Development of real-time flood forecast model for vamsadhara river through hydrological approach

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Abstract
Hydrologic simulation of large river catchments, and the decision to choose a computerized model, is a complex job that necessitates a thorough knowledge of rainfall-runoff processes. While modeling involves proper estimation of direct surface runoff volume and peak discharge in a watershed. In the present study, a real-time flood forecasting model is developed using Hydrological Modelling System (HMS) to forecast floods and River Analysis System (RAS) to identify inundation areas in the Vamsadhara river basin located between Odisha and Andhra Pradesh in India. The flood prediction model is constructed using a simulation of spatial data. The approach includes a loss model is utilized to compute infiltration loss, a transform model to simulate runoff rate, and a muskingum routing method to route flow in a river along with model calibration, and validation with field data. Topographic and hydrologic parameters for each of 17 sub-basins are computed using land use land cover (LULC), muskingum parameters are also calculated. The hydrological model has been calibrated using the precipitation and gauge discharge data of the 2006 flood event. For validation of the modeling process, flood events in 2010 and 2013 at two Gunupur and Kashinagar gauge stations were chosen. The simulated peak discharges obtained are sufficiently accurate with observed data at both the gauge stations. The Nash-Sutcliffe efficiency (NSE) obtained for the calibration period are 0.78 & 0.77, which shows that model performance is good and accepted for simulation of streamflow. Similarly the model performance for validation period are 0.81 & 0.80 for 2010 flood event while for 2013 flood event are 0.84 & 0.82 indicating very good model performance. Overall the study revealed that the HMS model could be employed for the calculation of surface runoff and flood forecasting in similar areas and conditions existing nearby catchments. Flood inundation maps generated with HEC-GeoRAS and HEC-RAS for 1D steady flow demonstrate the model’s output. As a result, this would help in the effective monitoring of flood hazards and the sustainable management of watersheds.

Keywords
GIS, Flood forecast, DEM, Flood inundation map, HEC-HMS, HEC-GEORAS, HEC-RAS.

1.Introduction
River floods are usually caused by a combination of wind-driven flood surges, low barometric pressure, and massive waves colliding with high upstream river flows. These floods are known to be the most devastating natural hazards. In India, wide sectoral and regional variables impact country climate change adaptability [1]. According to Markus et al. [2] climate change effects in the catchment, this change in climate is the leading cause of floods, mostly due to deforestation, urbanization, etc.

Statistics suggest that floods account for almost 15% of all deaths from natural disasters and that the economic damages caused by floods have been seen to surpass billions of dollars worldwide, not just in developed countries in Asia but also in the countries of the European Union [3].

The occurrence of catastrophic weather conditions in recent years has proven the need of realistic flood models, which function as early warning systems in severe storm situations, reducing economic damage. An early warning system comprises both structural and non-structural measures. While structural incorporates physical construction of embankments, canals, and so on, non structural initiatives include

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flood forecasting models that reduce flood risks \cite{4, 5}. Many countries have made modeling and forecasting such occurrences a top priority \cite{6}.

Hydrological Modelling System (HMS) developed by the United States Army Corps of Engineers helps in simulating the hydrologic cycle of a dendritic watershed system\cite{7}. This model is especially well adapted for simulating direct runoff, which incorporates (overland flow and interflow) and runoff volume, as well as routing to the outlet \cite{8}.

Infiltration loss (Loss model), Transform model, and Muskingum routing model are the three most important components in watershed management. The loss model is based on the Soil Conservation Service–Curve Number (SCS-CN). The transformation of rainfall to direct runoff is based on SCS-Unit Hydrograph (UH). The channel routing of river flow based on Muskingum routing method. This methods has been successively used for several hydrological case studies \cite{9, 10, 11}.

The Vamsadhara river basin flows east between Mahanadi and Godavari. Its catchment area is 10,830 km2, of which 8015 km2 is in Odisha and 2815 km2 is in Andhra Pradesh (SANDRP)\cite{12}). Almost every year, severe cyclones and heavy rain causes flooding in the Vamsadhara River affecting both Orissa and Andhra Pradesh. Both states experienced devastating floods in 2001, 2003, 2006, 2008, 2011, 2013 (Phallin) & 2019 (Fani). Rivers flowing downstream are primarily responsible for raising the risk of flooding and cause extreme flood events \cite{13}. Andhra Pradesh lies downstream of the river basin, with districts like Guntur, Krishna, Srikakulam, and Vizianagaram being extremely vulnerable.

Odisha's Rayagada, Ganjam, Kendrapada, and Jagatsinghpur districts are susceptible upstream. These flood disasters wiped out entire neighbourhoods or even towns, destroying a large portion of agricultural fields, and resulting in severe property and life loss. With the frequent occurrence of floods in Vamsadhara River, it's essential to develop and use event based watershed model that explain precipitation–runoff processes, which have been a major focus of hydrological study and investigation for decades\cite{14}.

