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A comprehensive review on rainfall-runoff modelling using HEC-HMS

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Abstract

Rainfall-runoff modeling is fundamental to understanding hydrological behavior, flood forecasting, and watershed management. The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) has been widely applied worldwide due to its modular flexibility and adaptability to varying spatial and climatic conditions. This review synthesizes various national and international studies conducted that implemented HEC-HMS for event-based and continuous rainfall-runoff simulations. The review focuses on the methodologies employed—loss estimation, transform computation, baseflow modeling, and channel routing—and their performance in calibration and validation. The findings reveal that the Soil Conservation Service Curve Number (SCS-CN) and SCS Unit Hydrograph (SCS-UH) methods remain dominant due to simplicity and reliability. Muskingum and recession methods are the most adopted for flow routing and baseflow, respectively. Calibration and validation commonly employ statistical indicators such as Nash-Sutcliffe Efficiency (NSE), Coefficient of Determination (R^2), and Root Mean Square Error (RMSE). Overall, studies demonstrate that HEC-HMS effectively simulates hydrological responses even in data-limited regions, particularly when combined with GIS, remote sensing, and parameter optimization techniques.

Keywords: Rainfall-runoff modeling, HEC-HMS, watershed hydrology, model calibration, hydrologic simulation

1. Introduction

Rainfall-runoff modeling is central to hydrological studies and plays a key role in watershed management, flood forecasting, and water resources planning. The HEC-HMS model, developed by the U.S. Army Corps of Engineers, provides a conceptual framework that enables the simulation of surface runoff generation and streamflow routing under different hydrological conditions. Its modular structure allows users to select appropriate physical representations of hydrological processes, such as infiltration, transformation, baseflow, and channel routing, according to data availability and basin characteristics (Verma *et al.*, 2010; Fanta and Feyissa, 2021)^[43, 10].

Over the past decade, numerous studies have applied HEC-HMS across diverse climatic and geographic regions including India, Ethiopia, Vietnam, Malaysia, Morocco, and Greece (Anh and Canh, 2013; Bunganaen *et al.*, 2021; Frysali *et al.*, 2023)^[1, 5, 11]. The model's versatility has been demonstrated for both gauged and ungauged watersheds, arid and humid environments, and small to large river basins. The objective of this review is to consolidate the methodological frameworks, calibration strategies, and performance evaluations used HEC-HMS applications to highlight the best-performing techniques and identify global trends in hydrological modeling.

2. Methodology of Review

The review compiled and analyzed various national and international studies that applied HEC-HMS for rainfall-runoff modeling. The papers were retrieved from peer-reviewed journals and conference proceedings. Each study was reviewed for key modeling parameters, including loss, transform, baseflow, and routing methods, simulation type (event-based or continuous), and performance metrics. The studies were further examined for model calibration, validation techniques, and acceptable parameter variation limits such as Curve Number (CN), lag time, and recession constant adjustments.

Common evaluation indicators across studies included NSE, R², RMSE, and Percent Bias (PBIAS). The synthesis was conducted by grouping studies according to their methodological similarities rather than geographical or chronological order.

3. HEC-HMS Simulation Methods

3.1 Loss Methods

The loss method in HEC-HMS determines the portion of precipitation that does not contribute to direct runoff.

3.1.1 Soil Conservation Service Curve Number (SCS-CN) Method

The SCS-CN method was the most frequently applied loss model across both event-based and continuous simulations (used in over 70% of the studies). Reviewed studies Belani *et al.* (2024)^[3], Namwade *et al.* (2023)^[24], Kencanawati *et al.* (2023)^[17], Belay *et al.* (2022)^[4], Daide *et al.* (2022)^[8], Obuya *et al.* (2022)^[26], Armain *et al.* (2021)^[2], Bunganaen *et al.* (2021)^[5], Fanta and Feyissa (2021)^[10], Gopi and Rema (2021)^[12], Hamdan *et al.* (2021)^[14], Jabbar *et al.* (2021)^[15], Karna *et al.* (2021)^[16], Othman *et al.* (2021)^[27], Msaddek *et al.* (2020)^[23], Gunathilake *et al.* (2019)^[13], Khan *et al.* (2019)^[18], Paudel *et al.* (2019)^[31], Sarminingsih *et al.* (2019)^[37], Tassew *et al.* (2019)^[41], Shaikh *et al.* (2018)^[38], Skhakhfa and Ouerdachi (2016)^[40] and Choudhari *et al.* (2014)^[7].

