International Organization of Research & Development (IORD)
ISSN: 2348-0831
Vol. 08 Issue 02 | 2020

Development of HEC-HMS model for flood early warning system in Brahmani basin

Abhinav Pankaj[1], Kapil Singh Tomar[2], Devidas B. Vanve[3]
[1,2,3,4] *Department of Civil Engineering, Alamuri Ratnamala Institute of engineering and Technology Thane, Maharashtra-421601*

DOI: 10.5281/zenodo.4916200

ABSTRACT

Flood warning and Stream flow forecast prior to the event are an effective and non-structural method of flood damage mitigation. In this paper, a hydrological was developed for Flood warning Brahmani river basin, India. HEC-HMS software is used to develop the model. The HEC-HMS model relates precipitation upstream to river flow downstream. The modelling approach includes rainfall-run-off modelling, flow routing, calibration and validation of the model with the field discharge data. CARTOSAT Digital Elevation Model of 30 m resolution, land use/land cover and soil textural data of the study area were used in the modelling to compute topographic and hydraulic parameters. Using historical precipitation event of 2001 and 2005, the model was calibrated and validated to accurately predict the peak hydrograph caused by the precipitation event. From the results, it is found that computed discharges are very well matching with the observed discharges. The developed model can provide the Flood warning with more than 30 h lead time.
Keywords: HEC-HMS, Flood Early Warning System, rainfall-runoff modelling

1. INTRODUCTION

Flood is a natural disaster which occurs mostly due to accumulation of water in excess in any area. Flood waters caused by heavy rains have led to fatal consequences due to diseases. This leads to lots of causalities, spreading of diseases, inflation, economic loss, imbalance in environment and many other issues. Floods are classified on their type and severity.

In India, Major causes of floods are heavy precipitation, low capacity of riverbanks to contain high flows, and accumulation of silts and sediments at riverbeds. Some other factors include obstruction to the flow due to landslides, meandering of rivers, bad natural drainage, cyclone and heavy rainstorms/cloud bursts, snowmelt and glacial outbursts etc.

The Brahmani River Basin in India is experiencing floods that are devastating and causing much damages to the communities living in downstream. Floods occur when heavy rainfall in an upstream area flows to the area in downstream, overflowing into the riverbanks in low-lying areas. This flood destroys buildings, damage crops, pollute the water, causes food shortages. Flood also damage and block highways, making it difficult to provide relief. For the preparation of an effective evacuation plan and to provide the flood warning prior to the event "Flood Early Warning System" is required. The motive of the Flood Early Warning System is to provide information prior to flood to the authorities of area to be affected and to facilitate pre-event evacuation and to minimize potential damage.

This model is fundamentally dependent on precipitation data. IMD gridded data used in this study is only an estimate of actual precipitation. It is unlikely that whole grid will experience same amount of precipitation; rainfall is likely more concentrated in some areas than others. The data therefore may not represent the actual precipitation that occurred. The limited quantity of data was available for the Brahmani Basin. It restricts employing the full analytic capabilities of this developed model. Observed flow at only one location, Jenapur is used to develop this model. If observed flow was available at more locations, the model can investigate a wider range of results.

2. LITERATURE REVIEW

The flood analysis system involves the development of hydrologic models. It is one of the non-structural measures that may help to reduce the number of damages occurred. Various works have been done by hydrologists to improve the capability of hydrologic models for accurate analysis of flood events (Pamela 1992; Lawal et al., 2004; Knebl et al., 2005; Yener et al., 2006; Yonatan et al., 2009).

In Jordan, a study compared the performance of HEC-HMS to another hydrologic model for a single rain event and found that the calibrated HEC-HMS hydrograph fit well with observed data (Abushandi & Merkel, 2013) under different soil and climatic conditions.

Kafle, et al., 2010 developed a HEC-HMS model for flood forecasting. This model resulted in a predicted peak discharge of 98% of the observed value. This study suggested that the HEC-HMS model can be applied to other basins in Indian sub-continents.

