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Flood Mapping For Jamuna River In Bangladesh Using Hec-Ras 1d/2d Coupled Model To Assess The Adverse Effect Of The Flood On The Agriculture And Infrastructure Of The Jamuna Flood Plain

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ABSTRACT

Flood hazard mapping is essential for flood mitigation and management. Bangladesh is located in the South Asian subcontinent and is prone to flooding. Being a flat country, Bangladesh has regularly faced devastating floods in 1974, 1984, 1987, 1988, 1998, 2000, 2004, 2007, 2010 and 2016. Almost every year, extreme floods produced by the Jamuna River displace thousands of people, as well as huge agricultural and poultry losses. In this research, a 1D-2D coupled hydrodynamic model for the Jamuna River to identify low-lying flood-prone regions. The hydrodynamic model was calibrated and verified in 2004 and 2012 respectively, using water level data. Nearly forty-two Upazila are found to be in danger within the research region. Boro and T-Aman were identified as the most sensitive crop, while the cultivation pattern in the northwestern part of the research region was found to be less hazardous. Based on the frequency analysis using the extreme distribution of the Gumbel method, the flooded area for a return period of 10 and 20 years is 28.39% and 51.62%, respectively. The model's risk map also demonstrates that an event comparable to the 20-year return period would damage most crop models in the research region. Overall, the study proved that the 1D-2D coupled hydrodynamic model-based river flood analytical method is general and adaptable to similar geographical situations. The predicted results, together with the flood map, can be used in the future to reduce property damage and human loss.

Keywords: *Jamuna River; hazard map, crop pattern, flood maps, flood modelling.*

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I. INTRODUCTION

Bangladesh is renowned for being one of the most flood-prone countries in the world due to its location in the lower Hindu Kush Himalayan region. It is created by the confluence of the rivers Ganga, Brahmaputra, and Meghna, as well as their tributaries, all of which originate in the Himalayas (except for the Meghna) and run into the Bay of Bengal. The topography is essentially flat, with a landmass that rises over 10 meters above mean sea level; it is primarily a rural river plain (Rahman et al., 2014). Floods in Bangladesh are produced by several factors, including enormous inflows from upstream catchments, low floodplain slopes, cyclonic storm surges, drainage congestion in older floodplain zones, and the effects of major river confluences, and siltation during dry seasons (Minkin et al. 1996). For a multitude of reasons, floods are an expected and welcomed yearly occurrence in this country. Extreme floods, on the other hand, inundate more than half of the country's surface, harming people's lives, property, and the economy.

Since attaining independence in 1971, Bangladesh has endured catastrophic floods in 1974, 1984, 1987, 1988, 1998, 2000, and 2004 (FFWC, 2005). The nation had its greatest flooding in terms of depth and length in 1998, with about 70% of the country inundated for months (Nishat, 2000). Floods in Bangladesh have become more severe and prolonged, inflicting significant human misery, disruption of everyday life and activities, and damage to infrastructure, crops, and farms, all of which have had considerable economic effects. Flood damages in 1988, 1998, 2004, and 2007 totalled US$1.4, 2.0, 2.3, and 1.1 billion, respectively (World Bank, 2007).

The Jamuna Brahmaputra is 276 kilometres long in Bangladeshi land (Best et al., 2007). During the monsoon season, 25-30% of the territory around the river is regularly inundated (Hossain, 2003). The Jamuna River has an average annual flow of 19,600 m3/sec and discharges roughly 620 billion cubic meters of water into the Bay of Bengal each year, with 80% of this flow entering the sea between June and September, resulting in nearly 9 meters of standing water in our floodplain (Islam, 2012). The Jamuna River had its highest flow (approximately 64 percent) from July to September (Rahman, 2015). The basin is noteworthy for its annual rainfall, which fluctuates between 1058 and 2601 mm. The months of June, July, August, and September saw the most total precipitation. During the monsoon season, the watershed gets around 73.23 percent of its annual rainfall. Heavy rains produce floods during the monsoon season.

It is critical to understand how the Jamuna River is flooded. This study might calculate how much area would be inundated as a result of a certain flow. Furthermore, it is vital to know how quickly or at what rate the flood zones are inundated because of a specific flow; this study was carried out to answer these critical problems. Flood modelling necessitates a two-dimensional model; however, A hybrid one-dimensional (1D) and two-dimensional (2D) hydrodynamic model that combines floodplains as a 2D component and rivers as a 1D component can be used to examine floods. In this aspect, HEC-RAS represents groundbreaking research in the subcontinent and throughout the world, since it employs combined 1D and 2D modelling. The elevation of the water surface determines the accuracy of the flood map, and further 1D model construction is necessary to differentiate the river from the floodplain. As a result, while GIS and HEC-RAS 1D models may be inadequate to portray actual circumstances, automated floodplain mapping and analysis using HEC-RAS (2D) will provide more efficient, effective, and consistent results.

