DEVELOPMENT OF A HYDROLOGIC MODEL FOR FLOOD PREDICTION AND SUITABILITY ANALYSIS OF BORO CROP CULTIVATION FOR SUNAMGANJ HAOR REGION USING HEC-HMS

Muhtasim Haque Nahian[1], Nafees Ul Haque Akhand[2], Satyajit Dey Sagar[3], Refat Tabassum*[4] and Md Arafat[5]

[1] *Undergraduate Student, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh, e-mail: nahianmh67@gmail.com*
[2] *Undergraduate Student, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh, e-mail: nafees0416@gmail.com*
[3] *Undergraduate Student, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh, e-mail: itstruthssc16@gmail.com*
[4] *Undergraduate Student, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh, e-mail: tabassumfarah.24@gmail.com*
[5] *Undergraduate Student, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh, e-mail: 1816027@wre.buet.ac.bd*

***Corresponding Author**

ABSTRACT

The Haor region in Bangladesh, covering one-fourth of the entire region, is highly vulnerable to flash flood. Sunamganj is one of the worst affected Haor areas. During the Rabi season, these Haor areas are occupied by Boro crop fields, where water remains stagnant or experiences flash flooding. These flash floods spill onto low-lying flood plain lands in the region, inundating standing Boro crops, causing loss of thousands of hectares of lands. Although these sudden water surges primarily occur due to heavy rainfall in the Meghalaya region, it is necessary to develop a hydrological model for the low-lying areas in Bangladesh. Additionally, a strong and dedicated early warning system of flash flood forecasting with a considerable leading time for Sunamganj Haor region is essential to mitigate this enormous loss. In this study, we set up a hydrologic model of the Sunamganj Haor basin using Hydrologic Engineering Center, Hydrologic Modeling System (HEC-HMS). The discharge data for the Sunamganj station (Station ID: SW269) was collected from the Bangladesh Water Development Board (BWDB), while the hydrologic data originated from ERA5 (ECMWF Reanalysis v5) data available on the Copernicus Climate Data Store. The methodology involved delineation of catchment areas and stream networks, and setting up the model for different methods of different hydrological processes, including the Simple Canopy Method, Simple Surface Method, Initial & Constant Loss Method, SCS Unit Hydrograph, Recession, and Muskingum. The proposed model provides a sufficient lead-time forecast and computes the stage threshold condition for Boro crop cultivation. The model was calibrated and validated using historical observed data of two significant flood years 2007 and 2010 respectively. The model's accuracy was assessed using statistical measures, including Coefficient of Determination (R^2), Nash Sutcliffe Efficiency (NSE), Root Mean Squared Error Ratio (RSR), and Percent Bias (PBIAS). The parameters for different hydrologic methods were such that the determination coefficients and coefficients of agreement for all the flood events surpassed the acceptable threshold, including the R^2 values 0.9976 and 0.9631 for calibration and validation respectively. The calibrated and validated model was further applied to generate a flood hazard map categorizing the area into Threshold Zone, High Risk Zone, and Low Risk Zone. The Hazard Map, particularly relevant for Boro crop cultivation, considered the critical water level for the Surma-Meghna River and identified areas susceptible to flooding.

Keywords: *Haor; flash flood; Hydrologic Engineering Center, Hydrologic Modeling System; stage threshold; calibration-validation*

1. INTRODUCTION

The Haor basin, situated in the north eastern region of Bangladesh, holds significant importance as a wetland ecosystem. Haors refer to expansive, concave lowland areas located amidst the natural levees, which experience annual monsoon floods. These regions are collectively known as Haor basin (Miah, 2013). In Bangladesh, there are a total of 423 Haors, varying in size. The Sunamganj district boasts the highest concentration of Haors, with 133 of them located in this area (Alam et al., 2010). The Haor regions make a significant contribution to the country's rice production, accounting for 18% of the total output (Huq, 2012).

In the Sunamgonj district's Haor areas, approximately 78% of the total cultivated land, equivalent to about 0.14 million hectares, follows the Boro-Fallow-Fallow cropping pattern. This pattern involves planting crops exclusively during the Rabi season (from November to April), with the land left with standing boro crops during the Aus season (April to July) and the Aman season (July to November) (Alam et al., 2010).

A report on the project based on Bangladesh's Haor Infrastructure by the Government of Bangladesh (2011) stated that the Haor basin experiences mainly two flood phases: the early flood (pre-monsoon) phase and the deeply flooded (monsoon) phase. The early flood takes place from April to June, while the deeply flooded phase persists from June to November. The early flood leads to flash floods, causing significant damage to the standing boro rice crop. In contrast, the deeply flooded phase results in relatively less damage to the crops in the fields, as there is little crop present during this period.

