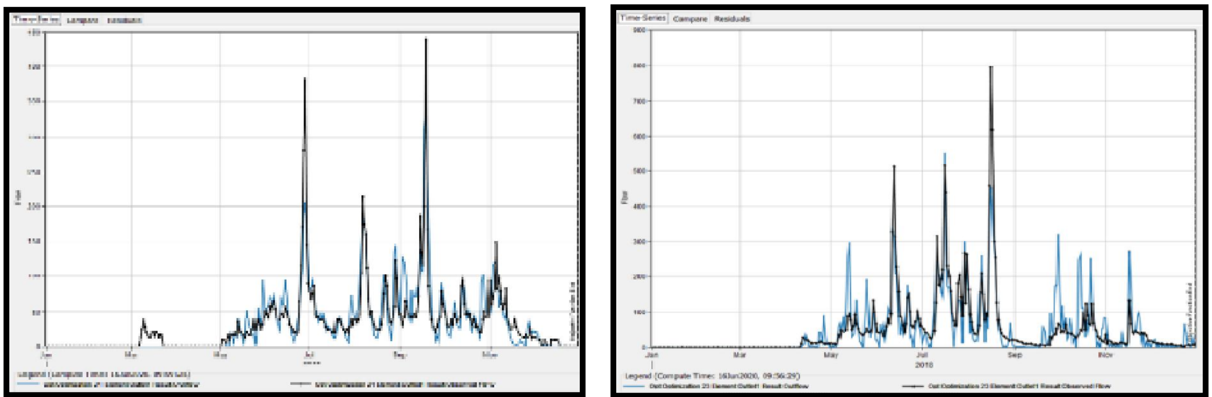

Fig. 7 Simulated and observed hydrograph during validation period

The maximum peak discharge was shown in the year 2014 during the calibration period with a peak flow of 406.2 m^3/s. At some points, it was also visible that the peak of the hydrographs of calibrated one was not matching with the peak of observed hydrographs. This might be due to the changes in watershed physical parameters from time to time and point to point in the drainage area. Moreover, in summer season, only base flow might have been contributed to the discharge at outlet when there was no or least precipitation occurrence over the watershed. But in monsoon season, the maximum precipitation that fell over the watershed created high discharge at the outlet, which caused the situation of flood in the catchment.

In addition, initial loss, imperviousness and curve number of the sub basin areas may also create some effect on the runoff in the watershed. Areas with more imperviousness lead to reduced infiltration and thereby surface runoff was increased in some part of the catchment. This made an effect in volume of discharge, peak discharge and time of attaining peak discharge. Increased imperviousness and curve number influenced the time of peak which eventually resulted in rise in peak discharge and volume. Thus, imperviousness of the basin showed high correlation with changes in hydrological indicators, time to peak, peak discharge and volume. In addition to these factors, the soil property of the catchment was highly clay mineral distributive; hence, larger volume of storm water drains into the streams quickly. However, the initial losses including interception loss and surface depressions reduced the surface runoff at some stages of flow because of more resistance caused in flow path and the availability of more infiltration opportunity time for initial loss. Performance indices of the model during calibration are shown in Table 3.

S.N.	Year	Nash Sutcliffe Efficiency (NSE)	Error in Peak Flow (%)	Error in Volume (%)	Coefficient of correlation (R^2)	Root mean square error-standard deviation ratio (RSR)

1	2013	0.725	6.50	-7.12	0.7410	0.5
2	2014	0.751	-30.4	8.14	0.7591	0.5
3	2015	0.708	-7.30	-5.56	0.7569	0.5
4	2016	0.868	16.40	2.21	0.8755	0.4

Table 3 Performance indices of the model during calibration

The maximum peak discharge occurred between July and September in validation period which was about 795.3 m³/s that represented the 2018 Kerala flood. After accounting for all losses, the total volume discharged from the watershed was calculated inorder to estimate the volumetric error. It was discovered that the calibrated discharge volume was within 20% of the total volume of the accessible range of the observed discharge volume. It was likewise in the permitted range, as indicated by the RSR value being less than 0.5. Furthermore, a good NSE value for the validation period was obtained. Table 4 displays the model's performance measures during validation.

S.N.	Year	Nash Sutcliffe Efficiency (NSE)	Error in Peak Flow (%)	Error in Volume (%)	Coefficient of correlation (R^2)	Root mean square error-standard deviation ratio (RSR)
1	2017	0.776	12.3	2.10	0.7867	0.5
2	2018	0.708	-20	0.51	0.7115	0.5

Table 4 Performance indices of the model during validation

The scatter plot of observed vs simulated flow during calibration and validation indicating the R^2 value are shown in Fig. 8 and 9