Equations

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \text{ for } P > I_a \quad \dots(1)$$

Where:

Q = Direct runoff (mm)

P = Total rainfall (mm)

I_a = Initial abstraction (~0.2S for SCS method)

S = Potential maximum retention after runoff begins

$$S = \frac{25400}{CN} - 254 \quad \dots(2)$$

The CN value (ranging from 30-100) depends on soil type, land use, and antecedent moisture. Studies such as demonstrated that calibration of CN within ± 10 -15% of estimated values yielded optimal performance.

3.1.2 Initial and Constant Loss Method:

The Initial and Constant Loss (ICL) model is one of the simplest rainfall-loss (infiltration) models used in HEC-HMS to estimate the effective rainfall that contributes to runoff.

Let:

$P(t)$ = cumulative precipitation at time t

I_0 = Initial loss (mm)

C = Constant loss rate (mm/hr)

$Pe(t)$ = effective rainfall at time t

Condition 1: Before initial loss is satisfied

If

$$P(t) < I_0 \quad \dots(3)$$

then

$$Pe(t) = 0 \quad \dots(4)$$

Condition 2: After initial loss is satisfied

Once $P(t) \geq I_0$, losses occur at a constant rate C :

$$Pe(t) = P(t) - I_0 - C \cdot t \quad \dots(5)$$

But since effective rainfall cannot be negative:

$$Pe(t) = \max(0, P(t) - I_0 - Ct) \quad \dots(6)$$

HEC-HMS applies the constant loss rate on each computational timestep (Δt):

$$Pe_{\Delta t} = \max(0, P_{\Delta t} - C \cdot \Delta t - L_r) \quad \dots(7)$$

Where:

L_r = remaining portion of initial loss (I_0) if any.

After initial loss becomes 0, only constant infiltration (C) is subtracted.

This method was applied by Frysali *et al.* (2023)^[11], Belay *et al.* (2022)^[4], and Sarminingsih *et al.* (2019)^[37]. It assumes an initial abstraction followed by a constant infiltration rate. Performance ranged from Good to Satisfactory, with NSE values between 0.53-0.73, depending on watershed characteristics.

3.1.3 Deficit and Constant Loss Method:

The Deficit and Constant Loss (DCL) method is an infiltration model in HEC-HMS designed to represent the soil moisture accounting of a watershed. It calculates rainfall losses by tracking soil water deficit (unsatisfied soil moisture) and applying a constant rate of infiltration once the soil begins to saturate.

Used for continuous simulation in Yilmaa and Kebede (2023)^[44], Matli and Hunashal (2021)^[21], Din *et al.* (2019)^[9] and Chatterjee (2014)^[6]. The results were typically very good, with R² values above 0.90 and NSE values up to 0.92, showing that this method performs reliably for long-term hydrologic studies.

(b) Infiltration Loss Calculation

Case 1: Soil not yet saturated ($D(t) > 0$)

All rainfall goes into satisfying soil deficit:

$$L(t) = P(t) \quad \dots(8)$$

Case 2: Soil saturated ($D(t) = 0$)

Constant loss rate applies:

$$L(t) = f^c \quad \dots(9)$$

Where runoff begins:

$$\text{Runoff}(t) = P(t) - f^c \quad (\text{if } P(t) > f^c) \quad \dots(10)$$

3.1.4 Green-Ampt Method

The Green-Ampt (G-A) infiltration model is a physically-based method used in HEC-HMS to estimate infiltration losses during rainfall-runoff simulation. It represents infiltration as a sharp wetting front moving vertically downward into the soil. This method is best suited for event-based simulations, infiltration-excess runoff conditions, and well-defined initial soil moisture.

Cumulative infiltration (F):

$$F = K_s t + \Psi_f (\theta_s - \theta_i) \ln \left(1 + \frac{F}{\Psi_f (\theta_s - \theta_i)} \right) \quad \dots(11)$$

Infiltration rate (f):

$$f = K_s \left(1 + \frac{\Psi_f (\theta_s - \theta_i)}{F} \right) \quad \dots(12)$$

Where:

F = cumulative infiltration (mm)

f = infiltration rate at time t (mm/hr)

K_s = saturated hydraulic conductivity (mm/hr)

Ψ_f = wetting front suction head (mm)

θ_s = saturated moisture content

θ_i = initial moisture content

$$\Delta\theta = (\theta_s - \theta_i) \quad \dots(13)$$

Used in event-based studies such as Prabha and Tapas (2020) [32] and Rathod *et al.* (2015) [34]. It applies physically-based infiltration parameters and produced very high accuracy, including R^2 reaching 0.97 and NSE 0.96, indicating excellent suitability for high-intensity rainfall events.

