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Hydrological Analysis of the 2019 Flood Event in the Vishwamitri River Basin

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Abstract: ***This study presents an event-based rainfall–runoff simulation of the 2019 flood in the Vishwamitri River basin, Gujarat, India, using HEC-HMS 4.14. The basin was represented by three subbasins with a combined drainage area of 516.33 km², connected through junctions and reaches to Sink-1, the principal basin outlet which was defined at location on Vishwamitri river at a point before entering the city of Vadodara. Rainfall observations at 15-minute intervals were obtained from Vadodara Municipal Corporation (VMC), while observed discharge at the Pilol gauging station was obtained from the State Water Data Centre (SWDC), Gandhinagar. Data preparation covered a two-year record; however, the simulation and optimization presented in this study were restricted to 2019. The Initial and Constant loss method was coupled with the Clark Unit Hydrograph transform method. Model parameters were optimized against the discharge series at JH2, representing the Pilol comparison location. The optimized trial yielded R^2 = 0.57, Nash–Sutcliffe efficiency (NSE) = 0.437, normalized NSE = 0.64. The optimized simulation produced a peak discharge of 944.4 m^3/s at the principal basin outlet. The results demonstrate the applicability of an optimized HEC-HMS configuration for reconstructing the 2019 basin response and generating a principal-outlet hydrograph for subsequent flood studies.***

Keywords: Vishwamitri River basin; Hydrological modelling, Vadodara floods 2019.

I. INTRODUCTION

Flooding is a major hydrometeorological hazard in monsoon regions, where factors like short, intense rainfall, prior wet conditions, catchment features, and river controls combine to quickly change streamflow. Floods can greatly impact communities, transport systems, public services, agriculture, and other infrastructure. In areas experiencing urbanization, these effects can worsen due to changes in land cover, encroachment into natural drainage paths, and limited river channel capacity. Therefore, accurately estimating runoff hydrographs is essential for flood assessment, mitigation planning, and hydraulic modeling.

Rainfall–runoff modelling helps convert rainfall data into estimates of runoff and discharge in specific areas. Event-based models are useful for recreating past flood events, studying the timing and size of the response, and setting hydrologic conditions for further hydraulic analysis. The model's accuracy relies on the quality and timing of rainfall data, how infiltration and other losses are represented, how excess rainfall is turned into direct runoff, how baseflow is handled, and how flow is routed through the drainage system. A model can create a hydrograph even with limited data, but the discharge estimates need to be compared with independently observed or validated flows.

The Vishwamitri River basin in Gujarat is important because the river flows through Vadodara, a key city. The flood in August 2019 showed the need to understand how rainfall affects runoff in the basin and the impact of upstream areas. The basin has been studied for flood control and hydrodynamic modeling. A study by the National Institute of Hydrology used rainfall and Pilol flow data to calibrate and validate a MIKE-NAM rainfall–runoff model, followed by MIKE-FLOOD modeling of the Vishwamitri and Surya River systems. This research offers valuable regional insights for using hydrologic and hydraulic models in the basin. [1].

The Hydrologic Engineering Center–Hydrologic Modeling System (HEC-HMS) is a tool for modeling rainfall and runoff in watersheds. It uses hydrologic elements like subbasins, reaches, junctions, reservoirs, and sinks to represent a watershed. Different methods can be used to model precipitation losses, direct-runoff transformation, baseflow, and channel routing. The HEC-HMS Technical Reference Manual explains the concepts and math behind these methods [2]. The software is used for various hydrologic tasks, such as event simulation and creating inflow hydrographs for hydraulic studies.

In this study, version 4.14 of HEC-HMS was employed to model the flood response of the Vishwamitri River basin in 2019. The model comprises three subbasins, collectively covering a drainage area of 516.33 km².

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Rainfall data, recorded every 15 minutes, were sourced from the Vadodara Municipal Corporation (VMC) [7], while discharge measurements at Pilol were provided by the State Water Data Centre (SWDC) in Gandhinagar [8]. Although the data preparation spanned a two-year period, the simulation and optimization detailed in this paper focused solely on 2019. To account for precipitation losses, the Initial and Constant method was applied, and the Clark Unit Hydrograph method was utilized to convert excess precipitation into direct runoff. The optimization target was set at JH2, the model component representing the Pilol discharge data. Sink-1 was maintained as the final element and main basin outlet, positioned at a point along the Vishwamitri River before it flows into the city of Vadodara.

The study aims to achieve the following objectives: (i) to model the Vishwamitri River basin using a HEC-HMS framework divided into three subbasins; (ii) to incorporate 15-minute rainfall data and discharge measurements at Pilol for the 2019 simulation; (iii) to fine-tune the main loss and Clark transform parameters by comparing them with the discharge series observed at JH2; (iv) to assess the refined model through additional statistical metrics; and (v) to determine the peak discharge and its timing at Sink-1, the main outlet of the model.