The most difficult aspect of analyzing the river basin is model selection, data availability, calculating the hydrological parameters of the watershed, and project budget. The decision to choose a model is a challenging and critical one since the success of the analysis is dependent on the accuracy of the results and the computer's processing speed. To date, however, no extensive hydrological investigations have been carried in most of the Vamsadhara River catchments. As a result, evaluating and predicting flood risk has become a necessity to undertake a study on hydrologic simulations, and an effort is made to develop a suitable watershed model and classify flood-prone areas in the watershed.

The study's main objective is to produce flood hydrographs from real-time data at Gunupur (GD) and Kashinagar (K) (GDSQ). Calibrate and validate the flood forecast model's peak discharges using CWC data. A steady flow analysis for peak discharges was also done for selected flood events in 2006, 2010 and 2013.

2. Literature review

Remote sensing datasets from many satellites provide significant information not only for monitoring watersheds but also for extracting input data such as Landuse landcover(LULC), Digital Elevation Model (DEM) etc. These geospatial data are utilized for land use mapping, ground water model, and flood risk assessment \cite{15}. Geographic Information System (GIS) facilitates in the processing of SRTM DEM data used as input for rainfall runoff modeling in order to extract basin features for the Vamsadhara River basin. Numerous researches have established that integrating GIS with HEC-GeoHMS enables the creation of a hydrological model \cite{16, 17, 18}. Hydrological models provide a framework for forecasting and evaluating rainfall runoff processes.

The HMS components used in hydrological modeling systems range from lumped conceptual models to spatially distributed hydrological modeling techniques \cite{8}. HEC-HMS is a lumped, event-based runoff model that may possibly simulate rainfall–runoff relationships within a basin \cite{19, 20}. Event-based models are intended to simulate individual events, with a focus on infiltration and surface runoff, and they predict peak discharge and runoff volume. Many studies have demonstrated that event-based models outperform continuous models \cite{21, 22}.

The Hydrological Modeling System is widely utilized in a variety of applications, like in design of drainage systems quantifying the land-use effects on streamflow \cite{23, 24}. Several studies have shown that hydrologic models can be used efficiently for flood forecasting and simulating rainfall–runoff processes in
various basins around the world [25–31]. Flood hydrographs obtained by HEC-HMS is used directly in various geographical areas to solve a high level of complexity, including large river basins, flood warning system, and natural watershed runoff [32].

A study on flood damage reduction indicates measuring the increased volume of runoff for proposed land-use changes in a watershed owing to floods [33–35].

Previous research has found that the HEC-HMS model can simulate direct runoff with a number of distinct combinations of loss methods, transform methods, and routing strategies [36].

Halwatura and Najim [37] applied the HMS model to the Attagalagu Oya river basin in Sri Lanka for simulation and validation. Finally, they concluded that Snyder's UH was the best transformation approach.

Azam et al. [38] obtained acceptable results using the modified SCS loss method and the Clarke Unit hydrograph to simulate peak runoff, whereas [39, 40] simulated runoff using the SCS-CN technique and the SCS UH method to estimate losses and direct runoff.

Vaishnava [41] examined several catchments of the Mahanadi basin, Seonath, and Jonk. The simulation findings of rainfall-runoff processes obtained for the Jonk catchment were preferable to those produced for the Seonath catchment.

The hydrologic model can further be utilized in floodplain studies which generate water surface profiles and flood inundation maps for flood-prone areas. [42–44] investigated steady flow analysis, i.e. river channel behavior, and found that HEC-RAS is an excellent tool for creating floodplain maps.

In [45, 46] investigated using both hydrologic and hydraulic modeling for estimating runoff from intense rainfall events, further flood risk and damages can be predicted and mitigated to some extent. Based on the review of the various literatures related to the application of HEC-HMS for hydrological modeling, it is concluded that this type of study provides a better response to analyzing future extreme conditions and serves as a tool for issuing early warnings during severe cyclonic rainfall in the basin. Large data needs, as well as a lack of clear guidance on the circumstances for their applicability, are few key factors to consider while studying the river basin.

3. Methods

The HEC-HMS model is a physically based and conceptually event-based model that is designed to simulate rainfall-runoff processes in a wide variety of geographic areas, from large river basin water supply and flood hydrology to small urban and natural watershed runoff [8]. Figure 1 illustrates the overall methodology for accomplishing hydrological and hydraulic modeling for the current study. Using real time daily rainfall data, discharge data in every reach of the river is determined for the selected flood events in the years 2006, 2010 and 2013 in HEC-HMS 4.2.1. Comparison between computed and observed flows is determined at the gauge station Gunupur and Kashinagar.

River geometry such as stream centerline, Bank lines, cross-section cutlines, levees are digitized in HEC-GeoRas. Further stream centerline attributes and Cross section cutline attributes are generated to export the HEC-GeoRas file data to HEC-RAS 5.0.4. The steady flow analysis for the peak discharges obtained in the river is generated for the selected flood events using HEC-RAS 5.0.4. Further the water surface profiles obtained are imported in HEC-GeoRAS to generate flood inundation mapping. Section 3.3 contains a brief overview of methods.

