Plant Archives Vol. 26, Supplement 1, 2026 pp. 50-55 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.supplement-1.008

A COMPREHENSIVE REVIEW ON HYDROLOGIC ENGINEERING CENTRE-HYDROLOGIC MODELLING SYSTEM (HEC-HMS)

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(Date of Receiving : 26-07-2025; Date of Acceptance : 16-10-2025)

ABSTRACT

Most hydrologic systems are extremely complex and we cannot hope to understand them in all detail. Therefore, abstraction is necessary if we are to understand or control some aspects of their behaviour. Catchment modelling helps to gain a better understanding of the hydrologic phenomena operating in a catchment and of how changes in the catchment may affect these phenomena. A hydrologic model is a simplification of a real-world system (e.g., surface water, soil water, wetland, groundwater, estuary) that aids in understanding, predicting, and managing water resources. Both the flow and quality of water are commonly studied using hydrologic models. The number of hydrological models has been evolved since many years for simulating runoff from the rainfall data. The HEC HMS (a Centre for Hydrological Engineering and Hydrological Modelling Systems introduced by the US Army Corps of Engineers) is a popularly used watershed model to simulate rainfall runoff process. The goal of the current paper is to analyse the studies that have been done on the HEC-HMS model globally to determine its accuracy in simulating runoff and its suitability for decision-making. From the reviewed literature it could be summarised that, model provided very good correlation between observed and simulated value of runoff and may be suitable for flood modelling and/or forecasting in the studied catchments.
Keywords: HEC-HMS, Rainfall–runoff modelling, Hydrological simulation, Water resources management, Streamflow simulation

Introduction

Measurement of accurate peak discharge and runoff volume in a watershed is a difficult task especially in the developing countries mainly due to limitations of having inadequate number of hydrometric stations and time and cost incurred in collecting hydrometric data from the low-order drainage streams that are the major areas of watershed-based operations and management (Tayfur and Singh, 2006). Thus, it is required to use hydrological models for estimating the peak discharge and runoff volume, which are based on the other indirect hydrological factors such as rainfall, land use/land cover, soil type, etc.

Rainfall-runoff models describe a portion of the water cycle. The movement of a fluid / water is explicitly or implicitly based on the laws of physics, and in particular on the principles of conservation of mass, conservation of energy and conservation of momentum. Depending on their complexity, models can also simulate the dynamics of water quality, ecosystems, and other dynamical systems related to water, therefore embedding laws of chemistry, ecology, social sciences and so forth. On account of Rainfall-Runoff modelling, a Rainfall-Runoff model is utilized to assess the unknown runoff data by utilizing the known precipitation information. There is the quantity of Rainfall-Runoff models is accessible, one of them is – HEC-HMS. This paper presents some reviews on work done by different analyst utilizing HEC-HMS Rainfall-Runoff model for representing rainfall runoff processes occurring over the basins.

HEC-HMS model

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) was designed as a part of the U.S. Army Corps of Engineers Hydrologic engineering Center’s Next Generation Software Development Project. It is designed for event-based as well as continuous hydrologic modeling. The Hydrologic Modeling System is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology and small urban or natural watershed runoff. Hydrographs produced by the program are 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.

History of HEC-HMS

The computation engine draws on over 30 years’ experience with hydrologic simulation software. Many algorithms from HEC-1 (HEC, 1998), HEC-1F (HEC, 1989), PRECIP (HEC, 1989), and HEC-IFH (HEC, 1992) have been modernized and combined with new algorithms to form a comprehensive library of simulation routines.

The initial program of HEC release was called Version 1.0 and included most of the event-simulation capabilities of the HEC-1 program. It did introduce several notable improvements over the legacy software including an unlimited number of hydrograph ordinates and gridded runoff representation. The second major release was called Version 2.0 and focused on continuous simulation. The addition of the soil moisture accounting method extended the program from an event-simulation package to one that could work equally well with event or continuous simulation applications. The reservoir element was also expanded to include physical descriptions for an outlet, spillway, and overflow. An overtopping dam failure option was also added.

The third major release was called Version 3.0 and introduced new computation features and a brand-new graphical user interface. The meteorologic model and basin model were enhanced by introducing some new methods. The new graphical user interface was designed to simplify creating and managing the many types of data needed for hydrologic simulation. The fourth major release was called version 4.0 and focused primarily on new computation features. A broad range of surface erosion and sediment transport features were added to the subbasin, reach, reservoir, and other elements. A preliminary capability was also added for nutrient water quality simulation. Finally, a new simulation component was added to facilitate real-time forecasting operations (HEC-HMS User’s Manual, 2022).