3.1.5 Soil Moisture Accounting (SMA)

The Soil Moisture Accounting (SMA) method is a physically-based continuous infiltration and runoff model in HEC-HMS. It represents the watershed as a series of vertical storage layers, each with specific moisture capacities and percolation rules.

Applied in Kumar and Pandey (2023) [19], Msaddek *et al.* (2020) [23], Ouedraogo (2017, 2018) [28, 29], and Singh and Jain (2015) [39]. SMA provides detailed accounting of infiltration, percolation, storage, and evapotranspiration. Studies reported high to very high performance, with R^2 up to 0.96 and NSE up to 0.95, confirming the method's robustness for continuous simulations.

3.2 Transform Methods

The transform method converts excess precipitation into direct runoff at the subbasin outlet. It represents how rainfall moves over the watershed surface and through channels to generate streamflow.

3.2.1 SCS Unit Hydrograph

The dominant transform method across most studies. It was used in event and continuous simulations including Belani *et al.* (2024) [3], Namwade *et al.* (2023) [24], Kencanawati *et al.* (2023) [17], Kumar and Pandey (2023) [19], Daide *et al.* (2022) [8], Belay *et al.* (2022) [4], Obuya *et al.* (2022) [26], Armain *et al.* (2021) [2], Bunganaen *et al.* (2021) [5], Fanta and Feyissa (2021) [10], Gopi and Rema (2021) [12], Hamdan *et al.* (2021) [14], Jabbar *et al.* (2021) [15], Karna *et al.* (2021) [16], Matli and Hunashal (2021) [21], Msaddek *et al.* (2020) [23], Khan *et al.* (2019) [18], Tassew *et al.* (2019) [41], Paudel *et al.* (2019) [31], Shaikh *et al.* (2018) [38], Shkhakhfa and Ouerdachi (2016) [40], Rathod *et al.* (2015) [34], Choudhari *et al.* (2014) [7]. Reported performance was consistently strong, with NSE values often exceeding 0.80-0.90. The SCS-UH assumes a dimensionless hydrograph shape defined by:

$$Q_p = \frac{484A}{T_p} \quad \dots(14)$$

Where

Q_p = Peak discharge (m³/s),

A = Watershed area (m²),

T_p = Time to peak (hours).

The method requires lag time estimation

$$T_{lag} = 0.6T_c \quad \dots(15)$$

Where

T_c = Time of concentration.

3.2.2 Clark Unit Hydrograph

The Clark Unit Hydrograph (Clark UH) is a synthetic unit hydrograph method that combines two hydrologic processes:

1. Time-Area Histogram (Translation)

2. Linear Reservoir (Attenuation)

It is widely used in HEC-HMS because it represents both runoff translation and runoff storage (attenuation) in a watershed. Applied in Din (2019) [9], Gunathilake (2019) [13], Ouedraogo (2017, 2018) [28, 29], Chatterjee (2014) [6] etc. The Clark UH combines translation and attenuation, explaining its good performance in mixed terrain basins, with R^2 commonly above 0.85.

3.2.3 Snyder Unit Hydrograph

The Snyder Unit Hydrograph (SUH) is one of the earliest synthetic unit hydrograph methods and is commonly used in HEC-HMS for rainfall-runoff modeling, especially when streamflow data is limited. The method was originally developed for watersheds in the Appalachian region and later generalized for other ungauged basins.

Used in Belay (2022) [4] and Sarminingsih (2019) [37]. Studies reported very good performance with NSE up to 0.94.

3.3 Baseflow Methods

HEC-HMS simulates baseflow as the slow component of streamflow emerging from groundwater storage. Baseflow accounts for the longer-term drainage of subsurface water, sustaining streamflow during inter-storm periods. The model provides several conceptual baseflow methods, each with different mathematical formulations.

3.3.1 Recession Method

The Recession Method is the most commonly used for baseflow estimation in HEC-HMS.

It expresses discharge Q_t as:

$$Q_t = Q_0 K^t \quad \dots(16)$$

Where

K = Recession constant (0.8-0.98).

Widely used in Belani *et al.* (2024) [3], Gopi and Rema (2021) [12], Gunathilake *et al.* (2019) [13], Khan *et al.* (2019) [18], Ouedraogo *et al.* (2018) [29] and Singh and Jain (2015) [39]. Models using recession baseflow achieved satisfactory to very good performance (NSE > 0.70).