The river system within the Haor region is part of the Meghna basin (Ahmed, 2010). This wetland area is intersected by numerous rivers originating from the Indian hills, carrying substantial runoff water. This often leads to sudden and severe flash floods, with annual extensive flooding being a common occurrence during the monsoon season (Rabby et al., 2011). Flash floods in the Haor region cause crop damage on a biennial basis. Between 2000 and 2004 in the Sylhet division, the Boro crop areas that experienced complete and partial damage due to flash floods were approximately 4.7 lakh acres and 3.0 lakh acres, respectively (MoEF, 2012).

The primary objective of a model for flood prediction is to minimize the loss of property and crop production by delivering precise and timely warnings to users and emergency management authorities, particularly in the Haor regions. The most effective method for integrating meteorological forecasts with hydrological models in flood forecasting systems is by utilizing forecasted hydro-meteorological data. The HEC-HMS model was used for runoff prediction in this study since it plays a crucial role in providing early flood warnings. The basin model comprises six vital processes; the loss, the transform, the base flow, the canopy, the surface & the routing. Lastly, the study combined GIS with HEC-HMS, and analyzed the model's suitability for the studied catchments.

2. STUDY AREA & DATA COLLECTION.

2.1 Study Area

Sunamganj District is located in the north eastern part of Bangladesh. It is situated in the Sylhet Division, which is known for hills and numerous Haors. The district of Sunamganj is bordered by the Indian states of Meghalaya and Assam to the north, Habiganj District to the south, Maulvibazar District to the east, and Kishoreganj District to the west. The district's geographic coordinates are approximately 25.0657° N latitude and 91.3960° E longitude. The Discharge station name is Sunamganj station (SW269), with an approximated coordinate of 25.0772° N latitude and 91.4122° E longitude. Tanguar Haor, Shanir Haor, Karchar Haor, Pagnar Haor, Kalikota Haor, Dekar Haor and Naluar aor are the major Haors within this area (Figure 01).

2.2 Data Collection & Software Used

A SRTM 1-arc second global DEM was downloaded from the United States Geological Survey (USGS) website. Discharge data at Sunamganj (Station ID: SW269) have been collected from BWDB. Precipitation, evaporation & temperature data were collected from ERA5 reanalysis data of Copernicus Climate Data Store for the months April-November. For the calibration & validation, two flood years 2007 & 2010 were chosen. The soil map was downloaded from Food & Agriculture Organization (FAO) website.
The hydrologic model for flood prediction was prepared by using HEC-HMS 4.10. The Land Use Land Cover (LULC) map, soil map processing and flood hazard map were created using ArcGIS 10.8.

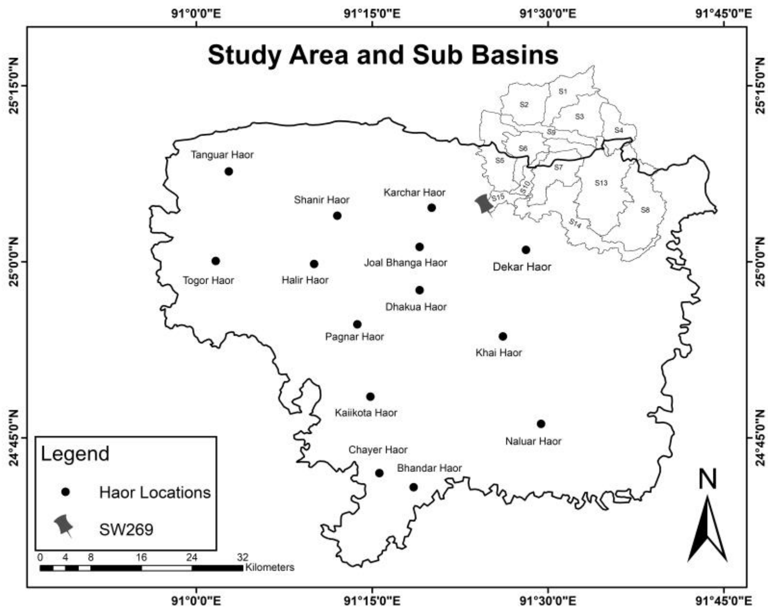

Figure 01: Study Area

3. METHODOLOGY

3.1 Delineation of Catchment Area and Stream Network

Delineation is necessary to create sub-basins & reaches for the HEC-HMS basin model using GIS tool section. In order to delineate a watershed, an outlet point location (Break Point, point of analysis) was specified.