3.1 Study area

Vamsadhara basin as depicted in (Figure 2) lies between the Mahanadi and Godavari river basins in the eastern part of India between 180 151 to 190 551 N latitudes and 830 201 to 840 201 East Longitudes. It has five principal tributaries viz. Chaldea, Phalphalia, Ganguda (Harbhangi), Sannanadhi, and Mahendrathanaya; all are on the left side of the river [47].

The basin is influenced by the south-west monsoon during these five months (June to October), receiving around 84.6 percent of rainfall and occasionally cyclones as a result of the emergence of a low pressure in the Bay of Bengal. The average annual rainfall of magnitude is 1400mm. Two barrages are falling on the river are Neradi barrage and Gotta barrage. Since 1891 more the 11 no. of severe cyclones have occurred on this river basin(Source: Disaster Management Dept. A.P). The above categorization of river basins indicates that the Vamsadhara river basin with such a large catchment area needs a flood response time in terms of weeks and reflects major seasonal meteorological conditions.
3.2 Input data

3.2.1 precipitation and river gauge discharge data
A basic prerequisite for any hydrological model, including the HEC-HMS model, is data on rainfall amount and timing. The National Remote Sensing Centre (NSRC) in Hyderabad provided gridded rainfall data with a resolution of 0.25°*0.25 degrees for the years 2001 to 2013. The daily rainfall data has a spatial reference GCS_WGS_1984. To ensure the consistency of precipitation data, gridded raster data was converted into station rainfall using the zonal statistics mean method for 17 sub-basins that have been created within the catchment [48].

Vamsadhara river basin is having two-level forecasts and one inflow forecast station i.e Kashinagar (GDSQ), Gunupur(GD), and Gotta (G) (Source: Integrated Hydrological Data Handbook 2013)[49]. Gunupur and Kashinagar, located at a latitude and longitude of 180 42l N and 830 57l E, are the gauge stations considered for river discharge. The gauge discharge data are collected for the years 2006, 2010, and 2013 from Central Water Commission (CWC), Water Resources Department, Bhubaneswar, Odisha.

3.2.2 DEM and satellite data
The Digital Elevation Model (DEM) with 30 m * 30 m resolution is projected using UTM (Universal Transverse Mercator) zone 44; WGS 1984, and was acquired from Shuttle Radar Topography Mission (SRTM) from NRSC, Hyderabad. It is taken as input, for preprocessing, basin processing, characteristics, and various hydrologic parameters in HEC-GeoHMS. Once the processing is completed mapping GeoHMS units to HMS units, background shapefile, and basin model file, meteorological model files are generated to export the file data from GeoHMS to HMS.

Bhuvan website provided Resourcesat-1, LISS III image of 3-02-2012 with a resolution of 23.5 m has been used to generate the river geometry and flood plains HEC-GeoRAS 10.2.

3.2.3 Soil and LULC data
The National Bureau of Soil Science & Land Use Planning(NBSS&LUP) provided the research region with soil data. Most of the soils in the river basin are identified as loamy, clayey, and clay soils which have low, medium, and high erosion properties respectively [50].

Land use land cover chart (LULC) was collected from NRSC, Hyderabad. It has been divided into eight classes of built-up/urban areas, cultivating land, current fallow, plantation, evergreen forest, deciduous forest wasteland, water bodies. LULC data are primarily required for the assigning of curve numbers (CN) to land areas for the computation of runoff and hydrological study.

3.2.4 Geology and slope data
The study area is part of the Achaeans' eastern ghats group, which is dominated by charnockites and kondalites on the left banks of the river basin and granite gneisses on the right bank [51]. The basin is narrow and undulated [52], with significant slope frequencies indicating rapid runoff in the northeast and northwest region. The slope of the river basin has been grouped into five classes i.e level, gentle, strong moderate, and steep slopes [50].

3.3 Methodology
Runoff computations and execution phases in the HEC-HMS and HEC RAS model is shown in Figure 3.

3.3.1 Rainfall-runoff model development
Basin Model: HEC-Geo HMS is used to create a basin model by DEM processing in ARC GIS 10.2. The processing includes DEM reconditioning, fill sinks, flow direction, stream definition, catchment delineation, drainage line delineation using 30m * 30 m resolution SRTM DEM. A total of 17 sub basins were generated for the present study. Delineation of the watershed into the appropriate number of subbasins is another critical job in modeling. According to Hromadka et al. [53] accuracy of the hydrological model increases, with the effect of watershed division. So to increase the model’s overall accuracy, the catchment is divided into 17 sub-basins by different trials, and specified threshold values are used in the research area’s watershed. The basin model with sub-basins and basin features created in the form of a background map file is imported to HEC-HMS from the data derived by HEC-GeoHMS for model simulation. In HEC-HMS 4.2.1 each model run combines with a basin model, meteorological model control specification and time series data. Basin model consists of hydrologic elements (sub-basins, junctions, reach) and drainage network of the catchment. While in meteorological model defines daily rainfall given as input. In control specification starting date, time and ending date time are scheduled for simulation. Real time series date for all meteorological elements are fed with gauge discharge data for calibration and simulation of the developed model. Figure 4 depicts the entire hydrological modeling with sub-basins, junctions, and reaches of the upper Vamsadhara river generated in HEC-HMS 4.2.1.
**Figure 1** Methodology for modeling process