Case Studies of HEC-HMS in Rainfall–Runoff Modelling

Verma *et al*. (2010) computed rainfall runoff modelling utilizing the WEPP and HEC-HMS rainfall runoff model for the Upper Baitarani River basin of Eastern India. They utilized day to day observed rainfall discharge data from June to October for the year1999 to 2005. The GIS techniques and remote sensing were utilised for preparing slope map, soil map, LULC of the study area. The results uncovered that, for the year 1999, 2002, 2004 and 2005 the simulated streamflow was less than the observed stream flow and the simulated streamflow for the year 2003 and 2001 was higher than the observed stream flow for both WEPP and HEC-HMS. But in 2000, the simulated stream flow was lesser in case of HEC-HMS and was higher in case of WEPP. The calibration and validation results indicate that the stream flow computed using HEC-HMS was more acceptable than that estimated using WEPP. Hence, at last it was summarised that the HEC-HMS is better acceptable than WEPP for simulating discharge for Basin of Baitarani River.

Nandalal and Ratnayake (2010) performed the event-based modelling of a watershed using HEC-HMS for Kalu-Ganga River watershed having basin area 2658 km^2. Rainfall-runoff modelling for this basin was developed using HEC-HMS software. There are two different models, one model having four sub basins and the other model having ten sub basins. Initial and constant method was utilized for loss estimation, Clark's model method for transformation, Exponential Recession for base flow and both lag model and Muskingum model are used for routing because lag model is used for steeper reaches and Muskingum model is used for gradual slope. The results showed that HEC HMS software is suitable in modelling of the Kalu-Ganga watershed. Further it can be concluded that there is no impact of the number of sub basins considered in modelling the Kalu-Ganga River basin using HEC-HMS for flood prediction.

Kumar and Bhattacharjya (2011) simulated the rainfall-runoff process using of HEC-HMS (with both Distributed and Lumped modelling), remote sensing and GIS techniques for estimating infiltration parameters in the Ranganadi river basin of North-Eastern India. The required precipitation and stream flow data were collected for 3 years (2006-2008) together with topographic maps and DEM images of the study area. The input file for the proposed hydrologic models was prepared using remote sensing and GIS techniques. For simulating stream flow by the HEC-HMS model, the SCS unit hydrograph transform method was used to compute direct surface runoff hydrograph, the SCS curve number loss method was used to compute runoff volumes and the constant monthly method was used for base flow separation. Lumped and Distributed modelling was simulated and validated using the rainfall-stream flow data of May 2006 to May 2007, and rainfall-stream flow data of 2008 respectively. It was shown that the HEC-HMS distributed approach simulated daily stream flow better than the lumped simulated parameters and for simulating daily stream flow in the Ranganadi river basin.

Majidi and Shahedi (2012) performed rainfall-runoff modelling on the Abnama basin in Iran using the HEC-HMS model. Used Green-Ampt method was utilised for loss estimation and SCS unit hydrograph method was utilised for transforming excess rainfall into direct runoff Muskingum method was used for routing. Five rainstorm events were taken for the examination. Calibration, validation, and sensitivity analysis was finished. The connection of the observed and simulated discharge was discovered to be 0.89 which shows a solid match. It finished up the ability of the model for runoff simulation in the Abnana basin.

Asadi and Boustani (2013) conducted research on the Delibajak basin in Kohgoilpuye and Boyerahmad, Iran. They first measured the basin as a lumped and then divided it into sub-basins and then created a rainfall-runoff model for each case using the HEC-HMS model separately. The result was compared for both cases. The SCS-CN method was used as a loss method. Both models underwent calibration and validation and it was found that the semi-distributed model produces better results.

Kishor *et al.* (2014) simulated rainfall-runoff process using HEC-HMS model for Balijore Nala watershed. Estimation of accurate runoff for a given rainfall event is a difficult task due to various influencing factors. The model has been calibrated and validated for the 12 rainfall events. It was found that HEC-HMS model performed satisfactorily for the simulation runoff for the different rainfall events. The HEC-HMS model used for rainfall-runoff simulation in the selected watershed with RMSE as 0.09 and MARE as 0.06 for peak discharge and RMSE as 0.70 and MARE as 0.05 for runoff depth.