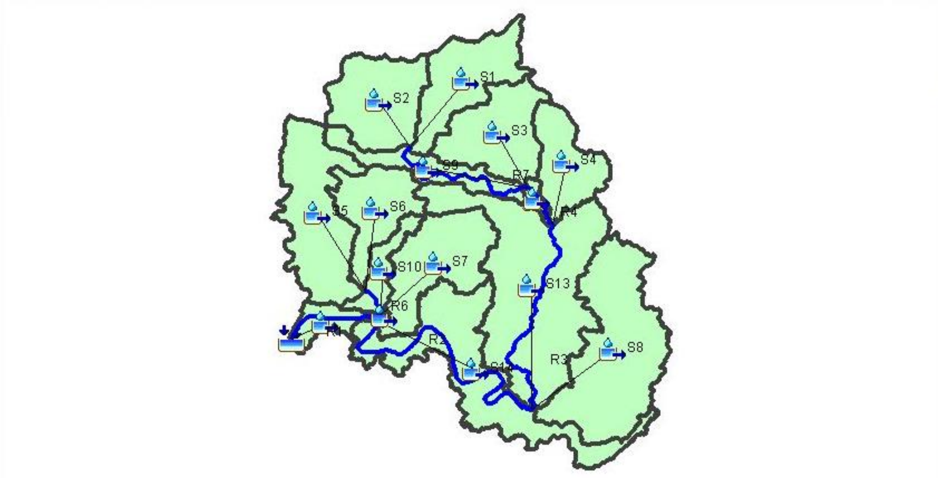

Figure 02: Delineation of Catchment Area and Stream Network

For the study, we have used our discharge station SW269 as the breakpoint, the shapefile of which was imported using GIS tools in HEC-HMS. First, the sink was pre-processed to fill sinks of the terrain data to generate a hydraulically connected DEM which is superimposed on top of existing terrain data. Then the drainage was pre-processed to create two Flow Direction and Flow Accumulation. Identify Streams was used to create stream networks. Lastly, outlet was added and the elements were delineated. The total number of sub-basins were 15 & the total number of reaches were 7, which is shown in Figure 02.

3.2 Land Use and Land Cover Map

A LULC map, which stands for Land Use and Land Cover map, is a geographical representation that categorizes and illustrates the different types of land use and land cover within a specific area or region.

For our study parameter for initial and constant loss method, imperviousness of the study area needed to be calculated. We used Landsat 7 reflectance bands for the process. We composited all the Bands from Band 1 to 7. Then using Training Sample Manager, we gave input different pixels for four different classes (Build Up Area, Vegetation, Water Body and Barren Fields) and after that with Maximum Likelihood Classification Tool, we prepared Land Use Land Cover Maps for 2007 and 2010 (Figure 03 & 04). This Maximum Likelihood Classification Tool searches for the similar pixel categories by sample training manager and creates classes for similar pixels. Thus, Land Use Land Cover Map is prepared. After that converting the raster data to shape file, we calculated the area for each class. Then with the following formula, we determined the imperviousness for the total study area using equation (1).

$$Imperviousness = \frac{(Area\ of\ Total\ Build\ Up\ Class)}{(Total\ Area\ of\ the\ Sub\ basin)} * 100\% \qquad (1)$$

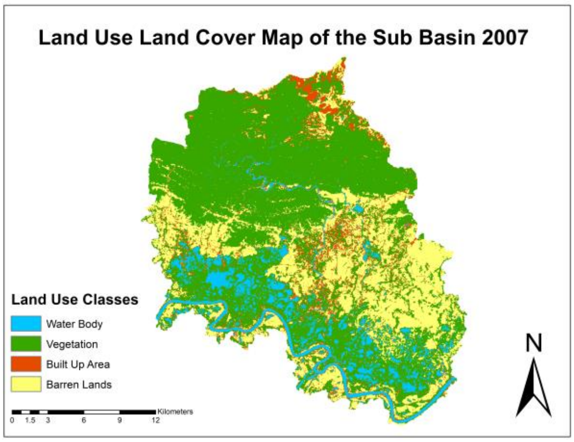

Figure 03: LULC Map for 2007

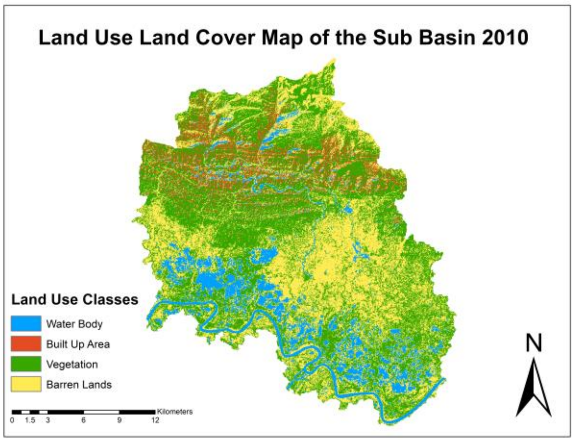

Figure 04: LULC Map for 2010

3.3 Soil Property Identification

In the context of the simple surface method, soil properties are essential. Within this method, we require soil property information for Initial Storage and Max Storage calculations. These parameters can vary significantly depending on the type of soil present. From the study conducted by Saha et al. (2016), we obtained information about the soil properties in the Sunamganj region. Their research indicates that the predominant soil type in the region is non-cohesive, which corresponds to lower initial storage values.