3.3.2 Constant Monthly Baseflow Method

Assumes baseflow varies month-wise but is constant within each

month. The model uses user-defined monthly flow values.

Formula

$$Q_b(t) = Q_m \quad \dots(17)$$

Where:

$Q_b(t)$ = baseflow at time t

Q_m = constant baseflow assigned for month m

Mostly apply in regions with predictable seasonal groundwater fluctuation. Applied in Karna (2021) ^[16], Din (2019) ^[9], Paudel (2019) ^[31], Chatterjee (2014) ^[6]. These studies reported good consistency with R^2 above 0.80.

3.3.4 Linear Reservoir Baseflow Method

Groundwater is represented as one or more linear reservoirs. Outflow is proportional to the storage.

Formula

$$Q_b(t) = \frac{S(t)}{K} \quad \dots(18)$$

$$S(t + \Delta t) = S(t) + (R - Q_b)\Delta t \quad \dots(19)$$

Where:

- $S(t)$ = groundwater storage
- K = reservoir coefficient (time units)
- R = recharge

This is the same concept used in hydrogeology for linear aquifer drainage. Observed in Frysali (2023) ^[11] and Ouedraogo (2017) ^[28]. The method yielded good performance, with R^2 around 0.72-0.74.

3.3.5 Exponential Recession (Exponential Baseflow Method)

Represents baseflow using a two-term exponential curve with an asymptotic minimum baseflow.

$$Q_b(t) = Q_{\max} e^{-\alpha t} + Q_{\min} \quad \dots(20)$$

Where:

$Q_{\max}$ = maximum initial recession flow

$Q_{\min}$ = minimum constant groundwater outflow

α = exponential decay coefficient

It is used in Yilmaa and Kebede (2023) ^[44], Bunganaen *et al.* (2021) ^[5] and Choudhari *et al.* (2014) ^[7].

3.4 Routing Methods

Routing methods simulate how water flows through channels or river reaches after runoff is generated

3.4.1 Muskingum Routing Method

Channel routing in natural rivers, where storage depends on both inflow and outflow.

Muskingum uses a linear storage model:

$$S = K[xI + (1 - x)O] \quad \dots(21)$$

Where:

S = channel storage (m^3)

I = inflow (m^3/s)

O = outflow (m^3/s)

K = travel time through the reach (hrs)

x = weighting factor (0-0.5)

Routing Equation

Outflow at next time step:

$$O_{t+1} = C_0 I_{t+1} + C_1 I_t + C_2 O_t \quad \dots(22)$$

Where coefficients:

$$C_0 = \frac{-Kx + 0.5\Delta t}{K(1-x) + 0.5\Delta t} \quad \dots(23)$$

$$C_1 = \frac{Kx + 0.5\Delta t}{K(1-x) + 0.5\Delta t} \quad \dots(24)$$

$$C_2 = \frac{K(1-x) - 0.5\Delta t}{K(1-x) + 0.5\Delta t} \quad \dots(25)$$

Valid ranges

- $0 \leq x \leq 0.5$
- $\Delta t \leq 2K(1 - x)$

Most widely used routing technique reviewed in Yilmaa and Kebede (2023) ^[44], Daide *et al.* (2022) ^[8], Obuya *et al.* (2022) ^[26], Fanta and Feyissa (2021) ^[10], Gopi and Rema (2021) ^[12], Hamdan *et al.* (2021) ^[14], Jabbar *et al.* (2021) ^[15], Paudel *et al.* (2019) ^[31], Skhakhfa and Ouerdachi (2016) ^[40], Tassew *et al.* (2019) ^[41], Choudhari *et al.* (2014) ^[7]. Performance ranged from good to very good, with R^2 up to 0.90.

3.4.2 Muskingum-Cunge Routing Method

Physically based routing that accounts for channel geometry, slope, and roughness. The diffusive wave approximation of the Saint-Venant equations.

