ASSESSMENT OF DAILY SIMULATION OF RAINFALL RUNOFF USING HEC-HMS MODEL IN HEMAVATHI RIVER CATCHMENT, KARNATAKA

Ashwini B[1], Shivakumar J Nyamathi[2]

Research scholar, Department of Civil Engineering, UVCE, Bangalore University, Jnanabharathi Campus, Bengaluru, India[2]

Professor, Department of Civil Engineering, UVCE, Bangalore University, Jnanabharathi Campus, Bengaluru, India[2]

Abstract: Accurate estimation of surface runoff is vital for hydrological studies and water resources management. In the studies of extreme flood events, hydrologic modeling with computer models has drawn a lot of interest. This study applies the Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS), supported by the HEC-GeoHMS extension in ArcGIS, to simulate rainfall–runoff processes for the Hemavathi River catchment up to M.H. Halli gauging station in Karnataka. Digital Elevation Model (DEM), rainfall, evapotranspiration, and soil data were integrated for the model setup. The simple canopy and surface methods are used to calculate the interception losses, SCS curve number method is used to estimate the losses, SCS Unit Hydrograph transforms the rainfall into runoff, and the lag method is used to route the reach segments within the watershed. Calibration (1990–2011) and validation for two set of data (2012–2016), (2017-2021) against observed discharge data demonstrated reliable performance, with good correlation between simulated and observed flows. The findings highlight the potential of HEC-HMS for accurate hydrological simulation and its applicability in flood forecasting, water availability studies, and catchment management.

Keywords: Rainfall–runoff simulation, HEC-HMS, Hydrological modeling, Hemavathi River, Calibration, Validation.

1. INTRODUCTION

Estimation of surface runoff from precipitation is a fundamental task in hydrological studies, as it directly impacts on flood forecasting, water resources management, and ecological sustainability. The complexity of runoff processes requires robust modeling tools that incorporate watershed physical characteristics, including the topography and properties of the soil. The availability of suitable datasets and spatiotemporal variability of input parameters determines the complexity of a particular model. With advancements in remote sensing, GIS and open-source datasets, hydrological modeling has gained importance. HEC-HMS provides a flexible framework for simulating rainfall–runoff processes at different temporal and spatial scales and it is physical-based model that has several diverse advantages over other hydrological models, particularly in its applicability to varied hydrological problems and its adaptability to different environmental changes.

The present study focuses on applying HEC-HMS to the Hemavathi River catchment in Karnataka, India, the catchment supports for cultivation in the surrounding area and the river is useful for irrigation, drinking and other purposes. This study aims to generate the runoff hydrograph in the catchment with calibration and validation is performed against observed stream flow data. Estimating runoff hydrographs helps predict peak discharge and flood timings since the catchment is prone to seasonal rainfall, and it is vital for effective flood control, water resource management, infrastructure design, and environmental protection to ensure sustainable development of the region. The model selection for different components respectively for canopy, surface, loss, transform, routing are simple canopy, simple surface, SCS curve number, SCS unit hydrograph and lag methods used.

2. MATERIALS

2.1 Study Area

The study region covers the Hemavathi River catchment up to M.H. Halli gauging station, located in Hassan district, Karnataka having North Latitude of 12°49’08” and East Longitude of 76°08’00 is considered. Geographically, the study region is lies between 12°40’00” N to 13°20’00” N latitude and 75°30’00” E to 76°10’00” E longitude, covering an area of 3014 km² with a perimeter of 536 km. The Hemavathi River originates in the Western Ghats near Ballalarayanadurga at an elevation of about 1,219 meters and flows eastward through Hassan district before joining the Cauvery River. The catchment experiences significant monsoonal rainfall, making it hydrologically important for agriculture, water supply, and flood management. The location map of the study area is as shown in figure 1.