3.4 Rating Curve Generation

As HEC-HMS generates discharge output, it is necessary to utilize observed discharge data for model calibration and validation. However, the discharge data collected from BWDB is not available on a daily basis, which is essential for our study. Consequently, we needed to create a rating curve equation. A rating curve is a graphical representation illustrating the relationship between discharge and water level. In this study, we initially employed statistical methods to derive the rating curve equation, allowing us to estimate daily discharge values based on the available water level measurements.
We have collected the observed water level and discharge data of 2007 provided by BWDB and used the equations (2-7) for Rating Curve:

$$X = log(Water\ Level) \quad (2)$$

$$Y = \log(Discharge) \quad (3)$$

$$\beta = \frac{N(\Sigma XY) - (\Sigma X)(\Sigma Y)}{N(\Sigma X^2) - (\Sigma X)^2} \quad (4)$$

$$b = \frac{(\Sigma Y) - \beta(\Sigma X)}{N} \quad (5)$$

$$Cr = 10^b \quad (6)$$

$$Q = Cr * h^\beta \quad (7)$$

where,
Q = Discharge
h = Water Level
N = Number of Data

After generating the rating curve equation stated as in equation (8):

$$Q = 10.138 * h^{2.329} \quad (8)$$

we plotted the data in Excel and generated a power-based curve to validate the equation. Using the Rating Curve equation, we estimated the daily discharge using the daily water level data provided by BWDB.

3.5 Model Setup for Different Methods

Initially, hourly precipitation data, hourly evaporation data, hourly temperature data & daily discharge data for the catchment were inserted to the model. The model was run employing six different approaches using the parameters in Table 01 in order to determine the most suitable method for the study catchment.

Table 01: Parameters for Initial Model Run

Initial Parameter Values of Surma-Meghna Basin	
Simple Canopy	
Initial Storage (%)	10
Max Storage (MM)	90
Crop Coefficient	0.5
Evapotranspiration	Only Dry Period
Uptake Method	Simple
Simple Surface	

Initial Storage (%)	5
Max Storage (MM)	100
Initial & Constant	
Initial Loss (MM)	100
Constant Rate (MMHR)	1
Impervious (%)	26
SCS Unit Hydrograph	
Graph Type	Standard (PRF 484)
Lag Time (MIN)	Calculated
Recession	
Initial Type	Discharge
Initial Discharge (M^3/S)	0
Recession Constant	0.7
Threshold Type	Ratio to Peak
Ratio to Peak	0.1
Muskingum	
Initial Type	Discharge = Inflow
Muskingum K (HR)	1.5
Muskingum X	0.5
Number of Sub Reaches	1

3.5.1 Simple Canopy Method

Simple canopy method offers a simplified representation of a plant canopy. In this method, the canopy intercepts precipitation until its storage capacity reaches its limit. Once this storage capacity is reached, this storage amount is defined as an effective depth of water. Additionally, when calculating the amount of water to be extracted from the soil, a crop coefficient is applied to the potential evapotranspiration computed in the meteorological model (Roy et al., 2013).

3.5.2 Simple Surface Method

Simple surface provides a simple representation of the soil surface where rainfall on the soil surface is stored until the storage capacity of the surface is filled (Bhuiyan et al., 2017).

3.5.3 Initial Constant & Loss Method

This model incorporates two parameters: the constant rate and the initial loss. These parameters are indicative of the soil's physical properties, the land use characteristics, and the pervious moisture conditions within the basin (Sardoii et al., 2012).

3.5.4 SCS Unit Hydrograph

SCS unit hydrograph is applied for estimating direct runoff. The basin lag time (T_{lag}) is the parameter of SCS unit hydrograph model, which is 0.6 times the time of concentration (Tc), Value of Tc, is computed as suggested by Panigrahi (2013).

3.5.5 Recession

The recession base flow method is formulated to approximate the typical response observed in watersheds where channel flow exponentially diminishes following a hydrological event. It is crucial to define the initial base flow level at the onset of a simulation. The recession constant parameter quantifies the pace at which this base flow decreases in the interim between successive storm events (Scharffenberg, 2006).