Storage is computed using:

$$S = KQ + \frac{1}{2} D \frac{\partial Q}{\partial x} \quad \dots(26)$$

Where:

- K = travel time
- D = hydraulic diffusivity

Numerical Routing Equation Same form as Muskingum:

$$O_{t+1} = C_0 I_{t+1} + C_1 I_t + C_2 O_t \quad \dots(27)$$

But coefficients are computed automatically from:

- Manning's n
- Channel slope (S_0)
- Channel shape (rectangular, trapezoidal, etc.)
- Wave celerity C

Wave celerity

$$C = \frac{\partial Q}{\partial A} \quad \dots(28)$$

For wide channels

$$C = \frac{5Q}{3A} \quad \dots(29)$$

More stable and physically realistic than classical Muskingum. Muskingum-Cunge were used for smaller or steep basins Frysalı *et al.* (2023) ^[11] and Karna *et al.* (2021) ^[16]. Calibration of routing parameters ensured that the simulated hydrograph matched peak timing and volume accurately.

3.4. Lag Routing

Very simple routing method used when limited data is available. Outflow hydrograph (Ot) is simply the inflow hydrograph shifted by a fixed time lag (L):

$$O(t) = I(t - L) \quad \dots(30)$$

No attenuation of peak is modeled. Used in Kencanawati (2023) ^[17] and Armain (2021) ^[2], producing high accuracy, including R² up to 0.97.

4. Results and Discussion

HEC-HMS model provides strong and consistent performance across different climatic regions and watershed conditions. Most studies reported high model accuracy, with NSE values frequently between 0.80 and 0.95 and R² values commonly above 0.85, especially in event-based simulations. Continuous simulations also performed well, where NSE values ranged from moderate (0.63-0.75) to very high (0.90). Green-Ampt loss studies achieved particularly high precision with NSE > 0.95. A few studies reported moderate accuracy indicating the challenges of long-term or data-limited conditions. The lowest performance appeared, where rainfall-runoff correlation was weak. In summary, the results clearly show that HEC-HMS consistently reproduces peak flows, runoff depth, and hydrograph shape with acceptable to excellent accuracy across a wide variety of watersheds.

Table 1: Summary of HEC-HMS method used in several studies

Sr No	Author's Name	Research Title	Simulation Type	Loss Method	Transform Method	Base flow Method	Routing Method	Result
1	Belani <i>et al.</i> (2024) ^[3]	Temporal analysis of rainfall-runoff models using HEC-HMS in semi-arid region: a case of the shetrunji river sub-basin, India	Continuous	SCS-CN	SCS Unit Hydrograph	Recession	-	NSE (15.1137), R ² (0.8394) obtained in this study indicate a strong correlation between the simulated and observed runoff data.
2	Frysalı <i>et al.</i> (2023) ^[11]	Hydrologic Modeling of the Aliakmon River in Greece using HEC-HMS and Open Data	Continuous	Initial and Constant	Clark unit hydrograph	Linear reservoir	Muskingum-Cunge	Satisfactory to Good (NSE: 0.53-0.71)
3	Kencanawati <i>et al.</i> (2023) ^[17]	Hydrologic Modeling System HEC-HMS Application for Direct Runoff Determination	Event	SCS-CN	SCS Unit Hydrograph	-	Lag	Good (R ² =0.87)
4	Kumar and Pandey (2023) ^[19]	Rainfall-runoff simulation and modelling using HEC-HMS model	Continuous	Soil Moisture Accounting	SCS Unit Hydrograph	-	-	Very Good (R ² =0.96, NSE=0.95)
5	Namwade <i>et al.</i> (2023) ^[24]	Rainfall-Runoff modelling using HEC-HMS Model, Remote Sensing and GIS in Middle Gujarat, India	Event	SCS-CN	Clark unit hydrograph, SCS Unit Hydrograph	-	-	Daily timescale calibration and validation result over the study area shown good performance with NSE, R ² and Percent Bias PBIAS (%) 0.881, 0.913 and 9.76% respectively for calibration and 0.914, 0.947 and 14.8% respectively for validation. Whereas, The Nash-Sutcliffe efficiency, coefficient of determination, and 6 statistical performance indicators for the Clark unit hydrograph transform method were found to be 0.69, 0.77, 0.7461, and 0.9794, respectively. the model's results indicate a strong correlation between simulated and observed peak flows, suggesting that the water resource practices in the study area or similar basins are effective.
6	Yilmaa and Kebede (2023) ^[44]	Application of HEC-HMS Model for Flow Simulation in the Lake Tana basin: The Case of Gilgel Abay Catchment, Upper Blue Nile Basin, Ethiopia	Continuous	Deficit and constant	Clark unit hydrograph	Exponential recession	Muskingum	The model performance was improved with NSE, RSR, and R ² values of 0.793, 0.323, and 0.875, respectively
7	Belay <i>et al.</i> (2022) ^[4]	Comparison of HEC-HMS hydrologic model for estimation of runoff computation techniques as a design	Continuous	Initial and constant, the Green and Ampt, and the SCS-CN loss	SCS unit hydrograph method, Synder UH, Clark UH	-	-	NSE = 0.73, R ² = 0.75, and RMSE = 0.5