**Figure 2** Vamsadhara basin: location map
Figure 3 Block diagram showing execution phases in HEC-HMS & HEC-RAS

Figure 4 The hydrological modelling of Vamsadhara river
There are several approaches to calculate the hydrological parameters required to run a model before model simulation in HEC-HMS. Three methods were chosen for the study area to convert rainfall to runoff, the SCS-Curve number as a loss model, SCS-Unit Hydrograph as a transform model for simulating direct runoff, and a muskingum routing model for channel routing. These approaches were chosen based on data availability, adaptability for similar hydrologic conditions, and study applicability. The next section discusses these methods in further detail:

i) Loss model
The loss models in HEC-HMS determine runoff volume by computing volume of water that is intercepted, infiltrated, stored, evaporated and subtracting it from the precipitation [8]. The Soil Conservation Service (SCS) developed the SCS CN loss model was selected in this study to calculate the quantity of runoff from inputs such as rainfall and watershed coefficients for each sub-basin. The watershed coefficient is called the curve number (CN). It ranges from 0 to 100. This approach was chosen because it is widely utilized in many applications and produces better results than the initial and constant loss method [54].

McCuen [55] states that curve number is a simple conceptual method for computing direct runoff volume from a storm event, and is well supported by empirical data. It has been prepared by a combination of Land Use Land Cover (LULC) and hydrological soil group data following the USDA standard table [56].

In [21, 57] emphasized the need of applying the loss model using SCS-CN for event based models.

ii) Transform model
The transform model simulate the process of direct runoff of excess precipitation on a watershed. This excess precipitation is distributed uniformly spatially and is of constant intensity throughout a time interval [7]. A parametric unit hydrograph (UH) model was proposed by the Soil Conservation Service (SCS) (SCS 1972). The model is based on UH averages for a large number of watersheds calculated from gauged precipitation and runoff (HEC, 2000) [8]. SCS-UH was chosen because it is widely used and is more reliable in calculating runoff rate and produces better results than the Synder unit hydrograph method [58]. Lag time is the only input for this method.

iii) Muskingum flood routing model
McCarthy [59] designed the Muskingum method, which is a common lumped flow routing approach. It was chosen for this study. The Muskingum routing technique utilizes a basic conservation of mass approach to traverse a stream reach [8].

Muskingum K (travel time) & Runoff coefficient x are the two parameters. This method has mostly been employed in the study of river engineering to compute hydrological routing parameters, since its introduction in 1930 [60], the muskingum technique has been widely used. The data from the cross-section characteristics and flow conditions may be used to calculate travel time. Both of them are calibrated parameters whereas x ranges from 0 to 0.5. Typical streams have values of x=0.2 to 0.3. The routing parameters K & x values for eight reaches were calculated for the basin models are presented in Table 1. Calibrated routing parameter K and x evaluated were shown in Table 2.

Table 2 summarizes the HEC-HMS Curve Number values for all sub-basins. As mentioned in section 3.2.3, LULC is classified into eight classes for the current study, and CN values calculated range from 34.098 to 91.084, as shown in Table 3, indicating that the land used is in fair to good hydrologic condition with low to moderate runoff potential (NRCS, 2007).

| S. No. | Reach | Travel time (K) | X   |
|-------|-------|----------------|-----|
| 1     | R40   | 0.05           | 0.2 |
| 2     | R60   | 4.7            | 0.2 |
| 3     | R90   | 4.46           | 0.2 |
| 4     | R100  | 1.2            | 0.2 |
| 5     | R110  | 3.95           | 0.2 |
| 6     | R140  | 0.44           | 0.2 |
| 7     | R150  | 7.2            | 0.2 |
| 8     | R170  | 10.3           | 0.2 |
The Energy equation is written as follows:

\[ Z_2 + Y_2 + \frac{\alpha_z V_2^2}{2g} = Z_1 + Y_1 + \frac{\alpha_1 V_1^2}{2g} + h_e \]  

(Courtesy: HEC-RAS 5.0.1)  

\[ h_e = L_s f + C \left[ \frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g} \right] \]  

3.3.2.1D Steady flow in RAS

A river analysis system (HEC-RAS) is used for the current study to create water surface profiles. This system is capable of performing 1D steady flow analysis in natural or constructed channels and compute water surface profiles. This profile may be computed for various flow regimes such as subcritical, supercritical, and mixed flow regimes [61]. It may be computed from one cross-section to the next cross-section by solving the Energy equation with an iterative procedure called the standard step method. The Energy equation is written as follows:

\[ Z_2 + Y_2 + \frac{\alpha_z V_2^2}{2g} = Z_1 + Y_1 + \frac{\alpha_1 V_1^2}{2g} + h_e \]  

(Courtesy: HEC-RAS 5.0.1)  

\[ h_e = L_s f + C \left[ \frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g} \right] \]  

(1)

3.4 Model performance

The accuracy of the model is calculated by evaluating its performance prior to and post calibration, and during validation, using the following criteria proposed by Moriasi et al. [62]. In this study, Nash-Sutcliffe Model Efficiency (NSE) and Coefficient of Determination (R^2) are utilized to evaluate the overall performance of the model.