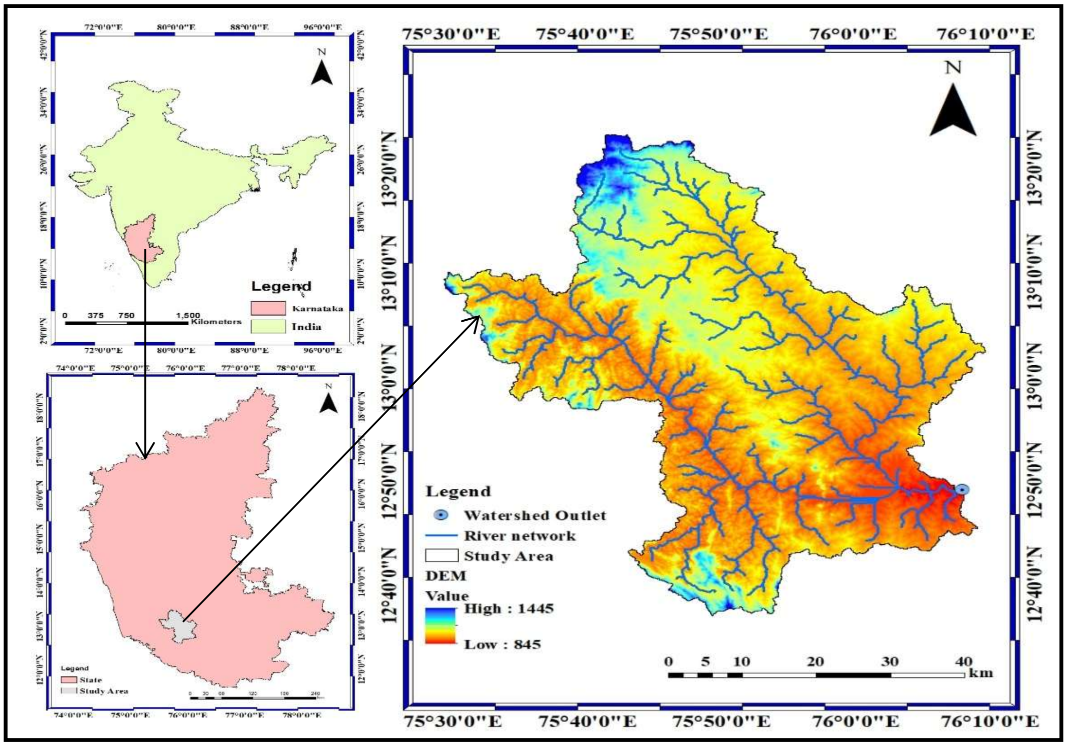


Figure 1. Location map of study area.

2.2 Data description

i) Digital Elevation Model (DEM): Shuttle Radar Topography Mission (SRTM) DEM is downloaded from USGS Earth Explorer. (https://earthexplorer.usgs.gov/) SRTM1N13E075V3, SRTM1N13E076V3, SRTM1N12E075V3, SRTM1N12E076V3 dated 23/09/2014, using these DEM, catchment is delineated in ArcGIS interphase.

ii) Rainfall data: For the present study daily rainfall data of the most influencing stations for the upstream Hemavathi river catchment is collected from Rainfall statistical department which covers the study region from the districts of Chikkamangalru, Hassan and Somvarpete for the period of 32 years (1990-2021). The locations of forty three rain gauge stations which cover the study area are as shown in figure 2, and the missing data is analysed using HEC-DSSVue which is developed by U.S. Army Engineer Hydrologic Engineering Center and corrected data is used.

iii) Evapotranspiration Data: Daily evapotranspiration data for the period of 1990-2021 is acquired from Nasa Power data access viewer (https://power.larc.nasa.gov/data-access-viewer/).

iv) Stream flow Data: Daily discharge data of M H Halli Gauging station (watershed outlet) for the specified period is obtained from India-WRIS portal (https://indiawris.gov.in/wris/#/timeseriesdata), the missing data is analysed using HEC-DSSVue which is developed by U.S. Army Corps Engineer Hydrologic Engineering Center and corrected data is used for both calibration and validation of the study.

v) Soil Data: Collected from National Bureau of Soil Survey and Land Use Planning-NBSS & LUP (https://nbsslup.icar.gov.in/) as presented in figure 3 and curve number map is prepared in ArcGIS.