It was also used for watershed management in different parts of India (Putty and Prasad, 2000; Shrestha, 2006; Kumar and Bhattacharya, 2011; Bhatt et al., 2012; Kadam, 2011). The model was found accurate in spatially and temporally predicting watershed response in event based and continuous simulation as well as simulating various scenarios in flood forecasting and early warnings.

D. Halwatura (2013) have described Hydrologic simulation employing computer models has advanced rapidly and computerized models have become essential tools for understanding human influences on river flows and designing ecologically sustainable water management approaches. The HEC-HMS is a reliable model developed by the US Army Corps of Engineers that could be used for many hydrological simulations. This model is calibrated and validated for Sri Lankan watersheds and need reliable data inputs to check the suitability of the model for the study location and purpose. Therefore, this study employed three different approaches to calibrate and validate the HEC-HMS 3.4 model to Attanagalu Oya (River) catchment and generate long-term flow data for the Oya and the tributaries.

The majority of the HEC-HMS modelling studies were conducted in watershed where sufficient data is available. There are two main classifications of data needed for HEC-HMS: 1) physical watershed characteristic data and 2) observed time-series data. Both data are available for Brahmani basin. After considering all these papers, this paper focuses on development of a hydrological model for Flood early warning system using HEC-HMS in Brahmani river basin.

3. METHODOLOGY

To implement methodology, it is required to have a study area, in current study Brahmani river basin is selected. Brahmani river basin is situated within the geographical co-ordinates of north latitude 20°28' to 23°35' and east longitude 83°52' to 87°03' approximately. The basin is bounded in the North by Chhotanagpur plateau, in the West and South by the Mahanadi basin and in the East by the Bay of Bengal. The basin flows through Jharkhand, Chhattisgarh and Orissa States and draining a total area of 39,033 sq.km. before it outfalls in to the Bay of Bengal. Geographic setting of Brahmani basin is shown in Figure 1.

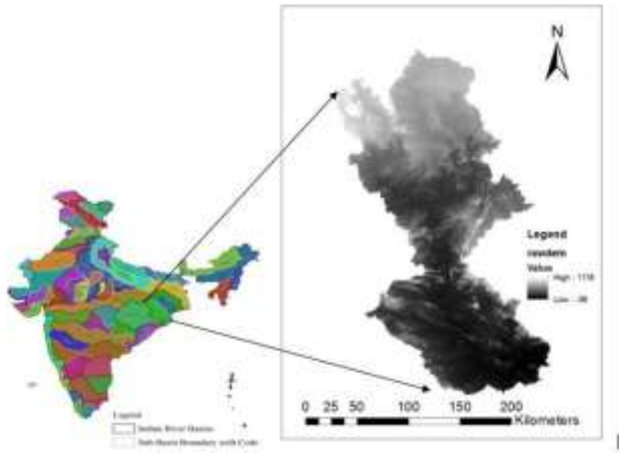

Fig.1 Study Area for this research work

The climate of the basin is tropical with a fairly hot summer and moderately cold winter. This basin is influenced by south west monsoon from June to October, in addition to some occasional down pours in the lower reaches due to the cyclonic depressions in the Bay of Bengal. The average annual rainfall of this basin works out to be 1460mm. The mean maximum temperature varies from 38 to 43° C and the minimum temperature ranges 10 to 15° C.

3.1 Data set required

Digital Elevation Model is the main input for physical parameter extraction in hydrological modelling. CARTOSAT DEM of 30 m resolution was used to extract various topographic and hydraulic parameters of the basin such as slopes, lag time, time of concentration, etc. Sub-basins and drainage network are also delineated using the DEM through an automated process.

The land use / land cover data of the study area is required for CN-Grid generation. The land use of an area is one of the most important factors that affect surface erosion, runoff, and evapo-transpiration in a watershed during simulation. The global Land use and Land cover map has obtained from (http://swat.temu.edu/software/links/india-dataset). Generally, the Curve Numbers (CN) should be assigned to the land areas for runoff computations and hydrological analysis. Land use Land cover distribution.