3.5.6 Muskingum

The derivation of the original Muskingum routing model is based on equations (9) & (10) for a channel or river reach without lateral inflow:

$$\frac{dW}{dt} = I - Q \tag{9}$$

$$W = K[xl + (1 - x)Q] \tag{10}$$

Where, 'W' is the water storage, 't' is time, 'I' is the inflow, and 'Q' is the outflow. Eq. (9) represents the mass balance, and Eq. (10) expresses the channel storage volume, which is a simple linear combination of the inflow discharge of the upstream section and the outflow of the downstream section. In Equations (9) and (10), K and x are the two model parameters determined from observations; they represent the storage-time constant, which has a value reasonably close to the flow travel time through the river reach, and a weighting factor usually ranging from 0 to 0.5 (Song, 2011).

3.6 Calibration

The calibration process involved good-to-fit parameters that exhibit greater responsiveness for the timeframe of a flood event in 2007. The effectiveness of this calibration can be assessed by visually comparing the results and employing statistical measures. Within this model, the singular discharge station in Bangladesh, namely the Sunamganj station (SW269), was designated as the focal point for calibration purposes. The calibration duration encompasses the period starting from April 1, 2007, through November 30, 2007.

3.7 Validation

Validation of the model was conducted for another flood year 2010 with the ultimate goal of producing an accurate and credible model. The duration encompasses the period starting from April 1, 2010, through November 30, 2010.

3.8 Flood Hazard Map

In order to apply the model's output to real-life scenarios, we have generated a flood hazard map categorizing the area into three distinct classes: the Threshold Zone, representing the critical risk area; the High Risk Zone, signifying an elevated risk; and the Low Risk Zone, indicating a relatively lower risk of flooding. As part of our study, we are developing a model to estimate water levels in response to rainfall in Meghalaya. This model enables us to assess the likelihood of a flood occurring within a timeframe of 12 to 48 hours. We have sourced data from Flood Forecasting and Warning Center (2023), which provides information on the critical water level for the Surma-Meghna River, set at approximately 7.8 meters above Mean Sea Level (MSL). Furthermore, we have identified a flood depth of roughly 1.85 mMSL above the danger level as particularly detrimental to Boro crops (Baky et al., 2012).

4. RESULT & DISCUSSION

4.1 Calibration Parameters

Optimization trials have been initiated to calibrate the values of crop coefficient, constant rate, recession constant & ratio to peak for each sub basin. Similarly, Muskingum K for each reach corresponding to Sunamganj Gage station (Station ID: SW269) is calibrated. Final calibrated values are shown in the following Table 2.

Table 02: List of Calibrated Parameters

Calibrated parameter Values of Surma – Meghna Basin										
Sub Basins	**Simple Canopy**		**Initial & Constant**		**Recession**				**Muskingum**	
	Crop Coefficient		**Constant Rate**		**Recession Constant**		**Ratio to Peak**		**K (hr)**	
	Initial	**Calibrated**	**Initial**	**Calibrated**	**Initial**	**Calibrated**	**Initial**	**Calibrated**	**Initial**	**Calibrated**
S1	0.5	1	1	0.9	0.7	0.99	0.1	0.11	-	-
S2	0.5	1	1	0.9	0.7	0.99	0.1	0.1	-	-
S3	0.5	1	1	0.7	0.7	0.99	0.1	0.1	-	-
S4	0.5	1	1	0.7	0.7	0.99	0.1	0.12	-	-
S5	0.5	1	1	0.7	0.7	0.99	0.1	0.12	-	-
S6	0.5	1	1	0.7	0.7	0.99	0.1	0.12	-	-
S7	0.5	1	1	0.7	0.7	0.99	0.1	0.12	-	-
S8	0.5	1	1	0.7	0.7	0.99	0.1	0.12	-	-
S9	0.5	1	1	0.7	0.7	0.99	0.1	0.12	-	-
S10	0.5	1	1	0.7	0.7	0.99	0.1	0.12	-	-
S11	0.5	1	1	0.7	0.7	0.99	0.1	0.12	-	-
S12	0.5	1	1	0.7	0.7	0.99	0.1	0.12	-	-
S13	0.5	1	1	0.7	0.7	0.99	0.1	0.12	-	-
S14	0.5	1	1	0.7	0.7	0.99	0.1	0.12	-	-
S15	0.5	1	1	0.7	0.7	0.99	0.1	0.12	-	-
R1	-	-	-	-	-	-	-	-	1.5	10
R2	-	-	-	-	-	-	-	-	1.5	10
R3	-	-	-	-	-	-	-	-	1.5	10
R4	-	-	-	-	-	-	-	-	1.5	10
R5	-	-	-	-	-	-	-	-	1.5	10
R6	-	-	-	-	-	-	-	-	1.5	10
R7	-	-	-	-	-	-	-	-	1.5	10

4.2 Observed Hydrograph vs Simulated Hydrograph

Figure 5 and Figure 6 represent the flow hydrograph of 2007 and 2010 flash flood events at Sunamganj station (SW269) respectively