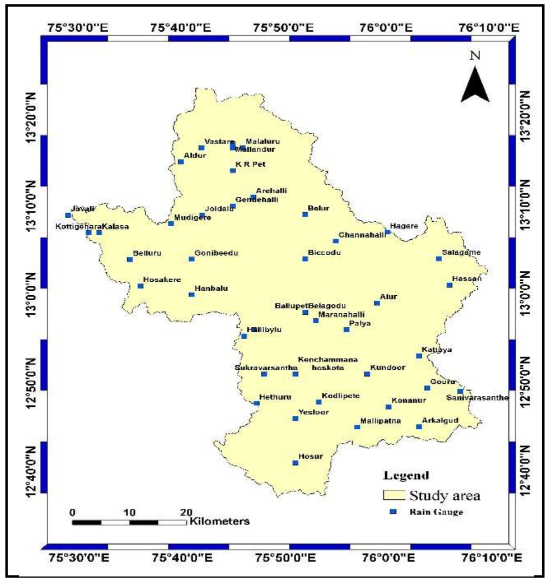


Figure 2. Location map of Rain gauge map

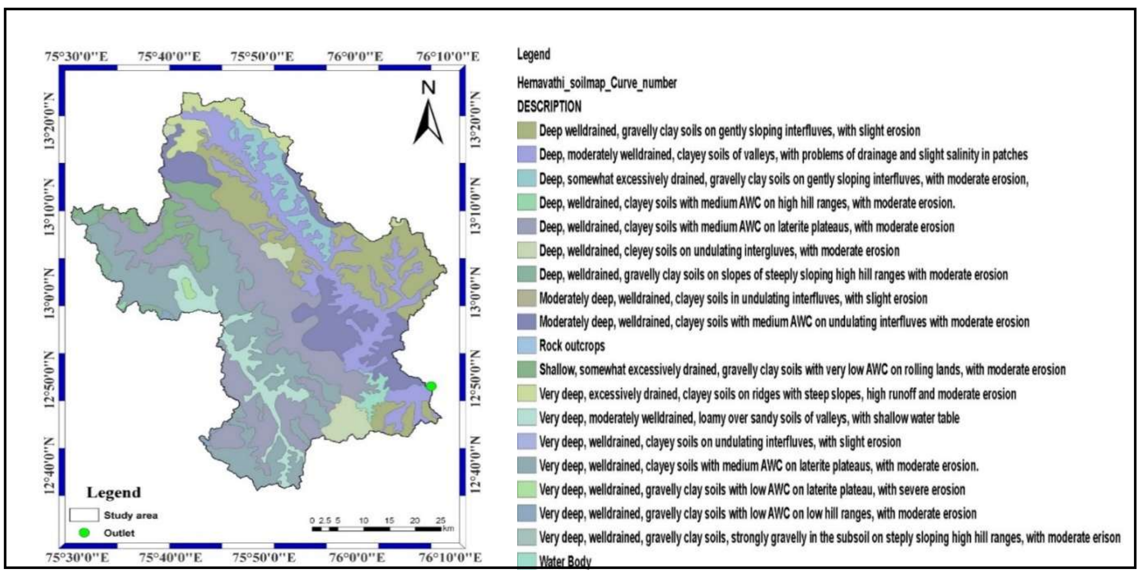


Figure 3. Soil map of study area

3. METHODOLOGY

3.1 Model Setup- Using the SRTM DEM, DEM pre-processing was carried out, including sink filling, flow direction, and flow accumulation analysis and terrain parameters such as flow direction, flow accumulation, and stream definition are derived. From these analyses, slope maps and catchment boundaries are extracted to establish the spatial framework of the basin. Hydrological properties are quantified, including basin delineation, longest flow path, and river network extraction. Basin geometric characteristics such as length, slope, centroid, and drainage density are computed to define hydrological response units. LULC and soil data are integrated to generate the Curve Number (CN) Grid, which governs runoff potential. By adding rain gauge stations, met stations were created, thiessen polygon was executed in order to find out the thiessen gauge weights which are required for the study and HydroID was assigned. Loss, transform, and routing parameters are estimated from these layers to characterize infiltration, surface runoff generation, and channel flow. The basin is subdivided into hydrological units (sub-basins, reaches, reservoirs, junctions, and outlets) using HEC-Geo HMS in ArcGIS platform. These units are represented in the HEC-HMS environment to create a digital replica of the physical watershed.