Sampath *et al.* (2015) performed continuous precipitation-discharge modelling using HEC-HMS for Deduru Oya river basin. The rainfall and discharge data in daily basis, with LULC and soil map the area research was utilized for the current research. The precipitation-excess was estimated using SMA method, while the discharge volume was computed using Clark UH model and recession model was utilized for base flow estimation. For the interval, from October to December 1985 the calibration was done. For period October 1984 to September 1985 and October 1987 to September 1989, the model validation was done. Hence, from the research, it is concluded that the HEC-HMS has enough potential for managing water in Deduru Oya river basin.

Singh and Jain (2015) utilised HEC-HMS hydrological model to setup a continuous model for Vamsadhara river basin which was divided into sub basins based on the topography and land use pattern. The soil moisture accounting technique was utilized for setting HEC-HMS model. The observed rainfall runoff data, from 1984 to 1989 was used for calibrating the model and model was verified using the observed data from 1990 to 1993.The Performance of the model during calibration was acceptable (with 0.71 coefficient of determination value and 0.70 as NSE value); likewise, the performance of the model during verification was also good (with R^2 0.78 and NSE 0.76). From the examination, it is concluded that the SMA method can be utilized to model streamflow in Vamsadhara river basin, India.

Hassan *et al.* (2017) assessed the applicability of RADARSAT-2-derived soil moisture data in HEC-HMS for flood forecasting with a case study in the Sturgeon Creek watershed in Manitoba, Canada. Soil moisture data from the Manitoba agriculture field survey and RADARSAT-2 satellite were used to set the initial soil moisture for the event simulations. The results confirm the benefit of using satellite data in capturing peak flows in a snowmelt event. A sensitivity analysis of SMA parameters, such as soil storage, maximum infiltration, soil percolation, maximum canopy storage and tension storage, was performed and ranked to determine which parameters have a significant impact on the performance of the model. The results showed that the soil moisture storage was the most sensitive parameter.

Derdour *et al.* (2018) utilised HEC-HMS hydrological model for simulated runoff in the Ksour Mountain's semi-arid area in Ain Sefra in South West

Algeria. The loss rate was estimated utilizing SCS-CN method and the runoff rate was estimated using SCS unit Hydrograph method. The computed peak discharge was exceptionally near the observed value during the calibration and validation of model.

Haibo *et al*. (2018) modelled the precipitation runoff process of Huan river basin of China for flood forecasting by utilizing the HEC-HMS and ArcGIS to extract watershed information as per Digital Elevation Model. The initial constant rate loss model was utilised to determine runoff volume, while the Synder unit line model was utilised to determine the direct runoff. Muskingum method was utilized for routing. The observed runoff data was used to calibrate and validate the developed model. The outcome demonstrated the satisfactory scope of coefficient of agreement and determination.

Shaikh *et al*. (2018) used HEC-HMS model to simulate the rainfall-runoff process in Rel watershed of Gujarat, India which is a sub-basin of lower Luni basin. The SCS curve number and SCS unit hydrograph methods were used to compute runoff and peak runoff rate. Rainfall-runoff simulation was conducted using data of one recent rainstorm event (July, 2017). Initial results showed that there was a large difference between observed and simulated peak flows. 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 was concluded that model developed could be used with a reasonable approximation for hydrologic simulation in watershed to predict runoff from a rainfall event.

Kishanlal *et al*. (2019) performed the rainfall-runoff modelling of Machhu river basin using HEC-HMS with using data of 12 rain gauge stations pertaining to 40 years period (1978-2017). Total runoff estimated for each year was correlated with the rainfall data by carrying out regression analysis. Results of the analysis indicate that coefficient of determination (R^2) was 0.85, suggest good correlation between observed rainfall and estimated runoff value. Performance of the model was also evaluated by regression analysis which gave R^2 0.89, indicate very good correlation between observed and simulated value of runoff. Results of HEC-HMS study were also used for the flood frequency analysis for the better watershed management.