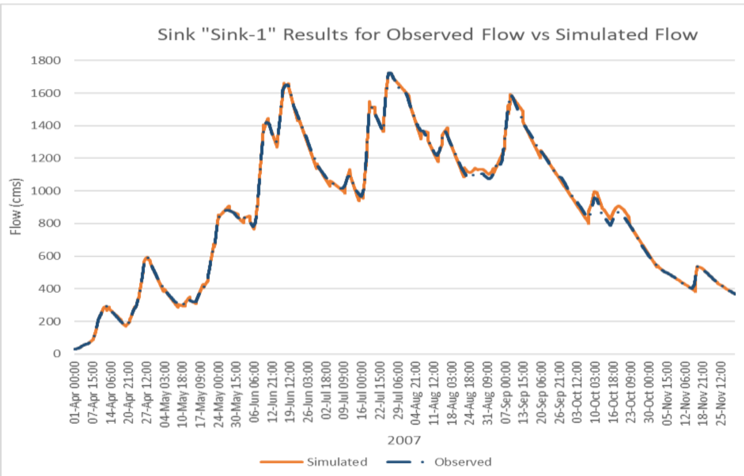

Figure 05: Observed vs Simulated Flow in 2007 for Calibration

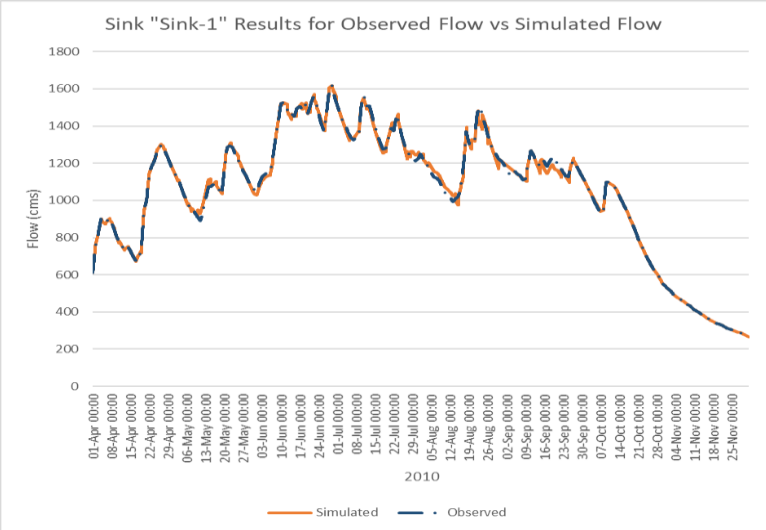

Figure 06: Observed vs Simulated Flow in 2010 for Validation

The observed data was plotted as daily discharge values, and the model interpolated the intermediate values to create an hourly discharge dataset. Conversely, the modeled data was provided on an hourly basis. Since Sunamganj is susceptible to flash floods, it is possible to experience high discharge values for a brief period, which cannot be accurately interpolated in the observed flow graph. Another contributing factor to these sudden peaks is the potential imperfections in the precipitation data itself. We sourced our hourly precipitation data from Copernicus (ERA5), which employs modeling techniques to generate these values based on gathered hydrological data. This phenomenon contributes to the abrupt peaks in the graph.

4.3 Statistics Report

The Statistics Report is a summary statistic for all observed flow locations in a simulation. Summary statistics included in the report are Coefficient of Determination (R^2), Nash Sutcliffe Efficiency (NSE), Root Mean Squared Error Ratio (RSR), and Percent Bias (PBIAS). Table 03 shows the formulas used to prepare the statistics, which are collected from Khan & Ali (2020):

Table 03: List of Formulas for Statistics Report

Statistics	Formula
NSE	$\mathrm{NSE} = 1 - \left[\frac{\sum_{i}^{n}(\mathrm{xobs(i)}-\mathrm{ymod(i)})^2}{\sum_{i}^{n}\left(\mathrm{xobs(i)}-\overline{\mathrm{xobs}}\right)^2}\right]$

PBIAS	$\text{PBIAS} = \left[\frac{\sum_i^n (\text{xobs(i)} - \text{ymod(i)})}{\sum_i^n \text{xobs(i)}}\right]$
RSR	$\text{RSR} = \left[\frac{\sqrt{\sum_i^n (\text{xobs(i)} - \text{ymod(i)})^2}}{\sqrt{\sum_i^n \left(\text{xobs(i)} - \overline{\text{xobs}}\right)^2}}\right]$
R²	$\text{R}^2 = \left[\frac{\left[\sum_i^n \left(\text{xobs(i)} - \overline{\text{xobs}}\right)\left(\text{ymod(i)} - \overline{\text{ymod}}\right)\right]^2}{\left[\sum_i^n \left(\text{xobs(i)} - \overline{\text{xobs}}\right)^2 \sum_i^n \left(\text{ymod(i)} - \overline{\text{ymod}}\right)^2\right]}\right]$

Here, xobs = observed flow, ymod = model flow

Based on the HEC-HMS Manual Version 4.12 (2023), the acceptability of results is categorized into four color codes, ranked from most acceptable to least acceptable: Dark Green > Light Green > Orange > Red.
The default color code for the statistics is mentioned in Table 04.