3.2 HEC HMS Model- Time series data of rainfall, evapotranspiration, and discharge are fed into the HEC-HMS model. Model components include meteorological input, basin configuration, control specifications, and time-step management. HEC-HMS simulates rainfall–runoff processes to produce runoff hydrographs at designated outlets. The results are analysed for peak discharge, runoff volume, and flow response characteristics. Simulated hydrographs are validated against observed discharge data from gauging station. Statistical performance indicators such as NSE, R^2, RMSE and percentage of bias are employed to assess model accuracy. Figure 4 indicates the model setup for the region under study.

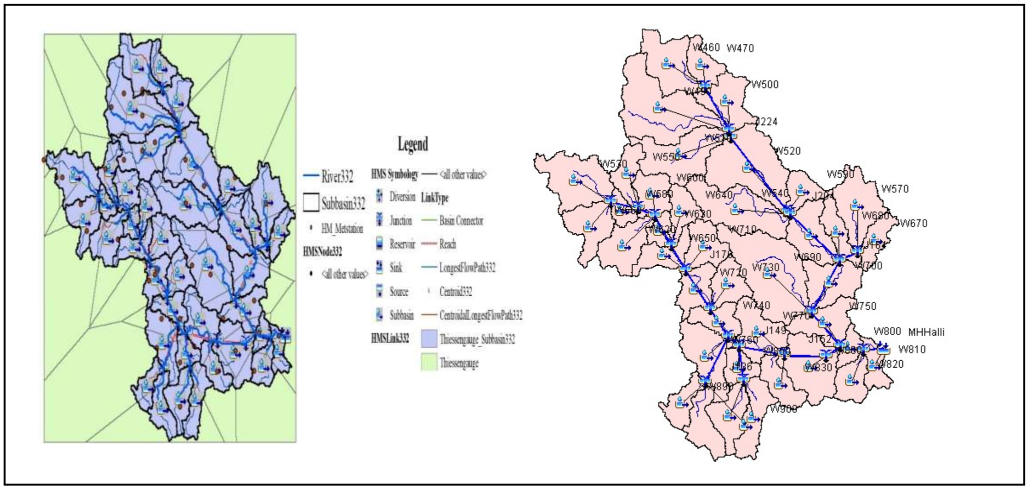


Figure 4. Model setup for the study area

The hydrological modeling framework involved several steps. DEM pre-processing was carried out, including sink filling, flow direction, and flow accumulation analysis. Catchment delineation and stream network generation were conducted using HEC-GeoHMS in ArcGIS. Basin characteristics such as slope, centroid, and river length were extracted. HEC-HMS basin and meteorological models were developed using precipitation, evapotranspiration, and discharge datasets.

The time of concentration required for the current work was determined using Kirpitch's formula.

$$T_c = \frac{1}{3000}\, x \left(\frac{L}{\sqrt{S}}\right)^{0.77} \tag{1}$$

Where, T_c = Time of concentration in hour, L =Length of river in meter, S = slope of the river, and L= Lag time is calculated using the formula

$$t_{lag} = 0.6T_c \tag{2}$$

where, t_{lag} = Lag time in hour.

3.3 Model performance assessment

Four selected statistical indicators were employed to evaluate the effectiveness of HEC HMS model: the root mean square error (RMSE), correlation coefficient (R^2), NSE, and Percentage Bias. Equation (3) to (6) is utilized for model performance analysis.

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left(Q_i^{sim} - Q_i^{obs}\right)^2}{n}} \tag{3}$$

$$R^2 = \frac{\sum_{i=1}^{n}(Q_{obs} - \overline{Q_{obs}})\,(Q_{sim} - \overline{Q_{sim}})}{\sqrt{\sum_{i=1}^{n}(Q_{obs} - \overline{Q_{obs}})^2}\sqrt{\sum_{i=1}^{n}(Q_{sim} - \overline{Q_{sim}})^2}} \tag{4}$$

$$\text{NSE} = 1 - \left[\frac{\sum_{i=1}^{n}(Q_i^{obs} - Q_i^{sim})^2}{\sum_{i=1}^{n}(Q_i^{obs} - \overline{Q_{obs}})^2}\right] \tag{5}$$

$$\text{PBIAS} = \left[\frac{\sum_{i=1}^{n}(Q_i^{obs} - Q_i^{sim}) * 100}{\sum_{i}^{n}(Y_i^{obs})}\right] \tag{6}$$

Where, Q_i^{sim} = Simulated discharge in cumecs.