Soils are important inputs into the model for determining the factors for hydrological processes including surface runoff, infiltration, percolation, lateral subsurface flow and plant water availability in the watershed. The soil map in the basin shows the presence of mainly Loam, Sandy Loam and Sandy Clay Loam.

Historical data are necessary for model calibration and validation, specifically, historical precipitation and the corresponding river flow. As the goal of this study is to model flooding, historical data that correspond to a flood event are required. The watershed's response to precipitation may be different depending on the magnitude and duration of the event, as well as the hydrologic state of the watershed in advance of a storm. Using known flooding events to calibrate the model ensures that calibrated parameters are representative of the watershed during a flood event. The data are entered into the model as time-series data, with each value corresponding to a specific date and time.

Daily rainfall data used in this model is obtained from IMD (Indian Meteorological Department). The data from year 1970-2006 is available in form of square gridded cells of dimension 0.5o x 0.5o. Every part on surface within each grid cell is assumed to experience the precipitation associated with that grid cell. It is important to note that the gridded rainfall data are only an estimation of rainfall; these data are not the actual measured rainfall. It is unlikely that the entire grid cell experiences the same exact rainfall at the same exact time; rainfall is likely more concentrated in some areas than others.

Daily Discharge data for Jenapur gauge station from year 1980-2013 was collected from IndiaWris (Water resources Information system). It was observed that maximum discharge of 10313.6 cumec occurred at 31st July 2005. Discharge data for year 2001 was used for calibration and year 2005 was used for validation.

Based on Literature review, Hydrologic Engineering Centre Hydrologic Model Simulation (HEC-HMS) is selected for model development in this study.

HEC-HMS is a precipitation-based runoff and routing modelling system used to develop and analyse a watershed's hydrologic relationships. The basic function of the model is to receive precipitation as an input, determine what volume of this precipitation infiltrates the ground and what volume becomes runoff, to route this overland runoff towards the river, and finally to route the flow down the river to determine the total flow downstream. The model is can perform both event and continuous simulations. Because this study is an analysis of flash floods, the focus of this study is on event simulation. The model allows the user to choose from a variety of calculation methods to compute each part of the hydrologic process.

Basin model created in HEC-GeoHMS imported in HEC-HMS. The model uses different calculation methods to describe each process of the hydrologic response of the watershed, and each method has associated input parameters. Base flow, canopy storage, surface depression storage, and channel loss were neglected in this study and do not appear in the analysis.

3.2 Model Simulation

The simulation is run using the methods and parameters defined previously. To determine the accuracy of model results, the simulated hydrograph at Jenapur is compared to the historically observed hydrograph at Jenapur.

In analysing a flood event, the most important aspect of the hydrograph is the peak flow, because the peak flow corresponds to the maximum downstream flooding. In contrast, peaks that are significantly less than the maximum may correspond to increased water levels, but not necessarily a flood event. The simulated hydrograph in generally represents the shape and peak of the observed hydrograph, although the simulated peak flow is greater than the observed peak flow rate.

For the purpose of this modelling exercise, it must be assumed that the measured hydrograph is an accurate representation of the peak flow that occurred that day. If the simulated hydrograph can be adjusted to match the peak of the observed hydrograph, the model can better facilitate placement of the river gauge. To do so, model parameters are adjusted through the calibration process.

3.3 Model Calibration and Validation

Model calibration is the process of adjusting physical watershed characteristic input parameters to create a simulated hydrograph that matches an observed hydrograph as closely as possible.

Calibration and validation approaches used for verifying the accuracy of the model for the simulated conditions. Validation involves the parameter used in model obtained from calibration. Here, the observed stream flow data (validation period data) is compared with simulated stream flow data. For calibration event from 17 Jun 2001 to 09Aug 2001 is taken and for validation storm event from 11 Jun 2005 to 11 Aug 2005 was taken.