		input: case of Middle Awash Multi-purpose dam, Ethiopia			initial model			
8	Daide <i>et al.</i> (2022) ^[8]	Beht watershed (morocco) rainfall-runoff simulation with the HEC-HMS hydrological model	Continuous	SCS-CN	SCS Unit Hydrograph	-	Muskingum	Relative Error in peak: REP = 9.6%, Relative Error in volume: REV = 1.69%, Nash-Sutcliffe Efficiency: NSE = 0.63, coefficient of determination: R ² = 0.870, and Ratio of standard deviation of observations to root mean square error: RSR = 0.36.
9	Obuya <i>et al.</i> (2022) ^[26]	Hydrodynamic modeling using HEC-HMS Model, river Kuja Basin, Kenya	Continuous	SCS-CN	SCS Unit Hydrograph	Exponential recession	Muskingum	The regression analysis focusing on the relationship between rainfall and streamflow resulted in correlation coefficient value of 0.64 and coefficient of determinant value of 0.41.
10	Armain <i>et al.</i> (2021) ^[2]	Development of rainfall-runoff modelling using the HEC-HMS at the catchment of Kelantan River, Malaysia	Event	SCS-CN	SCS Unit Hydrograph	-	Lag	R ² with the range of 0.80-0.97 and 0.64-0.93 in calibration and validation
11	Bunganaen <i>et al.</i> (2021) ^[5]	Rainfall-Runoff Simulation Using HEC-HMS Model in the Benanain Watershed, Timor Island	Continuous	SCS-CN	SCS unit Hydrograph	Exponential Recession	-	NSE=0.88, R ² =0.89, Very Good
12	Fanta and Feyissa (2021) ^[10]	Performance Evaluation of HEC-HMS Model for Continuous Runoff Simulation of Gilgel Gibe Watershed, Southwest Ethiopia	Continuous	SCS-CN	SCS Unit Hydrograph	-	Muskingum	The first phase of R ² , RMSE, PBIAS and PEP values (0.948, 30.583 m ³ s ⁻¹ , 28.2%, and -28.175%, respectively) were higher than the second phase of R ² , RMSE, PBIAS, and PEP values (0.884, 17.830%, 28.512 m ³ s ⁻¹ and -11.221%, respectively). The result showed that the model performs well in the second phase of the validation period.
13	Gopi and Rema (2021) ^[12]	Calibration and Validation Of HEC-HMS Model for Chalakudy River Basin	Continuous	SCS-CN	SCS Unit Hydrograph	Recession	Muskingum	Nash-Sutcliffe efficiency (NSE) and Coefficient of correlation(R ²) values were obtained above 0.7. Satisfactory performance of model simulation both in calibration and validation.
14	Hamdan <i>et al.</i> (2021) ^[14]	Rainfall-Runoff Modeling using the HEC-HMS Model for the Al-Adhaim River Catchment, Northern Iraq	Event	SCS-CN	SCS Unit Hydrograph	-	Muskingum	R ² was 0.9 for both calibration and verification.
15	Jabbar <i>et al.</i> (2021) ^[15]	HEC-HMS hydrological modelling for runoff estimation in cameron highlands, Malaysia	Continuous	SCS-CN	SCS Unit Hydrograph	-	Muskingum	(R ²) = 0.90, Nash-sutcliffe Efficiency = 0.92, Root Mean Square Error = 0.1 and the Percent Bias = 0.77%. Thus, the model can be applied in the Cameron Highland Watershed.
16	Karna <i>et al.</i> (2021) ^[16]	Application of HEC-HMS model for runoff simulation: a case study of kankai river basin in Nepal	Event	SCS-CN	SCS Unit Hydrograph	constant monthly	Muskingum-cunge	The calculated value of both NSE and R ² has found 0.805, 0.816 for the calibration period and 0.856, and 0.868 for the validation period, which indicates the finer accuracy of simulated outflow.
17	Matli and Hunashal (2021) ^[21]	Hydrological Modelling Studies of Paravar River Basin, a Tributary of River Godavari using HEC-HMS Model	continuous	Deficit and Constant	SCS Unit Hydrograph	-	-	Very Good (R ² =0.93, NSE=0.92)
18	Othman <i>et al.</i> (2021) ^[27]	Calibration and validation of hydrological model using HEC-HMS for Kuantan River Basin	Event	SCS-CN	Clark unit hydrograph	constant monthly	Muskingum	The calibration result shows an acceptable model efficiency (ME) of 0.85 which is in agreement with observed data while the ME of 0.76, 0.83 and 0.81 are satisfactorily validated with HEC-HMSmodel.
19	Msaddek <i>et al.</i> (2020) ^[23]	Hydrological Modeling of Upper oumerrabia Basin (Morocco), Comparative Study of the Event-Based and Continuous-Process HEC-HMS Model Methods	Event & Continuous	SCS-CN, Soil Moisture Accounting	SCS Unit Hydrograph	-	-	The average calibration NSE values were 0.740 and 0.585 for event-based (daily) and continuous-process (annual) respectively. The R ² , RSR and PBIAS values were 0.624, 0.634 and +16.7 respectively.
20	Prabha and Tapas (2020) ^[32]	Event-Based Rainfall-Runoff Modeling using HEC-HMS	Event	Green-Ampt	SCS unit hydrograph	-	-	Very Good (R ² =0.97, NSE=0.96)