The Nash-Sutcliffe Efficiency (E) criterion Nash and Sutcliffe [63] was recommended by an ASCE task committee in 1993. E is a positive integer in the range 0 to 1, with E equal to one being the optimum value. While values between zero and one are generally considered to be acceptable limits of performance, values less than or equal to zero imply that the observed discharge is a better indicator than the computed discharge, shows that the model performs insufficiently.
\[ NSE = 1 - \frac{\sum_{i=1}^{M}(m_{obs,i} - m_{sim,i})^2}{\sum_{i=1}^{M}(m_{obs,i} - m_{mean})^2} \]  

(4)

Coefficient of Determination \((R^2)\) describes the ratio of variance and how the simulated data correlates with the observed values of data in the model.

\[ RSR = \frac{\sum_{i=1}^{M}(m_{obs,i} - m_{sim,i})^2}{\sum_{i=1}^{M}(m_{obs,i} - m_{mean})^2} \]  

(5)

4. Results

4.1 Simulation of the model

The hydraulic parameters that are primarily important for the model’s good performance are calculated during the model’s simulation for the flood event of 2006. Initial loss, curve number (CN), basin lag time, travel time \((k)\), and runoff coefficient \(x\) are some of the most significant parameters in the model. The CN, \(k\), initial loss, and lag time are identified as major sensitive parameters based on several parameter sensitivity investigations [54, 64]. Among the four sensitive ones, curve number and lag time can be computed in the ARC GIS 10.2 in GeoHEC-HMS component (USACE), and thus travel time \((k)\) and initial loss become an emphasis for calibrating the model among the four sensitive ones. The initial loss is not taken into account in this study, and the remaining parameter, \(k\), the flood travel time along the channel, is calibrated in the HEC-HMS system using the trial-and-error approach [65]. The hydrologic order from upstream of the basin to the outlet includes reaches R40, R60, & R90 i.e Kutraguda to Gudari covering a distance of 60 km (CWC, Bhubaneswar), reaches R100, R110, R140 flows from Gudari to Gunupur covering a distance of 40 km (flood forecasting stations CWC, Bhubaneswar), while R150 flows from Gunupur to Kashinagar covers a distance of 37 km (gauge stations of the study area) and downstream of the basin is continued with R170 from Kashinagar to Gotta is 27.7 km. The Muskingum parameters \(K\) & \(X\) calculated for the run 2006 are shown in Table 1

4.2 Model calibration and validation

Parameters are finely tuned until the model’s output is consistent with historical data, this tuning is nothing but adjusting of model parameter values which is known as calibration. By calibrating parameters and evaluating until the model hydrographs match and fit well between computed and observed flow. Cunderlik and Simonovic [66]. The hydrological developed model for this study is simulated, and the optimal parameter values evaluated are presented in Table 2. Calibration is performed using the optimal parameter values from Table 2, i.e., from 15th August to 15th November 2006 for 90 days utilizing daily rainfall data, gauge discharge (GD) data, and stage data. The observed discharge data are taken as input at gunupur and kashinagar gauges which are located on J91 and J81 in the sub-basin. The computed hydrograph is compared to the observed hydrograph at gunupur and kashinagar gauge station. The observed data closely match with the output simulated hydrographs generated after the simulation run for 2006 flood event. The results tabulated for model calibration are listed in Table 3 for gunupur (GD) and in Table 4 for kashinagar (GDSQ).

In Table 3 the calculated peak discharge at gunupur is 3598.9 m³/sec is slightly higher than the observed peak, flood hydrographs exactly matches with observed peak discharge as shown in Figure 5(a). The total volume is underestimated and peak flow is overestimated than observed flow. Also as shown in Table 4 the calculated peak discharge at kashinagar is 3883.9 m³/sec is slightly higher than the observed peak with a discharge of 3830.3 m³/sec, flood hydrographs exactly matches with observed peak discharge as shown in Figure 5(b).

| Period     | Date                  | Simulated | Observed |
|------------|-----------------------|-----------|----------|
| Calibration | 15th Aug '06 to 15th Nov | 3883.9    | 261.70   |
| Validation | 15th Aug '10 to 15th Nov | 856.9     | 197.39   |
| Validation | 15th Aug '13 to 15th Nov | 2033.9    | 231.33   |

Table 4 Comparison results of simulated and observed flow for Vamsadhara Basin at Kashinagar (GDSQ)
The calibrated model parameters are then tested for another set of historic field observations i.e for the flood event 2010 & 2013 for validation. In this process, if the calibrated parameters do not match with the historical data, the parameters must be refined using multiple trials.

The validation results computed are shown in Table 3 and Table 4. From Table 3 at gunupur (GD) the computed peak discharge obtained is 756.8m3/sec & 1308.8 m3/sec which are slightly higher than the observed peak for the flood events 2010 and 2013, flood hydrographs representing the following flood events are shown in Figure 6(a) & Figure 7(a). The total volume is nearly matched with the observed volume as shown in Table 3.