II. REVIEW OF RELATED MODELLING STUDIES

A. Rainfall–Runoff Modelling and Event Simulation

Rainfall–runoff models are often used to estimate how precipitation turns into catchment discharge. These models, which can be conceptual or semi-distributed, simplify the main processes using basic relationships and parameter sets. Their effectiveness relies not only on their mathematical design but also on whether the input data and parameter values suit the specific catchment and event. Nash and Sutcliffe [3] highlighted the importance of systematic model development and testing in their key discussion on conceptual rainfall–runoff modelling. They also introduced the Nash–Sutcliffe efficiency criterion, now widely used to measure how well simulated streamflow matches observed data.

In event simulation, the timing of rainfall is crucial. A daily rainfall total does not indicate if the precipitation was steady, occurred in multiple bursts, or came as a brief, intense storm. When daily totals are divided equally to produce hourly figures, the overall daily amount is preserved, but the specific pattern within the day is lost. This method of disaggregation is useful for generating a computational time series in the absence of sub-daily data; however, it is an assumption that can affect the onset of runoff, as well as the peak's size and timing. This concern is especially pertinent for urban or highly responsive catchments, where short bursts of intense rainfall can significantly impact the hydrograph.

Model choice and parameterization depend on available catchment information. Detailed soil maps, land-use data, infiltration measurements, and streamflow observations help in estimating parameters for different areas. In cases with limited data, simpler methods may be used, but the parameter values should be clearly reported, and their uncertainty should be noted. HEC-HMS offers methods from simple event-based loss formulations to more detailed approaches. The choice of method depends on the study's purpose and available data [2].

B. HEC-HMS Loss and Transform Methods

The Initial and Constant loss method models precipitation losses by considering an initial abstraction followed by a steady ongoing loss rate.

The initial loss refers to the precipitation that is absorbed or retained before runoff starts. After this initial loss is met, any precipitation exceeding the defined constant loss rate is considered excess and can be used for direct-runoff calculations. This approach is ideal for event-based simulations where a simple representation of infiltration losses is necessary. The parameters involved are the initial loss and the constant loss rate [4].

The Clark Unit Hydrograph approach converts surplus rainfall into a direct-runoff hydrograph by modeling the movement of runoff across the watershed and the effects of storage and attenuation. The catchment's travel-time response is defined by the time of concentration, whereas the storage coefficient indicates the attenuation occurring within the watershed. These factors influence the timing, form, and concentration of the hydrograph produced by the simulation. Consequently, the Clark method offers a conceptual model of watershed response through the aspects of travel time and storage [2].

The choice of the Initial and Constant loss method, along with the Clark Unit Hydrograph transform method, was guided by the goal of simulating events and the data available on rainfall and discharge. Parameters were adjusted using the HEC-HMS optimization process, where the objective function was specified at JH2. The results section includes the optimized parameter values and their associated evaluation statistics.

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C. Model Evaluation in Hydrology

To assess how accurately a simulated hydrograph mirrors observed discharge, a quantitative analysis is necessary. The coefficient of determination (R^2) is frequently employed to indicate the strength of the linear relationship between paired data points, though it does not inherently assess magnitude agreement or bias. Nash–Sutcliffe efficiency (NSE) evaluates the squared error of the simulated discharge against the variability in the observed data [3]. An NSE value of 1 signifies an exact match, while an NSE of 0 suggests that the simulation's performance is on par with using the average observed discharge as a predictor. A negative NSE implies that the simulation is less effective than this mean-value benchmark.

Moriasi et al. [6] offered extensively referenced guidelines for the systematic assessment of watershed simulations, highlighting the importance of interpreting performance statistics in the context of the model's purpose, time step, constituent, and data quality. No single statistic can fully represent all facets of hydrograph performance. When the goal is event reconstruction, factors such as peak timing, peak magnitude, volume bias, and visual comparison are also significant. In this study, R^2 and NSE are presented for the Pilol comparison, whereas the Sink-1 outcome is addressed separately due to the unavailability of observed discharge data at the main outlet.

D. Regional Context: Vishwamitri River Modelling

The Vishwamitri River has been studied in relation to flood prevention strategies for Vadodara. According to a report by the National Institute of Hydrology, a MIKE-NAM rainfall–runoff model was tailored and validated using daily rainfall and flow data from Pilol. This information was then applied to the subcatchments of the Surya and Vishwamitri rivers, leading to the development of a MIKE-FLOOD model that incorporated surveyed cross-sections and bridge information [1]. This regional study highlights the significance of Pilol's discharge data and the integration of rainfall–runoff modeling with hydraulic flood routing.