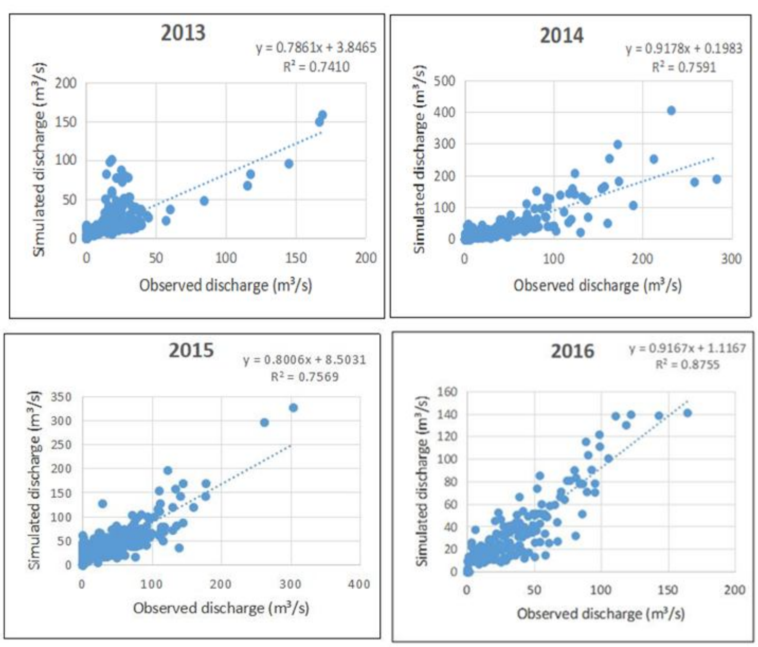

Fig. 8 Scatter plot of observed vs simulated flow during calibration

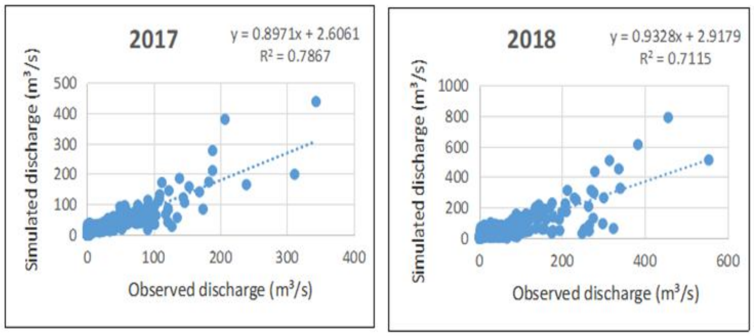

Fig. 9 Scatter plot of observed vs simulated flow during validation

During the entire period of simulation (2013-2018), the highest volume of flow was seen in the year 2018 with 1482.385 Mm^3 (Million m^3)as simulated one and 1474.842 Mm^3 as observed one which were the values corresponding to 2018 Kerala flood. Similarly, lowest volume of flow was seen in the year 2013 with 418.394 Mm^3 as simulated and 450.455 Mm^3 as observed. The highest peak flow of river was found during the year 2018 and it was predicted as 552.5 m^3/s and observed as 795.3 m^3/s. The model was calibrated using the CNs because it altered with changing rainfall (Kovar, 1990) which may be one of the reason for the unforeseen changes occurred in the watershed. The diversity of events, ideally encompassing a range of flood sizes (Wollongong City Council, 2015) can be another reason for the small deviation between simulated and observed values. It was the rarest flood peak event of 2018 Kerala flood. The lowest peak flow of river was found during the year 2013 and it was predicted as 168.9 m^3/s and observed as 158.5 m^3/s. Overall, it was found that all observed and simulated values of all the measures shown in the table depicted were inclose agreement between them. This similarity of trend inferred the better accuracy of the model for simulating the stream flow in Meenachil sub basin. Comparison of different measures of flow such as observed and simulated peak flow, volume and time of peak for Meenachil sub basin are also shown in the Table 5.

Measure	Simulated	Observed	Year	Time of peak
Peak flow (m^3/sec)	168.9	158.5	2013	5 Aug 2013
Volume (M m^3)	418.3944	450.4555		
Peak flow (m^3/sec)	382.8	406.2	2014	24 Aug 2014
Volume (M m^3)	871.0372	805.4446		
Peak flow (m^3/sec)	303.4	327.2	2015	27 Jun 2015
Volume (M m^3)	1040.6423	1101.8583		
Peak flow (m^3/sec)	164.3	141.1	2016	16 Jul 2016
Volume (M m^3)	573.6673	561.2699		
Peak flow (m^3/sec)	342.5	440.6	2017	18 Sep 2017

Volume (M m³)	1001.8950	981.2999		
Peak flow (m³/sec)	552.5	795.3	2018	16 Aug 2018
Volume (M m³)	1482.3850	1474.8428		

Table 5 Comparison of observed and simulated measures for the sub basin

5. CONCLUSIONS

HEC-HMS model simulated for the Meenachil river basin depicted that curve number, initial abstraction and lag time were the most sensitive parameters of the area. The loss rate parameters viz. curve number and initial abstraction were calibrated using SCS curve number model and the optimised values were obtained in the range between 61.46-79.93 mm and 10.29-31.87 mm respectively for the sub-watersheds. The SCS-UH model parameter, lag time was calibrated and the value was obtained between 208.27 min and 4456.2 min for the sub-watershed. It was also found that optimization of the parameters significantly improved the model performance in both calibration and validation period.

The observed and simulated hydrographs were found similar during calibration and validation for all the years. The simulated stream flow and the observed stream flow values indicated that the model is able to predict and present credible results for the sub-basin. The error in peak flow (%) and error in volume (%) were both less than 20 and the root mean square error-standard deviation ratio (RSR) was found to be 0.5 and lower, according to the statistical performance indices of the model. These numbers all showed that the model simulation performed satisfactorily during both the calibration and validation processes.

The better performance of model in rainfall-runoff transformation proved applicability of HEC-HMS model in the study area in spite of limited data availability. The findings in the present study are very useful for water resources engineers and researchers for efficient planning and management of water resources. These information are useful for policy makers to adopt suitable flood control measures and construct of structures which are important to protect the area from future floods.

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