With two objective functions and Nelder-Mead method for minimizing the objective function, two different calibration procedures are used. For all calibration procedures, the objective function tolerance is set at 0.02 and the maximum number of iterations is set at 50. Model prepared using HEC-HMS is used for Brahmani basin and model is calibrated and validated. Steps followed for the model development are Model setup using HEC-HMS which involves Terrain processing, Basin pre-processing, defining hydrologic parameters and develop HEC-HMS model file and simulation using HEC-HMS.

The shape of the calibrated hydrograph is primarily dependent on the objective function (Percent Error in Peak versus Peak-Weighted RMS Error). When the objective function is held constant, only slight changes are seen by changing the minimization method. The Percent Error in Peak function more closely approximates the magnitude of the peak, whereas the Peak Weighted RMS Error function more closely approximates the overall volume of the hydrograph. Because the goal of the calibration process in this study is to approximate the peak of the hydrograph, the Percent Error in Peak objective function is chosen.

The Univariate method only adjusts the parameter in an attempt to replicate the hydrograph, whereas the Nelder method simultaneously adjusts the K, X and basin lag time. So, the Nelder minimization of the Percent Error in Peak objective function was chosen to calibrate the model. The low objective function value, in combination with the resemblance of the peak of the calibrated hydrograph to the simulated hydrograph, indicate that the calibrated model is capable of representing the relationship between precipitation and observed peak river flow.