This research sets itself apart by employing HEC-HMS and thoroughly documenting a model for an event involving three subbasins from July to September 2019. It does not aim to replace a comprehensive hydrodynamic assessment or directly compare with the outcomes from MIKE-NAM/MIKE-FLOOD. Instead, it offers an independent HEC-HMS simulation based on the available rainfall data and model framework. The study's significance lies in detailing the selected basin configuration, the management of input data, the choice of methods, and the main outlet hydrograph, along with a clear statement regarding the limitations of the validation data available. Rana and Suryanarayana [9] conducted a study on the elements influencing flooding in the Vishwamitri watershed, utilizing tools such as remote sensing, GIS, field observations, Cartosat-1 DEM, morphometric parameters, and curve-number data. Their work focused on ranking the watershed's sub-basins according to their flood-related characteristics and examined the use of rain-on-grid modeling to identify flood-prone regions. This research provides a framework at the watershed level for understanding the spatial factors that affect runoff generation in the region. The present study expands on this analysis by developing an event-based HEC-HMS rainfall–runoff model and comparing the simulated discharge with data from the Pilol gauge..

Shah et al. [10] performed an examination of the Vishwamitri flood in 2019 by utilizing the rainfall–runoff features of HEC-RAS 5.0.7. Their study used GPM precipitation data to model flood inundation, velocity, water-surface elevation, and arrival time, which was subsequently applied to evaluate flood hazards in Vadodara. In contrast, the present research employs HEC-HMS 4.14, integrating 15-minute rainfall data from VMC weather stations along with observed discharge at Pilol. Consequently, both investigations analyze the same flood event through different modelling frameworks, providing complementary hydrologic and hydraulic perspectives.

Kumar [11] assessed flood risk at the watershed scale in Vadodara by employing HEC-RAS modeling to study the 2005 floodplain within the city and conducting field evaluations of affected areas. The study highlights the importance of considering the entire Vishwamitri watershed rather than limiting flood assessments to the city's boundaries. These regional studies emphasize the need for reliable hydrologic data and event hydrographs, which are the main focus of the ongoing HEC-HMS research.

Pandya and Jain [12] investigated a dam-break scenario at Ajwa Dam during a significant flood event in the Vishwamitri basin. Their study incorporated SWAT-based hydrological modeling of the Vishwamitri basin, estimated a flood with a 20-year return period, and utilized SWAT-CUP with the SUFI-2 algorithm for calibration and validation. The peak flood estimated through SWAT served as lateral inflow in the dam-break model, with breach parameters established according to Central Water Commission guidelines. The research also determined the arrival time of the dam-break flood at crucial downstream locations and stressed the application of the results for emergency action planning. This study is relevant to the current research as Ajwa Dam is situated on the Surya River, a tributary of the Vishwamitri system. While Pandya and Jain [12] examined the potential consequences of dam failure, the present paper focuses on the rainfall–runoff interactions of the Vishwamitri basin during the 2019 flood using HEC-HMS and observed discharge at Pilol..

III. STUDY AREA

In the current HEC-HMS application, the defined model domain consists of three contributing subbasins with areas of 245.29 km², 204.25 km², and 66.786 km², respectively, resulting in a total modeled drainage area of approximately 516.33 km². The model network incorporates junctions and reaches that converge at Sink-1, which serves as the primary model outlet. The model element JH2 corresponds to the Pilol gauging station and is utilized for comparison with the observed discharge record.

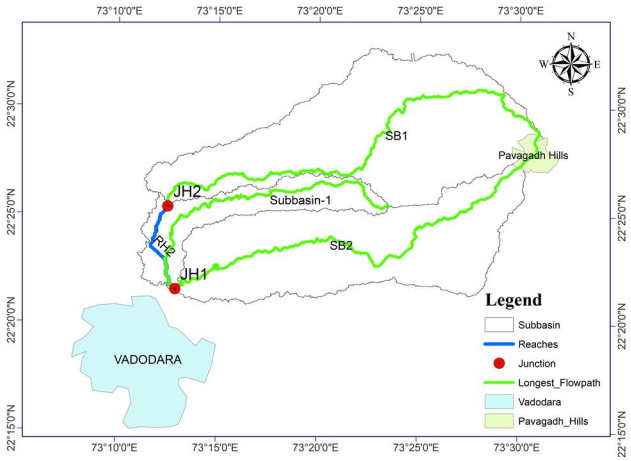


Fig 1 Location map and modelled basin details

Fig. 1 illustrates the location of the modelled Vishwamitri River basin in Gujarat, highlighting the three delineated subbasins, the drainage network, the Pilol gauging station (Represented by HEC-HMS element JH2), Vadodara city, and the principal model outlet (Sink-1, represented by JH1 in Fig. 1). The basin representation was derived from terrain data and the delineated drainage network. The model incorporates two upstream junctions and associated reaches that direct runoff towards the terminal outlet. The JH2 element was chosen as the site for optimization and discharge comparison, corresponding to the Pilol gauging record, while Sink-1 (represented by JH1) serves as the principal outlet of the entire modelled basin.