Similarly from Table 4 at kashinagar (GDSQ) the computed peak discharge obtained is 856.9m3/sec & 2033.9 m3/sec which are slightly higher than the observed peak for the flood events 2010 and 2013, flood hydrographs representing the following flood events are shown in Figure 6(b) and Figure 7(b). The total volume is nearly matched with the observed volume as shown in Table 4. The results calculated show that the model calibrated and validated illustrates a close agreement with computed and observed hydrographs in terms of timing of peak, peak flow, and volume of flow. The relative percent errors between the observed and simulated values obtained found to be below ±20% acceptance level [67].

4.3 Processing of river geometry
ARC GIS 10.2 is used to analyze the DEM and produce a Triangulated Irregular Network (TIN). River Cross-Sections, Stream Centerlines, Stream Bank Lines, and Flow Lines, as well as other river geometry information, are generated and digitized using the TIN in the HEC-GeoRAS model. For Steady Flow Analysis, the geometry data collected from TIN is transferred to HEC-RAS. Manning’s roughness coefficient is assigned to all river stations in the catchment after the cross-section is checked and the geometry is adjusted.

Manning’s roughness coefficient (n) often ranges between 0.030 and 0.050 in thick forest areas. The analysis used a value of 0.035. The peak discharge in each reach of the river has been provided as flow data for profiles PF 2006, PF 2010, and PF 2013, which represent the discharges from selected flood events in 2006, 2010, and 2013. The water surface profiles for PF 2006, PF 2010, and PF 2013 are created using subcritical flow as the flow condition. HEC-RAS exports the produced water surface profiles to HEC-GeoRAS together with the modified geometry. Water surface profiles and flood inundation maps created in ArcGIS10.2 using RAS Mapping Tools are displayed in Figure 11. The villages flooded in Andhra Pradesh state in 2006 are depicted in Figure 12. The following Table 5 and Table 6 details the villages that were impacted by the 2006 and 2013 floods.

5. Discussions
As illustrated in Figures 5 show graphs comparing observed and simulated flow at both Gunupur and Kashinagar gauge stations for the calibrated year of 2006. The observed flow recorded at gauge stations at the respective junctions (J91, J81) is represented by the black dotted lines. The simulated outflow at the junction is represented by the blue solid line. The stage data for that junction is indicated by the yellow dotted line. Figure 5(a) shows that the calculated hydrograph overestimates peak discharge; the computed peak is 3598.9m3/sec, whereas the observed peak discharge is 3127.2 m3/sec, a variance of approximately 400 m3/sec; nevertheless, the graph at Gunupur (GD) matches the historical data well. Figure 5(b) clearly shows that the calculated hydrograph overestimates the peak discharge, with a computed peak discharge of 3883.9 m3/sec compared to observed discharge 3830.3 m3/sec, a percent variation of less than 1.4 percent that is acceptable.

The model was verified at both Gunupur and Kashinagar discharge stations during the floods event of 2010 and 2013. Figure 6 shows validation period hydrographs for 2010, whereas Figure 7 shows validation period hydrographs for 2013. The calculated flow pattern resembles the observed flow pattern quite closely. From Figure 6(a) in 2010, the estimated peak discharge in Gunupur was 756.8 m3/sec, whereas the observed flow was 700 m3/sec, a variance of 50 cumecs that is negligible. Similarly, as shown in Figure 6(b), the estimated peak discharge at Kashinagar gauge stations is 856 m3/sec, with a range of 100 cumecs, which is acceptable.

Figures 7(a) &7(b) shows the calculated flood discharges during the 2013 cyclonic storm at gauge stations Gunupur and Kashinagar are 1308.8 m3/sec and 2033.9 m3/sec, respectively, but the observed flows are 1211.4 m3/sec and 1998.9 m3/sec. The variation at the upstream gauge station, J91, is higher than that at the downstream junction, J81 that may be owing to the travel time K taken from all upstream reaches. As this simulated hydrograph generated corresponds extremely well with the observed
hydrograph, the muskingum parameters $K$ and $x$ computed may be considered accurate.

The model performance was further computed using NSE [NASH, SUTCLIFFE 1970], between simulated and observed flow given by the equation (1). Figure 8 shows the scatter plot of the calibrated year, 2006 at J91 & J81 with a NSE value of 0.786 & 0.773 at Gunupur & Kashinagar gauge station. According to Moriasi et al. [62], E values obtained for calibrated model greater than 0.75 are considered to be good. Coefficient of determination ($R^2$) calculated given by the equation (2). The range of $R^2$ lies from 0-1 where 0 is unacceptable i.e. lesser value indicates high error variance but values greater than 0.5 are acceptable Van Liew [62]. The $R^2$ values obtained for the model are 0.703 & 0.707; Since $R^2$ values are greater than 0.5 are considered acceptable. Figures 9, 10 shows the scatter plot for the validated years, 2010 & 2013, with a NSE value of 0.812 & 0.801 where as $R^2$ values are 0.729 & 0.758. NSE value is 0.843 & 0.823 along with $R^2$ value 0.707 & 0.731 for the flood event 2013. The overall performance rating of the model validated has been found to be satisfactory indicating very good model performance. Figure 11 depicts the water surface profiles and flood inundation maps created in Arc GIS 10.2 using RAS Mapping Tools. The villages flooded in Andhra Pradesh state in 2006 are depicted in Figure 12. Most of the villages are located in the downstream area of the sub-basin. The following Table 5 and Table 6 details the villages of srikakulam district that were impacted by the 2006 and 2013 floods.