$\overline{Q_{sim}}$ = Average simulated discharge in cumecs.

Q_{obs} = Observed discharge in cumecs.

$\overline{Q_{obs}}$ = Average observed discharge in cumecs.

n= Total number of years.

4. Results and Discussions

4.1 Calibration of the model

In Calibration and Validation of the Model, the Calibration is systematically optimizes the watershed parameters until the simulated hydrograph matches the observed hydrograph. The observed dataset from 1990 to 2010 was selected for the purpose of calibration and the time period from 2011 and 2016 and from 2017-2021 is selected for validation. The model parameter values were altered to get a satisfactory relationship among the observed and the modeled stream flows. The values obtained during the hydrologic parameter estimation process during the pre-processing are used as the initial estimates of the model. These are altered by trial-and-error process to get the optimum values of the model parameters. The calibrated model is applied to validate its performance with a new set of rainfall data for the period from 2011 and 2016 and from 2017-2021. The daily stream flow data at the catchment outlet point is plotted as displayed in figure 5.

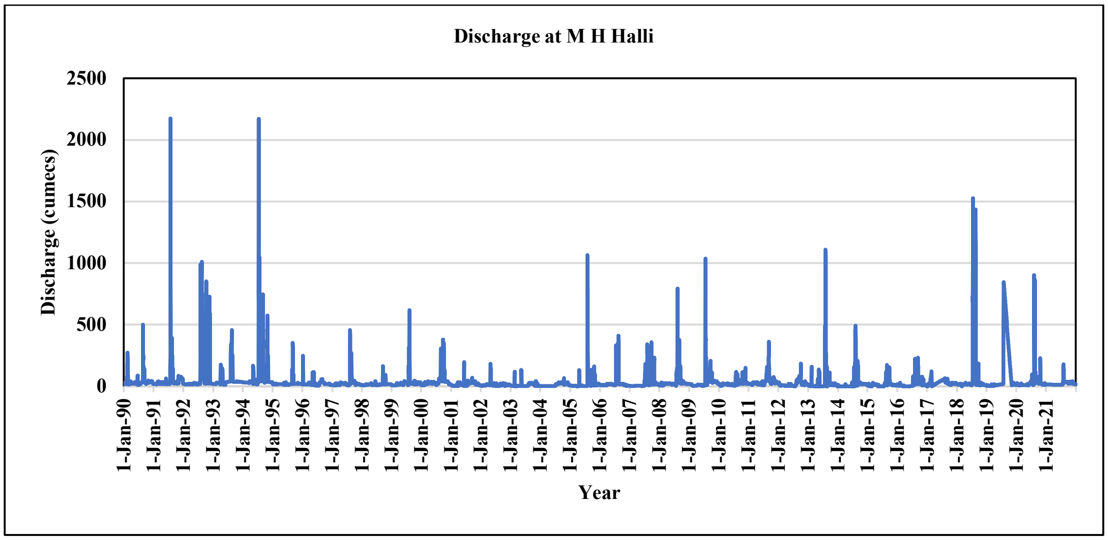
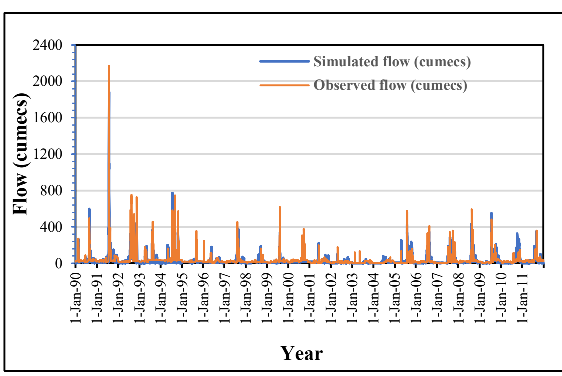


Figure 5. Daily measured flow rate at watershed outlet.