IV. DATA AND METHODOLOGY

A. Terrain Data and Basin Representation

A digital elevation model from JAXA was employed to facilitate the spatial representation and delineation of the study basin. The HEC-HMS basin model comprises three subbasins with areas of 245.29 km², 204.25 km², and 66.786 km², respectively. The total area of these subbasins is 516.336 km², which is rounded to 516.33 km². The basin model incorporates elements such as subbasins, junctions, reaches, and sinks. These model element properties were utilized to define connectivity and to differentiate the intermediate evaluation location from the principal outlet. The terrain model served as the foundation for delineating the contributing areas and establishing the basin network. The three subbasins constitute the primary spatial units within the HEC-HMS model, and their areas and connectivity were preserved in the optimized configuration. Fig 2 represents the model development in HEC-HMS interface.

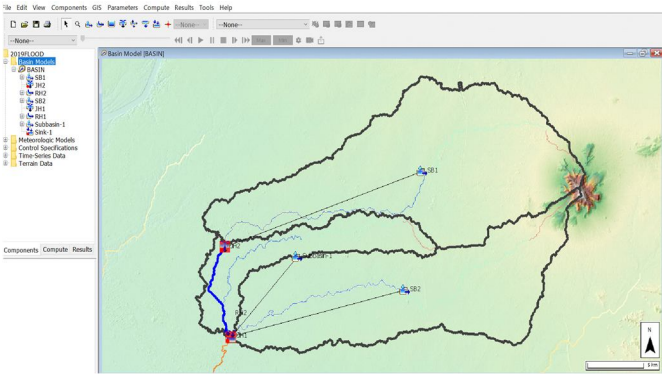


Fig 2: Model development in HEC HMS interface

B. Rainfall Data and Temporal Disaggregation

Rainfall data at 15-minute intervals were acquired from the Vadodara Municipal Corporation (VMC) for the analysis of the Vishwamitri basin. This dataset, compiled over a two-year period, facilitated data aggregation and model development. The data were sourced from a weather station located near the Ajwa reservoir within the Vishwamitri basin. It was assumed that the rainfall data were uniformly distributed throughout the basin. The current analysis employed the HEC-HMS simulation and optimization, focusing solely on the 2019 dataset. The 15-minute temporal resolution was maintained in the rainfall input, enabling the model to capture sub-hourly precipitation variations during the flood period. The 15-minute rainfall series was input into HEC-HMS at its recorded temporal interval, preserving the observed temporal structure of the rainfall input for the 2019 simulation and obviating the need to represent the rainfall event using daily totals. The rainfall observations served as the meteorological input for the three-subbasin basin model. Both the simulation and optimization periods discussed in this paper were confined to the calendar year 2019.

C. Observed Discharge Data

The discharge data for the Vishwamitri River at the Pilol gauging station were sourced from the State Water Data Centre (SWDC) in Gandhinagar. This observed dataset served as the reference for optimizing and evaluating the model's performance at the corresponding HEC-HMS element JH2. Consequently, the model evaluation statistics reflect the level of agreement at this specific gauging location.

The discharge record from Pilol and the output from the Sink-1 (JH1) model fulfill distinct roles. The Pilol record provides the observational foundation for optimization and evaluation at JH2, while Sink-1 (JH1) represents the primary outlet for the entire modeled basin. Therefore, the performance statistics reported for JH2 do not serve as a direct validation of the Sink-1 (JH1) discharge.

D. HEC-HMS Model Structure and Connectivity

The rainfall–runoff model was developed in HEC-HMS version 4.14. The basin model contains three subbasins connected through junctions and reaches to Sink-1 (JH1). The model element JH2 was selected as the objective location for optimization using the Pilol discharge observations. The complete basin outlet was represented by Sink-1(JH1). The global summary for the optimized 2019 run reports discharge at the subbasins, intermediate junctions, reaches and Sink-1.