5.1 Limitations
Although acquiring high resolution DEM as input data is so expensive, used SRTM 30m data as input to our model to decrease project costs. 30m resolution is extremely low for achieving high accuracy results. Data such as rainfall and river cross-section data necessitate extensive fieldwork, which aid in enhancing the model's accuracy.

![Graph for Junction J81](image1)

![Graph for Junction J91](image2)

Figure 5 Observed & Simulated discharge of Vamsadhara River for the selected flood event 2006
(a) Aug-Nov 2006 ; Gunupur (b) Aug – Nov 2006 ; Kashinagar
Figure 6 Observed & Simulated discharge of Vamsadhara River for the selected flood event 2010
(a) Aug-Nov 2010; Gunupur  
(b) Aug-Nov 2010; Kashinagar (2010)
Figure 7 Observed & Simulated discharge of Vamsadhara River for the selected flood event 2010
(a) Aug-Nov 2013; Gunupur  (b) Aug –Nov 2013; Kashinagar

Figure 8 Scatter plot comparison between simulated & observed flow for calibrated year 2006 for Vamsadhara river
(a) At Gunupur gauge station  (b) At Kashinagar gauge station
Figure 9 Scatter plot comparison between simulated & observed flow for calibrated year 2010 for Vamsadhara river
(a) At Gunupur guage station  (b) At Kashinagar guage station
Figure 10 Scatter plot comparison between simulated & observed flow for calibrated year 2013 for Vamsadhara river
(a) At Gunupur gauge station (b) At Kashinagar gauge station

Figure 11 Flood inundation map during the cyclone, 2006
Figure 12 The villages inundated in AP state during the selected floods in Vamsadhara River are identified.

| Object Id | Name            | Object Id | Name            |
|-----------|-----------------|-----------|-----------------|
| 1         | Kajarada         | 26        | Gollapeta       |
| 2         | Batteru          | 27        | Andhavaram      |
| 3         | Ronanki          | 28        | Ramakrishnapuram|
| 4         | Bhaity           | 29        | Achyutapuram    |
| 5         | Ponnam           | 30        | Nagarikatakam   |
| 6         | Buravalli        | 31        | Mettapeta       |
| 7         | Ambalavalasa     | 32        | Srimukhalingam  |
| 8         | Salihundam       | 33        | Suravaram       |
| 9         | Gara             | 34        | Komanapalle     |
| 10        | Posukudu         | 35        | Yatapeta        |
| 11        | Neradi           | 36        | Mahalakshmpur   |
| 12        | Nivagam          | 37        | Bhagirathipuram |
| 13        | Vasapa           | 38        | Pindravada      |
| 14        | Hamsa            | 39        | Ambavalli       |
| 15        | Kadumu           | 40        | Rellivalasa     |
| 16        | Sirusuvada       | 41        | Akkarapalle     |
| 17        | Kuntibadhra      | 42        | Ramachandrapuram|
| 18        | Somarajupuram    | 43        | Chevakulapeta   |
| 19        | Matala           | 44        | Ponnampeta      |
| 20        | Penugottivada    | 45        | Lukulam         |
| 21        | V.N. Puram       | 46        | Kameshwaripteta |
| 22        | Akulatampara     | 47        | Chennulavalasa  |
| 23        | Vadavalasa       | 48        | Butchipeta      |
| 24        | Dabbapadu        | 49        | Madapam         |
| 25        | Telikipenta      | 50        | Geddavanipeta   |
Table 6 Villages inundated in Srikakulam district during the cyclone Phailin, 2013