21	Din <i>et al.</i> (2019) ^[9]	Runoff modelling using HEC-HMS for rural watershed	Continuous	Deficit and Constant	Clark unit hydrograph	Constant monthly	Muskingum	Loss method, Deficit and Constant method with Clark transformation and constant monthly base flow perform well. This can be used as a decision support tool in the design and operation
22	Gunathilake <i>et al.</i> (2019) ^[13]	Application of A HEC-HMS Model on Event - Based Simulation in Tropical Watershed	Event	SCS-CN	Clark unit hydrograph	Recession		Good ($R^2=0.85$)
23	Khan <i>et al.</i> (2019) ^[18]	Hydrological Modeling of Upper Indus Basin Using HEC -HMS.	Continuous	SCS-CN	SCS Unit Hydrograph	Recession	-	While in the targeted watershed gave the value for Peak Discharge and Root Mean Square Method as 7.83 and R^2 value of 0.855 for the discharge. The performance of the HEC-HMS was found to be satisfactory for obtained square functions in the validated model during simulation.
24	Paudel <i>et al.</i> (2019) ^[31]	Application of HEC-HMS Model for Runoff Simulation: A Case Study of Marshyangdi River Basin in Nepal	Continuous	SCS-CN	SCS unit hydrograph	constant monthly	Muskingum	The Nash-Sutcliffe efficiency (ENS) and coefficient of determination (R^2) of model performance criterion are used to evaluate the model applicability for Marshyangdi river basin. Where the calculated value of both ENS and R^2 has found 0.778 for calibration period and 0.842 for validation period. Which shows the model has well simulated the daily stream flow at the outlet of the river basin, however there is a slight under and over prediction of the high flows; this is the common draw backs of hydrological models. The results obtained are satisfactory and acceptable.
25	Sarminingsih <i>et al.</i> (2019) ^[37]	Simulation of Rainfall-runoff process using HEC-HMS model for Garang Watershed, Semarang, Indonesia	Continuous	SCS-CN	Snyder Unit Hydrograph	Initial Constant	-	Very Good ($R^2=0.95$, NSE=0.94)
26	Tassew <i>et al.</i> (2019) ^[41]	Application of HEC-HMS Model for Flow Simulation in the Lake Tana Basin: The Case of Gilgel Abay Catchment, Upper Blue Nile Basin, Ethiopia	Continuous	SCS-CN	SCS Unit Hydrograph	-	Muskingum	Very Good (NSE=0.87 for calibration, 0.85 for validation)
27	Ouedraogo <i>et al.</i> (2018) ^[29]	Continuous Modeling of the Mkurumudzi River Catchment in Kenya Using the HEC-HMS Conceptual Model: Calibration, Validation, Model Performance Evaluation and Sensitivity Analysis	Continuous	Soil Moisture Accounting	Clark unit hydrograph	Recession	-	The coefficients of determination (R^2) for the calibration and validation periods were 0.80 and 0.67, respectively, indicating a very good and good model fit. Similarly, the indices of agreement (d) were found to be 0.94 and 0.88 during the calibration and validation periods, respectively, indicating a very good and good model fit. The RSR, which assesses the appropriateness of the model, ranged from 0.37 to 0.50 (0.50 to 0.74) for the calibration (validation) period, indicating acceptable to very good performance.
28	Shaikh <i>et al.</i> (2018) ^[38]	Simulation of rainfall-runoff event using HEC-HMS model for rel sub-basin, Gujarat, India	Event	SCS-CN	SCS Unit Hydrograph		-	The comparison of observed and simulated hydrographs with high R^2 value (=0.86) shows the capability of the model to be used in hydrologic simulation in Rel watershed.
29	Ouedraogo <i>et al.</i> (2017) ^[28]	HEC-HMS Model for Runoff Simulation in Ruiru Reservoir Watershed	Continuous	Soil Moisture Accounting	Clark unit hydrograph	linear reservoir	-	The Efficiency of the model 0.74 and 0.72 respectively for the calibration and the validation indicating that the results of the simulation are good.
30	Skhakhfa and Ouerdachi (2016) ^[40]	Hydrological modelling of wadi Ressoul Watershed, Algeria, by HEC-HMS model	Event	SCS-CN	SCS Unit Hydrograph	-	Muskingum	The results of the measuring approved the results of the model and showed that the difference between the peak discharge observed and validated model was about 8.86 percent with R^2 value is 0.867 and Nash-Sutcliffe efficiency is at 0.99. The present study concludes that the model can be utilized for the wadi Ressoul.
31	Rathod <i>et al.</i> (2015) ^[34]	Simulation of Rainfall - Runoff process using	Event	Green-Ampt	SCS unit hydrograph	-	-	Nash-Sutcliffe coefficient values come out to be more than 0.8 for all three sub basins.