The HEC-HMS model was configured employing the Initial and Constant loss method alongside the Clark Unit Hydrograph transform method across all three subbasins. Each subbasin was assigned an impervious area percentage of 50%. The Clark transform parameters, specifically the time of concentration and storage coefficient, were determined individually for each subbasin. Channel routing was executed using the Muskingum–Cunge method for both reaches, incorporating the respective reach characteristics such as channel length, slope, Manning's roughness coefficient, bottom width, and side slope. The model configuration did not include a baseflow method. This integration of rainfall-loss estimation, direct-runoff transformation, and channel routing facilitated the simulation of runoff movement through the watershed, enabling the estimation of the discharge hydrograph at the primary model outlet, Sink-1.

E. Loss Method: Initial and Constant

The Initial and Constant loss method was selected to represent precipitation losses in the three subbasins. For SB1, the initial loss and constant loss rate were adjusted from their initial values of 3.0 mm and 5.0 mm/h to 15.673 mm and 4.7666 mm/h, respectively. These values represent the optimized loss parameters for SB1.

The optimized loss parameters for SB1 were used in conjunction with the Clark Unit Hydrograph parameters during the optimization trial. The Initial and Constant method accounts for initial abstraction and continuing infiltration losses, while the optimization procedure adjusts the model parameters to improve the agreement between simulated and observed discharge at the selected objective location.

This event-based loss formulation provides a practical representation of precipitation losses during the 2019 flood simulation, with the reported parameter values identified according to their respective subbasins.

F. Transform Method: Clark Unit Hydrograph

The Clark Unit Hydrograph method was employed to convert excess precipitation into direct runoff at each subbasin outlet. This method characterizes watershed response through a time-area translation component and a storage-based attenuation component. The timing and attenuation of the resulting hydrograph are determined by the time of concentration and the storage coefficient [2].

In the case of Subbasin SB1, the HEC-HMS model initially used a storage coefficient of 19.05 hours and a concentration time of 10.26 hours. These values were later optimized to 47.191 hours and 31.426 hours, respectively. For Subbasin SB2, the time of concentration was set at 9.35 hours, with a storage coefficient of 17.37 hours. Meanwhile, for Subbasin-1, the time of concentration of 8.77 hours was applied and a storage coefficient of 16.28 hours.

G. Simulation Period and Computation

The HEC-HMS simulation and optimization presented in this study were conducted for calendar year 2019, from 1 January 2019 at 00:00 to 31 December 2019 at 00:00. Although the data preparation exercise covered a two-year record, only the 2019 period was used for the reported simulation and optimization. The optimization trial was named “Optimization 1” and used the Normalized Nash–Sutcliffe objective function at junction JH2 was applied.

TABLE I. SUMMARY OF HEC-HMS MODEL CONFIGURATION

Model component	Configuration / value
Simulation and optimization period	01 January 2019, 00:00 to 31 December 2019, 00:00
Rainfall data	Vadodara Municipal Corporation (VMC) weather-station observations at 15-minute intervals, applied uniformly over the river basin
Observed discharge	State Water Data Centre (SWDC), Gandhinagar; Pilol gauging station (JH2)
Subbasin areas	245.29 km² (SB1); 204.25 km² (SB2); 66.786 km² (Subbasin-1)
Total modelled area	516.33 km² (rounded)
Loss method	Initial and Constant
SB1 optimized initial loss	15.673 mm (initial value: 3.0 mm)
SB1 optimized constant loss rate	4.7666 mm/h (initial value: 5.0 mm/h)
Transform method	Clark Unit Hydrograph
SB1 optimized time of concentration	31.426 h (initial value: 10.26 h)
SB1 optimized storage coefficient	47.191 h (initial value: 19.05 h)
Baseflow method	None
Reach routing method	Muskingum–Cunge
RH1 routing parameters	Length: 102.25 m; slope: 0.02; Manning's n: 0.06; bottom width: 40 m; side slope: 1; index flow: 100 m³/s
RH2 routing parameters	Length: 9,564 m; slope: 0.00; Manning's n: 0.06; bottom width: 40 m; side slope: 1; index flow: 100 m³/s
Optimization objective	Maximize Normalized NSE at JH2
Optimization objective value	0.64
Calibration statistics at JH2	R^2 = 0.57; NSE = 0.437;
Sink-1 peak discharge	944.4 m³/s at 03:15 on 1 August 2019

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V. MODEL EVALUATION

A. Evaluation Locations and Data Pairing

Quantitative evaluation was conducted by comparing the observed discharge record at Pilol with the simulated discharge at JH2. The optimization and calibration summaries provide statistical performance metrics for this specific comparison location. The HEC-HMS calibration summary for JH2 indicates a Nash–Sutcliffe efficiency of 0.437 and a coefficient of determination R^2 of 0.57. The optimization objective-function report presents a Normalized NSE of 0.64, which aligns with the transformation NNSE = 1/(2 − NSE), where NSE = 0.437 results in NNSE ≈ 0.64. These measures are reported collectively as they represent different facets of model performance.