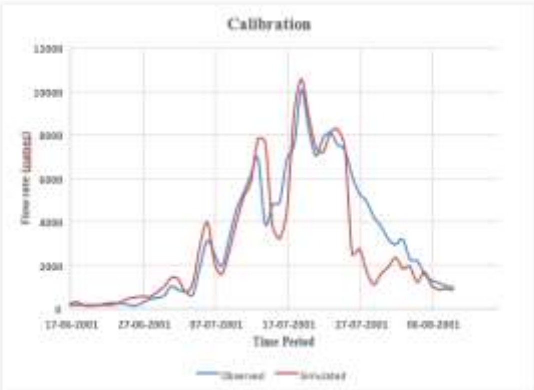

Figure 2 Calibration Hydrograph at Outlet

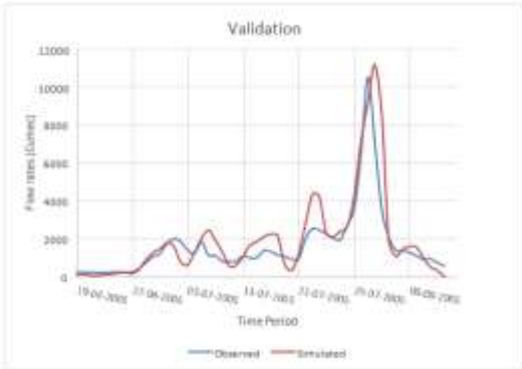

Figure 4 Validation Hydrograph at Outlet

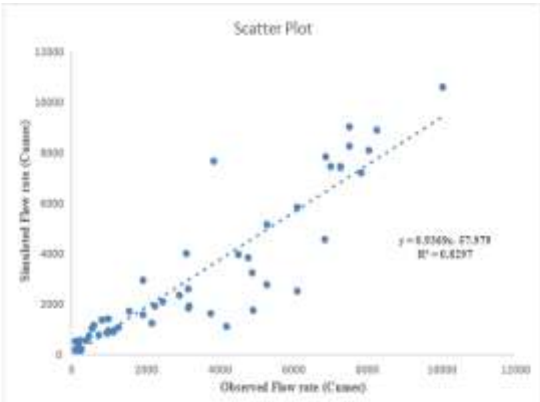

Figure 3 Scatter Plot for Calibration

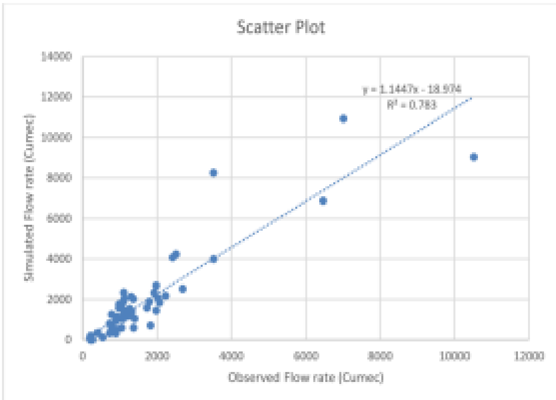

Figure 5 Scatter Plot for Validity

An upstream river gauge is more useful for flood warning when precipitation events occur upstream of the gauge and create a flood wave, as opposed to a precipitation event concentrated downstream, or a slow-rising flood caused by a widespread and/or gradual precipitation event. The speed of the flood wave (primarily a function of river slope and channel resistance) must be slow enough such that there is sufficient time between upstream observation and downstream effect within which to issue a warning. To issue flood warnings in the Brahmani basin, a precipitation event that is more likely to produce a flood wave is modelled.

This theoretical precipitation event applies the same volume of precipitation to the watershed as the August 2006 storm, but concentrates all of the precipitation upstream. Such an event is more likely to create a flood wave because the flow originates upstream, resulting in a constant volume of water being transported downstream.

For this storm event, the magnitude of flow over the entire hydrograph is larger than that of the Aug 2006 storm even though the same total volume of precipitation is used; this is because the precipitation is concentrated over a smaller area, resulting in less initial abstraction, and therefore more runoff.

4. RESULTS OF THE STUDY

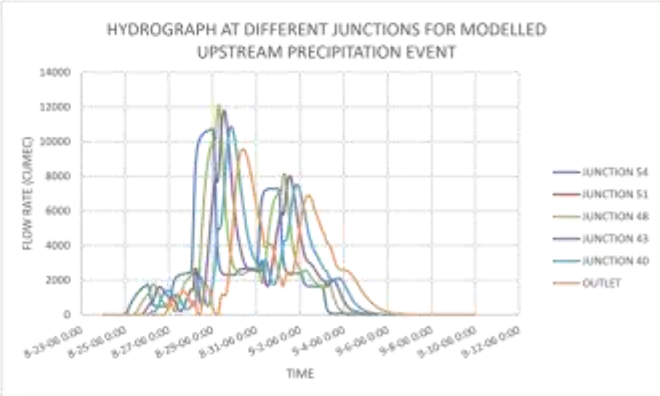

Figure 6 Hydrograph at Different Junctions

To illustrate the movement of flood peak discharge this, the overall peak of the hydrograph in Figure 6 considered. At 23:00 on 08/29, the flow rate at the outlet is relatively low, and more importantly, exhibits a near-zero slope. An observer at this location would not have a reason to believe a flood is approaching because they do not observe elevated water levels or increasing water levels. In contrast, the hydrograph at Sub basin, the most upstream location, shows a significantly higher flow rate during the same hour, and, more importantly, exhibits a steep slope. The steep slope indicates that the flow is increasing and will continue to rise at most upstream Sub basin, it is likely that these conditions (elevated and increasing flow) will soon occur at the downstream location.

To determine the amount of warning lead time available, the time at which the peak flow reaches each location is used to calculate the flood wave travel time.

JUNCTION (Upstream to Downstream)	PEAK DISCHARGE (Cumec)	TIME OF PEAK	REACH	TRAVEL TIME (HH:MM)
JUNCTION 54	10736.7	29Aug2006, 00:00	REACH 1	03:15
JUNCTION 51	11907.2	29Aug2006, 03:15	REACH 2	03:30
JUNCTION 48	12120.3	29Aug2006, 06:45	REACH 3	06:00
JUNCTION 43	11798	29Aug2006, 12:45	REACH 4	07:45
JUNCTION 40	10870.4	29Aug2006, 20:30	REACH 5	12:45
OUTLET	9578.5	30Aug2006, 09:15	**TOTAL**	**32:45**

The calculated travel times suggest that, for this theoretical storm, a river gauge placed Upstream in the Brahmani Basin could be used to provide a flood warning downstream. In this case, the maximum warning lead time available is 32 hours 45 minutes, calculated as the sum of the Travel times for each reach between the outlet and Sub basin It should be noted that the computed travel times represent the travel time of the peak of the hydrograph. As discussed above, the rising leg of the peak hydrograph would instead be used to provide a flood warning. To do so, a specific flow rate and change in hydrograph slope upstream that equates to a subsequent flood downstream need to be specified.