Table 04: Default Color Codes for Statistics Report

Color Code	NSE	PBIAS	RSR	R^2
Dark Green	$0.65<NSE\leq1.00$	$PBIAS< \pm15$	$0.00<RSR\leq0.60$	$0.65< R^2\leq1.00$
Light Green	$0.55<NSE\leq0.65$	$\pm15\leq PBIAS<\pm20$	$0.60<RSR\leq0.70$	$0.55< R^2\leq0.65$
Orange	$0.40<NSE\leq0.55$	$\pm20\leq PBIAS<\pm30$	$0.70<RSR\leq0.80$	$0.40< R^2\leq0.55$
Red	$NSE\leq0.40$	$PBIAS\geq\pm30$	$RSR>0.80$	$R^2\leq0.40$

Table 05 summarizes the statistics report for the acceptability of the calibration & validation.

Table 05: Summary of Statistics Report

	01 April-30 November, 2007	**01 April-30 November, 2010**
Volume, MM (observed)	36424.89	42108.76
Volume, MM (model)	35661.87	43254.17
Date of Peak (observed)	26 July 2007; 00:00	29 June 2010; 00:00
Date of Peak (model)	26 July 2007; 00:00	29 June 2010; 01:00
NSE	0.611	0.611
PBIAS	0.03%	2.10%
RSR	0.66	0.7
R^2	0.9976	0.9631

Among different types of estimators NSE, PBIASs, RSR and R^2 used to estimate this model's accuracy; the values were mostly adequate and satisfactory. Both the flood volume and timing were accurate. This shows that the HEC-HMS model is suitable for flood prediction.

4.4 Boro Crop Cultivation Time Suitability from the Hazard Map

A further application of the accuracy of the model was used in preparing a flood hazard map for Boro crop cultivation in Sunamganj Haor region in Figure 07. Using the elevation of the Surma river bed level as a benchmark, a threshold zone was defined, which extends into the Danger Zone when it exceeds a height of 1.85 mMSL. Additionally, a Low-Risk Zone was established, primarily encompassing hilly areas near Meghalaya where crop cultivation is not feasible. These delineations resulted in the creation of a Hazard Map, indicating a significant portion of the area falling within the Threshold Zone. Specifically, these areas correspond to the large Haors in Sunamganj, which remain inundated throughout the year. Subsequently, the majority of the region was categorized as a Danger Zone for Boro Crop, with a few areas designated as Low-Risk Zones.