B. Coefficient of Determination

The coefficient of determination reported by HEC-HMS for JH2 is $R^2 = 0.57$. This indicates a moderate linear association between the paired observed and simulated discharge values. R^2 describes association and should be interpreted together with the efficiency and bias statistics rather than as a standalone measure of agreement.

C. Nash–Sutcliffe Efficiency and Normalized NSE

The conventional Nash–Sutcliffe efficiency was calculated using the standard expression [3]:

$$NSE = 1 - \frac{\sum_{i=1}^{n}\left(Q_{obs,i} - Q_{sim,i}\right)^2}{\sum_{i=1}^{n}\left(Q_{obs,i} - \overline{Q_{obs}}\right)^2}$$

An NSE of 1 signifies perfect agreement, whereas an NSE of 0 indicates that the simulation's squared-error performance is equivalent to using the mean observed discharge. A negative NSE value suggests performance inferior to this benchmark. For JH2, the optimized HEC-HMS result yielded an NSE of 0.437, demonstrating an improvement over the mean-observed benchmark. HEC-HMS optimization reports may present a normalized form of NSE, calculated as follows:

NNSE = 1 / (2 − NSE) (3)

For the optimized JH2 result, an NSE of 0.437 results in an NNSE of approximately 0.64, calculated as 1/(2 − 0.437). Consequently, the value reported in the HEC-HMS objective-function summary aligns with the calibration summary. Both statistics are provided to differentiate between the conventional NSE and its normalized form. These statistics pertain to the comparison of Junction JH2 with the Pilol discharge observations and are not intended as direct validation statistics for Sink-1, where no corresponding observed discharge series was available.

VI. RESULTS AND DISCUSSION

A. Simulated Hydrograph at Sink-1

The global summary for the optimized 2019 simulation indicates a peak discharge of 944.4 m^3/s at the primary outlet of the basin, identified as Sink-1, occurring at 03:15 on 1 August 2019. The simulated basin response exhibits its dominant peak during the early hours of 1 August, with hydrographs from individual subbasins and intermediate elements contributing to the outlet response. The peak discharge and associated volume are outputs generated by the optimized HEC-HMS configuration. The peak at Sink-1 represents the principal full-basin result of this study. This discharge occurs at a location along the Vishwamitri River before it enters Vadodara city.

B. Spatial Contribution and Subbasin Configuration

The modelled basin is divided into three subbasins with unequal contributing areas. Subbasin SB1 has an area of 245.29 km^2, Subbasin SB2 has an area of 204.25 km^2 and Subbasin-1 has an area of 66.786 km^2. Together, the three subbasins cover approximately 516.33 km^2. The global summary reports peak discharges of 302.2 m^3/s for SB1, 638.7 m^3/s for SB2 and 221.1 m^3/s for Subbasin-1. These are element-specific simulated peaks and should not be summed to reproduce the outlet peak because their peak times differ.

The optimized global summary reports a peak of 727.0 m^3/s at JH1 and RH1 at 03:30 on 1 August 2019, and 301.9 m^3/s at RH2 at 00:45 on the same date. At Sink-1, the reported peak is 944.4 m^3/s at 03:15. These results describe the temporal and spatial progression of the simulated hydrograph through the model network.

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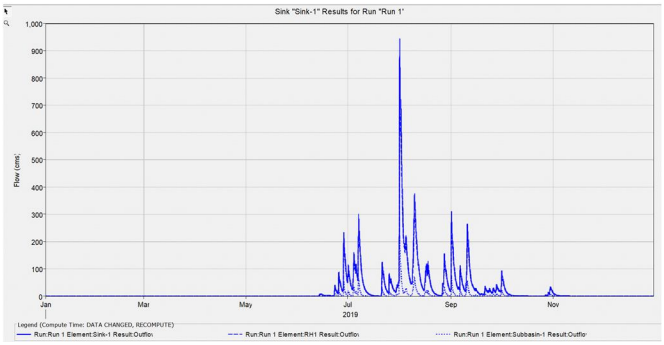


Fig3: Hydrograph at principal outlet of basin

C. Pilol Hydrograph Comparison

At JH2, the optimized model evaluation yielded R^2 = 0.57 and NSE = 0.437. The normalized NSE reported by the HEC-HMS objective function was 0.64.The observed and simulated time-series plot shows that the model reproduces the broad seasonal response and the timing of the principal early-August response, although differences remain between observed and simulated magnitudes during individual peaks. The comparison plot also shows dispersion around the one-to-one relationship, which is consistent with the reported performance statistics. The optimized model therefore provides a useful event-reconstruction result for the 2019 basin response, with the performance measures reported transparently.