6. CONCLUSION

This study documents how the HEC-HMS model is developed and used to determine a flood warning in the Brahmani Basin. Model parameters are defined and the model is calibrated to accurately predict the watershed's response to a storm event of July-Aug 2001. In the calibration, emphasis is placed on the ability to estimate the peak flow rate. Using the optimised parameters, the model was validated for July-Aug 2005 storm. After the model is validated, a theoretical storm is used to show that flood warning lead time of 32 hours and 45 minutes is computed.

This study uses HEC-HMS with its GIS extension HECGeo-HMS for development of a model to be used in development of "Flood Early Warning System". HEC-GeoHMS is used to create an input to be imported in HEC-HMS for simulating the runoff hydrograph. Using suitable rainfall events and parameters calibration and validation is done.

The following are the important conclusions arrived based on the present study.

- Three different rainfall events were chosen for calibration, validation and to check model performance. The Nash Sutcliffe efficiency (NSE) for calibration is 0.803 while for validation was 0. 654.This shows the suitability of HEC-HMS model for studies catchment.
- The developed “Flood Early warning system” model can issue warning with a lead time of 32 hours and 45 minutes, which is satisfactory for concerned authorities to prepare and evacuation plan.
- From the results, we can conclude that the complexity of the model structure does not determine its suitability and efficiency. Though the structure of HEC-HMS is simple, it is a powerful tool for flood forecasting and Flood Early Warning System.

7. REFERENCES

[1] Arash Asadi et al. “Application of HEC-HMS for Flood Forecasting in Kabkian Basin and Delibajak Subbasin in Iran”, IOSR Journal of Engineering (IOSRJEN) e-ISSN: 2250-3021, p-ISSN: 2278-8719 Vol. 3, Issue 9 (September. 2013)

[2] D. Halwatura, M.M.M. Najim (2013) “Application of the HEC-HMS model for runoff simulation in a tropical Catchment” Environmental Modelling & Software 46 (2013) 155e162

[3] James Oloche OLEYIBLO et al., “Application of HEC-HMS for flood forecasting in

[4] Misai and Wan'an catchments in China, Water Science and Engineering”, Mar. 2010, Vol. 3, No. 1, 14-22

[5] Kishor Choudhari et al “Simulation of rainfall-runoff process using HEC-HMS model for Balijore Nala watershed, Odisha, India”, INTERNATIONAL JOURNAL OF GEOMATICS AND GEOSCIENCES Volume 5, No 2, 2014

[6] M. Azam et al. “Development of flood alert application in Mushim stream watershed Korea”, International Journal of Disaster Risk Reduction 21 (2017) 11–26

[7] M.A.M. Razi, J. Ariffin, W. Tahir and N.A.M. Arish, 2010. Flood Estimation Studies using Hydrologic Modeling System (HEC-HMS) for Johor River, Malaysia. Journal of Applied Sciences, 10: 930-939.

[8] R.D Singh et al “Real Time Flood Forecasting -Indian Experiences”,2010,

[9] Ray Singh Meena (2012) ,“Simulation of runoff and flood inundation in kosi river basin using hydrological models, Ann, remote sensing and gis”

[10] Talchabhadel, R., Shakya, N. M., Dahal, V., and Eslamian, S. (2015). “Rainfall runoff modelling for flood forecasting (a case study on west rapti watershed).” Journal of Flood Engineering, 6(June), 53–61.

[11] U. S. Army Corps of Engineers (USACE). 2013. Hydrologic Modeling System: Technical Reference Manual. Davis, CA: U.S. Army Corps of Engineers, Hydrologic Engineering Center