Calibration of the model (1990-2011)



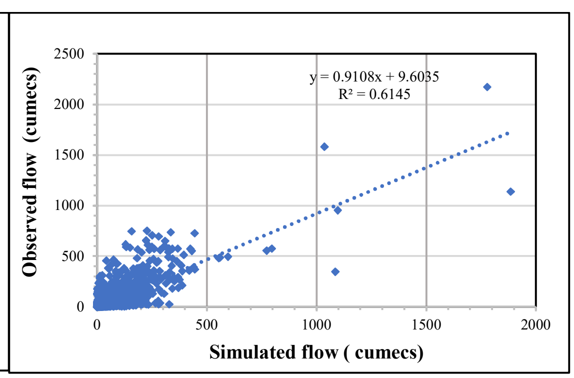


Figure 6. Flow comparison graph of calibration (1990-2011) **Figure 7. Scattered plot of co-efficient of determination**

Flow comparison graph of calibration for the period 1990-2011 is as shown in figure 6 and scattered plot of co-efficient of determination is as shown in figure 7. The Model performance results before and after calibration for the calibrated period is tabulated in table 1 and table 2 respectively.

Table 1. Model performance before calibration

Calibration period 1990-2011	
Simulated peak discharge	823.6 (m^3/s)
Date of simulated peak discharge	30/07/1991
Observed Peak Discharge	2172 (m^3/s)
Date of Observed Peak discharge	28/07/1991
RMSE standard Deviation	0.9
R^2	0.483
Nash-Sutcliffe Co-efficient	0.303
Percentage Bias	-21.56%

Table 2. Model performance after calibration

Calibration period 1990-2011	
Simulated peak discharge	1885.60 (m^3/s)
Date of simulated peak discharge	27/07/1991
Observed Peak Discharge	2172 (m^3/s)
Date of Observed Peak discharge	28/07/1991
RMSE standard Deviation	0.6
R^2	0.6145
Nash-Sutcliffe Co-efficient	0.638
Percentage Bias	-22.87%

From the above table 2, it is clear that RMSE, R^2, NSE and Percentage bias shows the good results with respect to the standard rating scale. The calibration was done by optimization, after calibration in simple canopy method, crop coefficient varies from 0.8-1.2 and in surface component initial storage is 0mm and maximum storage varies from 50-80mm. Further, SCS curve number in the sub basins watersheds varies form to 58-98 and percentage of imperviousness varies from 60%-90% depending upon type of land. The most sensitive parameters are SCS unit hydrograph lag time and river routing lag time.

4.2 Validation of the model (2012-2016) and (2017-2021)

The hydrological modeling of a watershed requires the identification of sensitive model parameters. Before model calibration, the HEC-HMS simulations are carried out using the initial estimates obtained during the hydrological parameter estimation process using HEC-Geo HMS tool in ArcGIS. Although the model initial performance was unsatisfactory, it was evaluated in terms of hydrograph visualization. In order to enhance performance, the model parameters were adjusted. The most sensitive basin parameters were determined to be time of concentration (Tc), storage coefficient, constant loss rate, and lag time. Their values demonstrated a significant departure from the model's initial estimates.

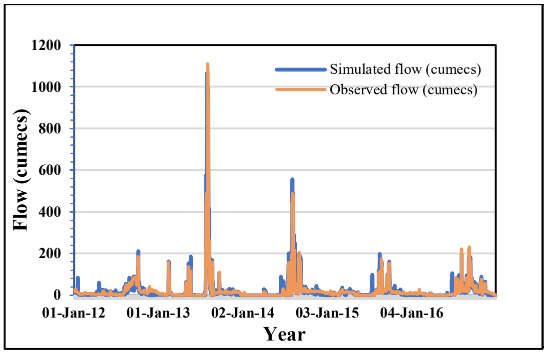


Figure 8. Flow comparison graph of validation (2012-2016)