| ID | Name       | ID | Name           | ID | Name       |
|----|------------|----|----------------|----|------------|
| 1  | Kajarada   | 27 | Yeragam        | 53 | Ponnampeta |
| 2  | Batteru    | 28 | PeddaSavalapuram | 54 | Lukulam    |
| 3  | Ronangi    | 29 | Dola           | 55 | Kameshwaripeta |
| 4  | Bhaby      | 30 | Pallipeta      | 56 | Chennulaavalasa |
| 5  | Ponnam     | 31 | Lingayudupeta  | 57 | Butchipeta  |
| 6  | Buravalli  | 32 | Udakalapeta    | 58 | Madapam     |
| 7  | Ambalavalasa | 33 | Dompaka        | 59 | Geddavanipeta |
| 8  | Salihundam | 34 | Porlam         | 60 | Muddadaipeta |
| 9  | Gara       | 35 | Gollapeta      | 61 | Kabagam     |
| 10 | Posukudu   | 36 | Andhavaram     | 62 | Venkatapuram |
| 11 | Neradi     | 37 | Ramakrishnapuram | 63 | Ambajipeta  |
| 12 | Nivagam    | 38 | Achyutapuram   | 64 | Gopalapenta |
| 13 | Vasapa     | 39 | Nagarikatakam  | 65 | Anguru      |
| 14 | Hamsa      | 40 | Mettapeta      | 66 | Rugada      |
| 15 | Kadumu     | 41 | Srimukhalingam | 67 | Chodavaram  |
| 16 | Sirusuvada | 42 | Suravaram      | 68 | Allada      |
| 17 | Kuntibadhra| 43 | Komanapalle    | 69 | Ramadasupeta|
| 18 | Somarajupuram | 44 | Yatapeta     | 70 | Gangammapeta|
| 19 | Matala     | 45 | Mahalakshnipuram | 71 | Ampalam     |
| 20 | Penugottivada | 46 | Bhagirathipuram | 72 | Nandigam    |
| 21 | V.N. Puram | 47 | Pindruvada     | 73 | Narasinghanaidupeta |
| 22 | Akulatapara| 48 | Amбавали     | 74 | Kottapalavalasa |
| 23 | Vadavala   | 49 | Rellivala      | 75 | Anandapuram |
| 24 | Dabbapadu  | 50 | Akkarapalle    | 76 | Kollavanipeta|
| 25 | Telikipenta| 51 | Ramachandrapuram |      |
| 26 | Sivaramapuram | 52 | Chevakulapeta |

6. Conclusion

The study’s primary aim is to develop a semi-distributed model for the Vamsadhara river basin. Further, the HEC-HMS model was calibrated and validated for two years using real-time historic flood events. In the study, SCS loss method, SCS-UH, muskingum routing methods were found to be very effective in calculating flood discharge in a sub-basin. The simulated peak discharge of the Vamsadhara catchment was slightly over predicted than the observed flow this variation in discharge values is due to differences in mean rainfall, geologic formation, slope, travel time, vegetation cover, and land use in the sub-basins. Model accuracy and performance still can further be improved by subdividing into more sub-basins [53].

Following are some of the specific conclusions from the analysis:

- Flood Hydrographs for flood events 2006, 2010 & 2013 showed that the model calibrated and validated illustrates a close agreement with computed and observed flow in terms of timing of peak, peak flow, and volume of flow.
- Reasonable results were obtained for semi-distributed model with efficiency 78.6% for calibration period (2006) and nearly 81.2%, 84.3 % for validation period (2010 &2013).
- The model outputs i.e the difference in total runoff volume resulted from the two flood events (validated) is within ±20% acceptance level for the modeling process Bingner et al. [68]
- The muskingum parameters K and x calculated can be considered to accurate.
- The Flood inundation maps generated from the present GIS modeling are also validated and the output maps generated are sufficiently accurate.

Though the structure of HEC-HMS is simple, it is a highly effective tool for flood forecasting. The above values obtained for the model are acceptable. This study also finds that, as it is a real-time hydrological model, it may be applied to other minor catchments in the Vamsadhara river basin as operational flood forecasting in monitoring floods and minimizing natural hazards to a certain extent.

Future scope

Future researchers may be able to expand their knowledge of flood modeling and develop two-dimensional unsteady flow analysis.
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Conflicts of interest
The authors have no conflicts of interest to declare.

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### Appendix I

| S.No | Abbreviation | Description |
|------|--------------|-------------|
| 1    | 1D           | One Dimensional |
| 2    | CWC          | Central Water Commission |
| 3    | DEM          | Digital Elevation Model |
| 4    | GCS-WGS84    | Geographic Coordinates System-World Geodetic System84 |
| 5    | GD           | Gauge Discharge |
| 6    | GDSQ         | Gauge Discharge Sediment Quality |
| 7    | GIS          | Geographic Information System |
| 8    | HEC-HMS      | Hydrologic Engineering Centre’s Hydrologic Modelling System |
| 9    | HEC-RAS      | Hydrologic Engineering Centre’s River Analysis System |
| 10   | LISS-III     | Linear Imaging Self Scanning Sensor |
| 11   | LULC         | Land Use Land Cover |
| 12   | NBSS & LUP   | The National Bureau of Soil Science & Land Use Planning |
| 13   | NRSC         | National Remote Sensing Centre |
| 14   | NSE          | Nash Sctcliffe model Efficiency coefficient |
| 15   | R²           | Coefficient of Determination |
| 16   | SCS-CN       | The Soil Conservation Service-Curve Number |
| 17   | SCS-UH       | The Soil Conservation Service-Unit Hydrograph |
| 18   | SANDRP       | South Asia Network on Dams, Rivers and People |
| 19   | SRTM         | Shuttle Radar Topography Mission |
| 20   | TIN          | Triangular Irregular Networks |
| 21   | USDA         | United States Department Of Agriculture |
| 22   | USACE        | United States Army Corps of Engineers |
| 23   | UTM          | Universal Transverse Mercator |