		HEC-HMS (Case Study: Tapi River, India)						Correlation coefficient between observed and simulated discharge is more than 0.9 for all three sub basins. Finally, study concludes that HEC-HMS model can be used with reasonable approximations on Tapi River.
32	Singh and Jain (2015) ^[39]	Continuous hydrological modeling using Soil Moisture Accounting Algorithm in Vamsadhara River Basin, India	Continuous	Soil Moisture Accounting	Clark unit hydrograph	Recession	-	The overall model efficiencies (EFF) given by Nash-Sutcliffe Efficiency criteria are 0.701 and 0.762 for the calibration and validation periods, respectively, indicating a good model fit. Percentage error in volume (PEV) for the calibration and validation periods was found to be 2.64% and 12.33%, respectively, which indicates good model fit. On the basis of percentage error in peak (PEP) criteria, which gives an error of 0.21% and -15.2% for the calibration and validation periods, respectively, the performance of the model can be rated as good. The coefficient of determination (R ²) for the calibration period was found to be 0.71 and 0.78 for the validation period, indicating good model fit.
33	Chatterjee <i>et al.</i> (2014) ^[6]	Hydrological Modeling studies with HEC-HMS for Damodar Basin, India	Continuous	Deficit and Constant Loss	Clark unit hydrograph	Constant monthly	-	R ² =0.88 for calibration, 0.84 for validation, Good
34	Choudhari <i>et al.</i> (2014) ^[7]	Simulation of rainfall-runoff process using HEC-HMS model for Balijore Nala watershed, Odisha, India	Event	SCS -CN	SCS unit hydrograph	Exponential recession	Muskingum	Final validation parameter was derived and considered as global values for the model. The HEC-HMS model used for rainfall-runoff simulation in the selected watershed shows RMSE as 0.09 m ³ /sec and MARE as 0.06 for peak discharge and RMSE as 0.70 mm and MARE as 0.05 for runoff depth.

5. Conclusion

HEC-HMS is a highly reliable and versatile hydrological model capable of effectively simulating both event-based and continuous rainfall-runoff processes. The dominant use and consistently strong performance of the SCS-CN loss method, paired with the SCS Unit Hydrograph transform method, indicate that this combination is the most dependable approach across diverse catchments. The Muskingum routing and recession baseflow methods were also widely preferred due to their stability and realistic representation of channel storage and groundwater recession. Continuous modelling benefited significantly from the Deficit-Constant and Soil Moisture Accounting (SMA) methods, especially in studies targeting seasonal or annual hydrologic responses. The collective findings confirm that HEC-HMS can be confidently applied for flood forecasting, watershed assessment, reservoir inflow estimation, hydrologic design, and water resources planning. Overall, the table-based evidence clearly concludes that HEC-HMS delivers dependable simulation results when supported by proper parameterization, calibration, and method selection appropriate to watershed conditions.

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