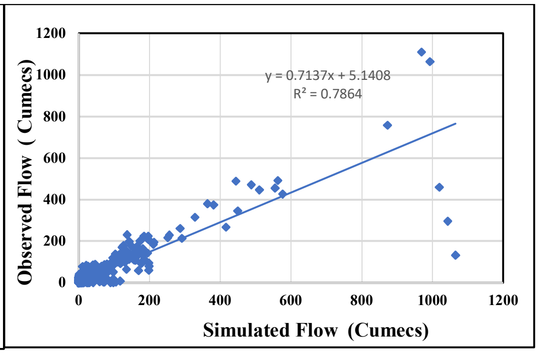
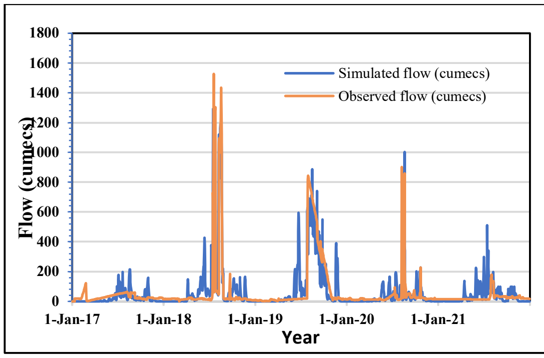


Figure 9. Scattered plot of co-efficient of determination

Figure 8 shows the flow comparison graph for the validation form 2012-2016, figure 9 shows the scattered plot of co-efficient of determination for the period 2012-2016.



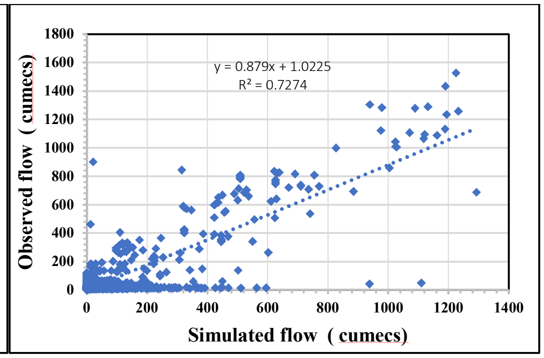


Fig.10-Flow comparison graph of validation (2017-2021)

Fig.11-Scatered plot of co-efficient of determination

Figure 10 indicates the flow comparison graph of validation for 2017-2021 and figure 11 shows scattered plot of co-efficient of determination for the period 2017-2021.

Table 3-Model performance for validation (2012-2016)

Validation for the period 2012-2016	
Simulated peak discharge	1065.06 m^3/s
Date of simulated peak discharge	30/07/ 2013
Observed Peak Discharge	1110.00 m^3/s
Date of Observed Peak discharge	02/08/ 2013
RMSE standard Deviation	0.58
R^2	0.7894
Nash-Sutcliffe Co-efficient	0.659
Percentage Bias	-10.07%

Table 4-Model performance for validation (2017-2021)

Validation for the period 2017-2021	
Simulated peak discharge	1292.80 m^3/s
Date of simulated peak discharge	17/07/2018
Observed Peak Discharge	1526.10 m^3/s
Date of Observed Peak discharge	19/07/ 2018
RMSE standard Deviation	0.57
R^2	0.7274
Nash-Sutcliffe Co-efficient	0.692
Percentage Bias	-11.86%

From the above table 3 indicates the results for model performance for validation for the period 2012-2016 and table 4 indicates the results for model performance for validation for the period 2017-2021, hence it is clear that it is clear that RMSE, R^2, NSE and Percentage bias shows the good results with respect to the standard rating scale.

5. CONCLUSIONS

In this study, evaluation of HEC-HMS is undertaken for simulation of runoff in the Hemavathi catchment. The finding reveals that RMSE, R^2, NSE and Percentage bias shows the good agreement with respect to the standard rating scale and the model could be implemented to produce very good results for different stretch periods. From the results and discussions it is clear that model predicted peak discharge accurately based on the available historical river gauge flow data and date of peak were also fairly accurate. The calibrated and validated models can be later used for future forecasts to simulate stream flows and the data sources used in this research can also be used for different hydrological studies such as flood assessments, stream restoration planning, and determining water availability by predicting stream flow under various conditions.

The outcomes have significant suggestions for water resource management, allocation, flood risk planning, and damage assessment. Future research could focus on hybrid modeling approaches that leverage the strengths of both HEC-HMS and ML models to enhance runoff predictions. Additionally, efforts should be made to improve the transparency and interpretability of ML models for better integration into decision-making processes within hydrological studies.

REFERENCES

Alrammahi, F. S., & Hamdan, A. N. A. (2022). Simulation of Rainfall-Runoff in the Diyala River Basin in Iraq using Hydrological Model by HMS with remote sensing, Geo-HMS and ArcGIS. *IOP Conference Series: Earth and Environmental Science*, *1120*(1). https://doi.org/10.1088/1755-1315/1120/1/012007.