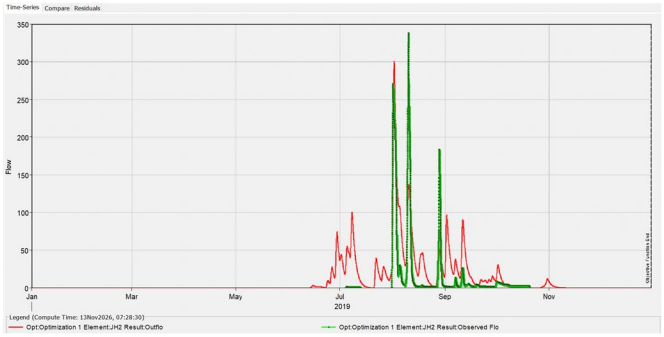


Fig 4: Observed and Simulated Hydrograph at JH2

Fig. 4. Observed and simulated discharge hydrographs at JH2 (Pilol gauging station) for the 2019 simulation and optimization period.

The Pilol comparison is associated with JH2 and is distinct from the Sink-1 outlet result. Accordingly, the JH2 performance statistics are used to describe the observed-versus-simulated comparison, while the Sink-1 peak discharge is presented as the modelled response at the principal basin outlet.

D. Interpretation of the Optimization Trial

The optimization trial employed junction JH2 as the target location, aiming to maximize the Normalized Nash–Sutcliffe statistic throughout the 2019 period. The summary of the objective function indicated a value of 0.64. At the same location, the calibration summary reported an NSE of 0.437 and an R^2 of 0.57.

The summary of optimized parameters highlights subbasin SB1 as the element for which parameters were modified. Specifically, the Clark Unit Hydrograph storage coefficient was increased from 19.05 to 47.191 hours, and the time of concentration was extended from 10.26 to 31.426 hours. Additionally, the Initial and Constant loss rate was adjusted from 5.0 to 4.7666 mm/h, while the initial loss was altered from 3.0 to 15.673 mm. These values are presented as the optimization results for subbasin SB1 and are not extrapolated to other subbasins.

E. Implications for Flood Modelling

The optimized HEC-HMS results yield a basin-scale estimate of the 2019 rainfall–runoff response and generate a principal-outlet hydrograph at Sink-1.

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This hydrograph is instrumental for subsequent hydraulic modeling, provided that the spatial location, time interval, and model assumptions align with the hydraulic model boundary conditions. The comparison between observed and simulated data at JH2 offers a quantitative foundation for interpreting the model response at the Pilol gauging location. These results underscore the importance of integrating sub-daily rainfall observations with systematic parameter optimization in an event-based hydrologic model. The distinction between the optimization point (JH2) and the full-basin outlet (Sink-1) is preserved to ensure that performance statistics and outlet discharge are accurately interpreted at their respective locations.

VI. LIMITATIONS AND FUTURE WORK

The model uses the Initial and Constant loss method and the Clark Unit Hydrograph transform method. The optimized parameters provide a calibrated representation of the 2019 response at JH2. As in other conceptual event-based applications, the results depend on the selected basin representation and parameter values. Further work may examine spatially differentiated soil and land-cover properties to refine the loss representation.

The three subbasins are represented through a common loss-method framework. Incorporating spatial soil and land-cover information may support further refinement of the loss parameters.

No baseflow method or explicit reach-routing method was selected in the configuration used for this study. Future applications may examine these processes where suitable supporting data and channel information are available.

Observed discharge from SWDC was available at Pilol and was used for optimization and evaluation at JH2. Sink-1 is reported as the principal model outlet, and the JH2 statistics are not transferred to Sink-1.

The optimized parameter values influence runoff volume, hydrograph concentration and timing. The reported optimization provides one parameter set for the 2019 objective period; further sensitivity testing may be used to examine alternative parameter combinations.

Further refinement may be achieved by incorporating additional discharge observations, spatially distributed soil and land-cover information, and testing suitable baseflow and channel-routing representations. These developments can support subsequent hydraulic flood-inundation studies.

VII. CONCLUSION

An event-based rainfall–runoff model was developed in HEC-HMS 4.14 for the 2019 flood response of the Vishwamitri River basin. The basin model comprised three subbasins with areas of 245.29, 204.25 and 66.786 km², giving a combined drainage area of approximately 516.33 km². Rainfall observations at 15-minute intervals were obtained from Vadodara Municipal Corporation (VMC), and observed discharge at the Pilol gauging station was obtained from SWDC, Gandhinagar. Although data preparation covered a two-year record, the simulation and optimization reported in this study were restricted to 2019.