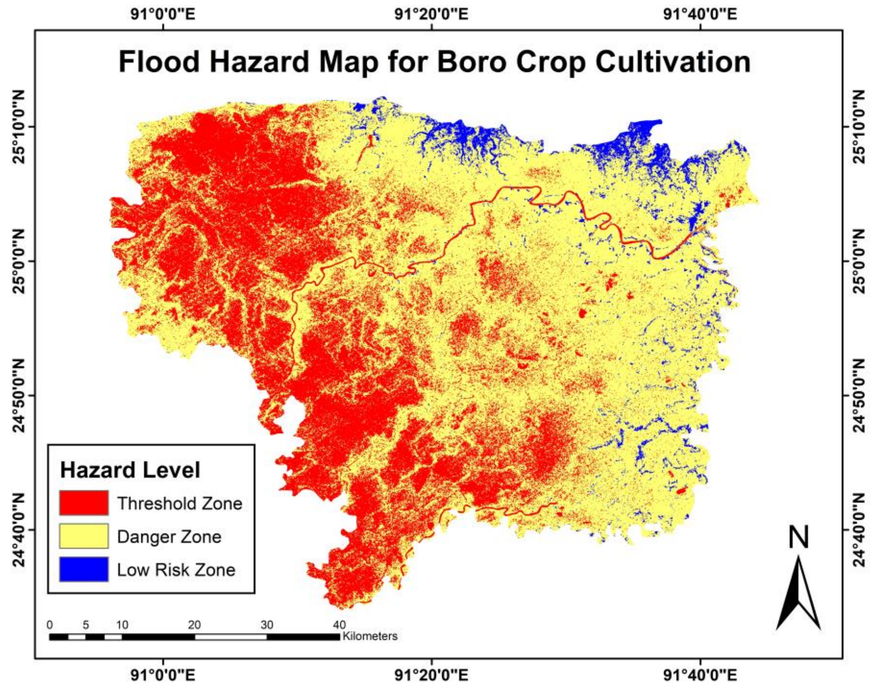

Figure 07: Flood Hazard Map for Boro Crop Cultivation in Sunamganj Haor Region

5. CONCLUSIONS

Developing a hydrologic model for flash flood forecasting for the Sunamganj Haor region of Bangladesh is a crucial initiative, given the vulnerability of this area to flash floods and the need to protect Boro crops. The model accurately forecasted the highest water flow during past floods, as evident from the findings presented. Additionally, it provided reasonably precise estimations for both the flood's extent and the timing of its occurrence. This demonstrates that the HEC-HMS model is suitable for the study area. Using the findings, flood hazard zones for Boro crop were determined accurately.

REFERENCES

Ahmed, A. U. (2010). Bangladesh: Environmental and Climate Change Assessment. Main report, prepared for IFAD's Country Strategic Opportunities Programme 2012-2018.

Alam, M. S., Quayum, M. A., & Islam, M. A. (2010). Crop production in the Haor areas of Bangladesh: insights from farm level survey. *The Agriculturists, 8(2),* 88-97.

Baky, A. A., Zaman, A. M., & Khan, A. U. (2012). Managing flood flows for crop production risk management with hydraulic and GIS modeling: case study of agricultural areas in Shariatpur. *APCBEE Procedia*, 1, 318-324.

Bhuiyan, H. A., McNairn, H., Powers, J., & Merzouki, A. (2017). Application of HEC-HMS in a cold region watershed and use of RADARSAT-2 soil moisture in initializing the model. *Hydrology, 4(1)*, 9.

Flood Forecasting and Warning Centre (2023), *Bangladesh Water Development Board*, Bangladesh. Retrieved on September 12, 2023 from http://www.ffwc.gov.bd/

Government of Bangladesh. (2011). *Bangladesh: Haor Infrastructure and Livelihood Improvement Project. Main Report, Volume I*, Report No.: 2263-BD, Local Government Engineering Department.

Huq, S., Rahman, A. K. M. A., Ali, S. M. I., Moeller, P. & Gnoyke, P. (2012). Conference Proceedings on 1st National Conference, Community Based Adaptation to Climate Change in Bangladesh Community Based Adaptation to Climate Change in Bangladesh. Bangladesh Centre for Advanced Studies (BCAS), Dhaka, Bangladesh, 08-09 April 2012.

Khan, N., & Ali, M. M. (2020). Flash flood forecasting of Jadukata River Basin at laurergarh, Sunamganj from real time satellite precipitation product by using HEC-HMS. In Water, Flood Management and Water Security Under a Changing Climate: Proceedings from the 7th International Conference on Water and Flood Management (pp. 201-208). *Springer International Publishing*

Miah, M. R. (2013). Enhancing food security through acclimatized species domestication in the Haor region. *ABC Journal of Advanced Research, 2(1)*, 49-65.

MoEF. (2012). Second National Communication of Bangladesh to the United Nations Framework Convention on Climate Change.

Panigrahi, B. (2013), A Handbook on Irrigation and Drainage, *New Indian Publishing Agency*, New Delhi, p. 600.

Rabby, T. G., Alam, G. M., Mishra, P. K., Hoque, K. E., & Nair, S. (2011). Different economic and policy perspectives in micro population for sustainable development: A study of the Haor livelihood in Bangladesh. *African Journal of Business Management, 5(6)*, 2475.

Roy, D., Begam, S., Ghosh, S., & Jana, S. (2013). Calibration and validation of HEC-HMS model for a river basin in Eastern India. *ARPN journal of Engineering and Applied Sciences, 8(1)*, 40-56.

Saha, U., Chowdhury, S. R., Shahabuddin, M., Ahmed, K. R., & Ghosh, N. C. (2016). A Geotechnical Profile of Haor Area of Bangladesh. *Technical Journal of River Research Institute, 13(1)*, 125-13.

Sardoii, E. R., Rostami, N., Sigaroudi, S. K., & Taheri, S. (2012). Calibration of loss estimation methods in HEC-HMS for simulation of surface runoff (Case Study: Amirkabir Dam Watershed, Iran). *Adv. Environ. Biol, 6(1)*, 343-348.

Scharffenberg, W. A., & Fleming, M. J. (2006). Hydrologic modeling system HEC-HMS: user's manual. *US Army Corps of Engineers*, Hydrologic Engineering Center.

Song, X. M., Kong, F. Z., & Zhu, Z. X. (2011). Application of Muskingum routing method with variable parameters in ungauged basin. *Water Science and Engineering*, 4(1), 1-12.