Aqnouy, M., Ahmed, M., Ayele, G. T., Bouizrou, I., Bouadila, A., & Stitou El Messari, J. E. (2023). Comparison of Hydrological Platforms in Assessing Rainfall-Runoff Behavior in a Mediterranean Watershed of Northern Morocco. *Water (Switzerland)*, *15*(3), 1–18. https://doi.org/10.3390/w15030447.

Ashwini B. and Mamatha. 2019. Development of Geomorphological Instantaneous Unit Hydrograph – A Case Study of Hemavati Catchment. International Journal of Innovative Research in Science, Engineering and Technology. 8(3): 1973-1980.

Belayneh, A., Sintayehu, G., Gedam, K., & Muluken, T. (2020). Evaluation of satellite precipitation products using HEC-HMS model. *Modeling Earth Systems and Environment*, *6*(4), 2015–2032. https://doi.org/10.1007/s40808-020-00792-z.

Gelete, G., Nourani, V., Gokcekus, H., & Gichamo, T. (2023). Physical and artificial intelligence-based hybrid models for rainfall–runoff–sediment process modelling. *Hydrological Sciences Journal*, *68*(13), 1841–1863. https://doi.org/10.1080/02626667.2023.2241850.

Halwatura, D., & Najim, M. M. M. (2013). Application of the HEC-HMS model for runoff simulation in a tropical catchment. *Environmental Modelling and Software*, *46*, 155–162. https://doi.org/10.1016/j.envsoft.2013.03.006.

Hu, S., & Shrestha, P. (2020). Examine the impact of land use and land cover changes on peak discharges of a watershed in the midwestern United States using the HEC-HMS model. *Papers in Applied Geography*, *6*(2), 101–118. https://doi.org/10.1080/23754931.2020.1732447.

Janicka, E., Kanclerz, J., Agaj, T., & Gizińska, K. (2023). Comparison of Two Hydrological Models, the HEC-HMS and Nash Models, for Runoff Estimation in Michałówka River. *Sustainability (Switzerland)*, *15*(10). https://doi.org/10.3390/su15107959.

Koneti, S., Sunkara, S. L., & Roy, P. S. (2018). Hydrological modeling with respect to impact of land-use and land-cover change on the runoff dynamics in Godavari river basin using the HEC-HMS model. *ISPRS International Journal of Geo-Information*, *7*(6). https://doi.org/10.3390/ijgi7060206.

Mohanty, R. S., & Kumari, S. (2024). A physical-based semi-distributed continuous hydrological modelling for Brahmani River Basin, Eastern India. *International Journal of River Basin Management*, 1–13. https://doi.org/10.1080/15715124.2024.2366400.

Natarajan, S., & Radhakrishnan, N. (2019). Simulation of extreme event - based rainfall – runoff process of an urban catchment area using HEC - HMS. *Modeling Earth Systems and Environment*, *0123456789*. https://doi.org/10.1007/s40808-019-00644-5.

Rajput, A., Rawat, U., Yadav, A., Pawar, P. S., & Vasht, D. (2021). *Hydrological Modelling of Banjar River Watershed using HEC-HMS*. *10*(37), 81–90. https://doi.org/10.37273/chesci.CS205201275

Sanjay Shekar, N. C., & Vinay, D. C. (2021a). Performance of hec-hms and swat to simulate streamflow in the sub-humid tropical hemavathi catchment. *Journal of Water and Climate Change*, *12*(7), 3005–3017. https://doi.org/10.2166/wcc.2021.072.

Tibangayuka, N., Mulungu, D. M. M., & Izdori, F. (2022). Evaluating the performance of HBV, HEC-HMS and ANN models in simulating streamflow for a data scarce high-humid tropical catchment in Tanzania. *Hydrological Sciences Journal*, *67*(14), 2191–2204. https://doi.org/10.1080/02626667.2022.2137417.

Vemula, S., Raju, K. S., & Veena, S. S. (2020). *Modelling impact of future climate and land use land cover on flood vulnerability for policy support – Hyderabad , India*. 1–15. https://doi.org/10.2166/wp.2020.106.