The Initial and Constant loss method and Clark Unit Hydrograph transform method were used. For subbasin SB1, optimization changed the Clark storage coefficient from 19.05 to 47.191 h and the time of concentration from 10.26 to 31.426 h. The optimized constant loss rate changed from 5.0 to 4.7666 mm/h, and initial loss changed from 3.0 to 15.673 mm.

At JH2, corresponding to the Pilol comparison location, the optimized model yielded $R^2 = 0.57$, NSE = 0.437 and normalized NSE = 0.64. At the principal outlet Sink-1, the simulated peak discharge was 944.4 m³/s at 03:15 on 1 August 2019.

The results demonstrate the use of 15-minute rainfall observations and HEC-HMS parameter optimization to represent the 2019 rainfall–runoff response of the Vishwamitri River basin. The optimized performance statistics at JH2 and the simulated peak at Sink-1 provide complementary information for hydrologic assessment and subsequent hydraulic flood modelling. The model outputs should be interpreted according to their respective locations within the basin network.

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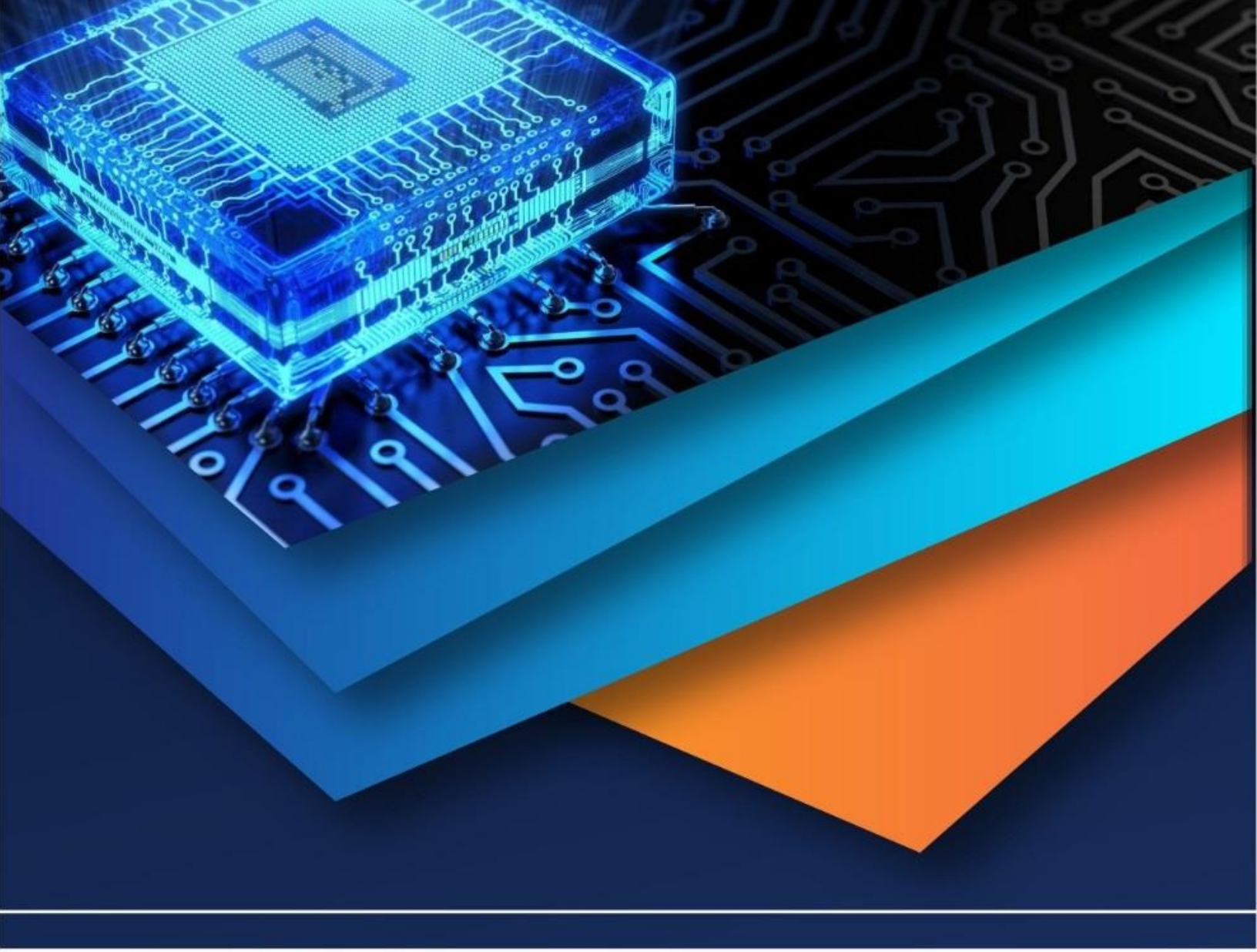
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