Sarminingsih *et al*. (2019) has performed simulation of rainfall runoff process using HEC HMS model for the Garang Watershed, Semarang of Indonesia. They used SCS (Soil Conservation Service) unit hydrograph method for loss estimation, SCS's UH method for transformation, Exponential Recession for base flow and lag for routing. For the calibration, observational discharge data is utilized from the AWLR Kreo. HEC HMS 4.2 software is used. Basing the optimization analysis, hydrological parameter were obtained CN composite as 66.4, and the groundwater content is 128.48 mm, with Initial Abstraction as 25.7 mm and lastly the imperviousness is 9.27%. The validity of the model is quite satisfactory, from the correlation values, RMSE and Nash. It is concluded that the HEC-HMS model is good enough to be used to model rain-runoff in watershed.

Namara *et al*. (2020) utilised HEC-HMS for rainfall runoff modelling: a study of Awash Bello sub-catchment of upper Awash basin, Ethiopia. The loss rate was estimated utilizing SCS CN method and the runoff rate was estimated using SCS unit hydrograph method. The rainfall-runoff model has shown good performance during calibration and validation with Nash Sutcliffe efficiency coefficient 0.855, R^2 0.867 for calibration and Nash Sutcliffe efficiency coefficient as 0.739 and R^2 estimation of 0.863 for validation respectively. The peak flood from the model is 573.7m^3/s was compared with direct observed flow is 546.4m^3/s. It is concluded that HEC-HMS can be applicable for rainfall runoff modelling for the specified sub-catchment.

Hamdan *et al*. (2021) developed a HEC-HMS model and used it by means of the Geospatial Hydrologic Modelling Extension (HEC-GeoHMS) and Geographical Information Systems (GIS) to identify the discharge of the Al-Adhaim river catchment and embankment dam in Iraq. The meteorological models were developed within the HEC-HMS from the recorded daily rainfall data for the hydrological years 2015 to 2018. The control specifications were defined for the specified period and one day time step. The Soil Conservation Service-Curve number (SCS-CN), SCS Unit Hydrograph and Muskingum methods were used for loss, transformation and routing calculations, respectively. The model was simulated for two years for calibration and one year for verification of the daily rainfall values. The results showed that both observed and simulated hydrographs were highly correlated. The model's performance was evaluated using a coefficient of determination of 90% for calibration and verification. The dam's discharge for the considered period was successfully simulated but slightly overestimated. The results indicated that the model is suitable for hydrological simulations in the Al-Adhaim river catchment.

Helder Guta (2021) evaluated the suitability of HEC-HMS to simulate event-based rainfall-runoff in the catchments of Revubue in Mozambique and Ardeche in France. Despite the low mean discharges in both rivers, it is common to observe floods in certain periods (October – January). The hydrologic models were calibrated and verified based on observed (historical) precipitation and runoff data. Availability of reliable hydrologic data remains an important issue in Mozambique. The study highlighted some limitations imposed by the scarcity and lower resolution of hydrological data in Mozambique. Despite the difficulties related to the unsatisfactory quality of the data in Revubue basin, it was found that the model performs relatively well in terms of time and magnitude of peak flows of the studied flood events. The good performance suggest that HEC-HMS may be suitable for flood modelling and/or forecasting in the studied catchments.

Conclusions

This review demonstrates that HEC-HMS is a technically robust and operationally versatile tool for rainfall–runoff modelling across diverse hydroclimatic and physiographic settings. Through integration with GIS and remote sensing, HEC-HMS enables refined representation of watershed inputs, enhancing the accuracy of streamflow simulation, peak discharge estimation, and hydrograph timing. Evidence from multiple studies indicates that both lumped and distributed model structures can be effectively tailored, with distributed approaches generally offering superior performance in spatially heterogeneous basins. Results from multiple basins validate the model's competence in capturing the magnitude, volume, and timing of floods. This capability is crucial for issuing early warnings, designing hydraulic structures, planning reservoir operations, and developing adaptation measures under climate variability. Adoption of advanced input data, particularly satellite-derived soil moisture, has further strengthened the model's predictive capability in flood forecasting and water resource management. Consistently favourable statistical metrics including NSE, R^2, and RMSE underline the reliability of HEC-HMS, even under varying data availability.

Overall, HEC-HMS emerges as an indispensable tool in flood risk management, early warning system design, and sustainable watershed planning. Its flexible structure, capability for calibration and sensitivity analysis, and proven global applications highlight its significance in hydrological modelling. Continued integration of emerging data sources and computational techniques will expand its applicability in dynamic and data-scarce environments. Future advancements involving high-resolution remote sensing, improved rainfall datasets, and machine learning-based parameter optimization are expected to further enhance predictive skill and operational efficiency in flood risk reduction and sustainable watershed management.

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