The purpose of this research is to show that the HEC-RAS 1D/2D linked version can simulate flood levels and inundation in the Jamuna River basin. The HEC-RAS wasversion's calibration and validation were used to create the HEC-RAS 1D/2D linked version, which was used to generate a flood inundation map. The MPO's land categorization was entirely based on inundation intensity, hence this method was used to categorize the study's territory. It developed risk maps to safeguard administrative Upazila barriers and land use patterns, then utilized Gumbel's extreme-price distribution to assess flood risks for certain periods.

The research would eventually provide a calibrated hydrodynamic version of the Jamuna River, a version to be used in the development, engineering, operation, and maintenance of flood manipulation facilities, and a monsoon flood inundation map of the Jamuna River basin. The Jamuna is a tangled river whose features alter throughout time. Therefore, more research on the Jamuna River is required in light of expected future climate change and its influence on the river.

Study Area

The Jamuna watershed is located in the North-Central and North-West Zones of Bangladesh. The middle portion and floodplain of the Jamuna, about 25 kilometers on the left bank and 35 kilometers on the right bank of the river. Its latitude ranges from 24°28'26" to 25°12'08" N, while its longitude ranges from 89°23'38" to 90° 70'30" E. The river reach is approximately 90 kilometers long, and the overall area, excluding the river, is 6,870 square kilometers. The research sites were chosen based on the 1998 flood inundation zones, which are the most flooded places in Bangladesh. Only the floodplains of the Jamuna River were included in this research, which included the districts of Gaibandha, Bogra, Sirajganj, Sherpur, Jamalpur, and Tangail (Figure 1).

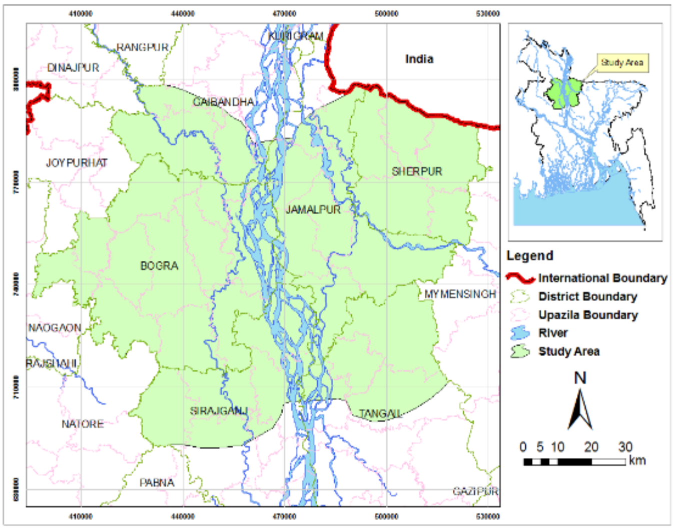

Figure 1: Base map of the study area.

II. METHODOLOGY AND MODEL SETUP

Flood hazard mapping provides the information needed to understand the nature and features of a community's susceptibility to floods, which serves as the foundation for risk management decision-making. In a flood-prone location, estimating the flood depth and the extent of the inundated area is critical for flood risk management. When using an iterative development method, modeling any physical phenomenon is successful. The model is modified based on the availability and quality of data, hydrological understanding, and study objectives.

Data Collection

Various data sets from recent and prior years were collected and merged to build the mathematical flood model. These data also serve as the foundation for further study and interpretation of the model findings, culminating in an accurate evaluation of the hydrological state of the Jamuna River floodplain. The Bangladesh Water Development Board provided a massive amount of data (BWDB) to set up a flood model based on the modeling requirements, including water flow, discharge, and cross-section.

Discharge and Water level data:

Bangladesh Water Development Board (BWDB) collected Jamuna River discharge hydrographs and cross-sections at measuring stations in Bahdurabad, Kazipur, and Sirajganj from 1956 to 2019. The hydrograph includes data at a one-day interval. Data from the year 2004 was used to calibrate and data from the year 2012 was used to validate the hydrodynamic model Figure 2-(a-b).

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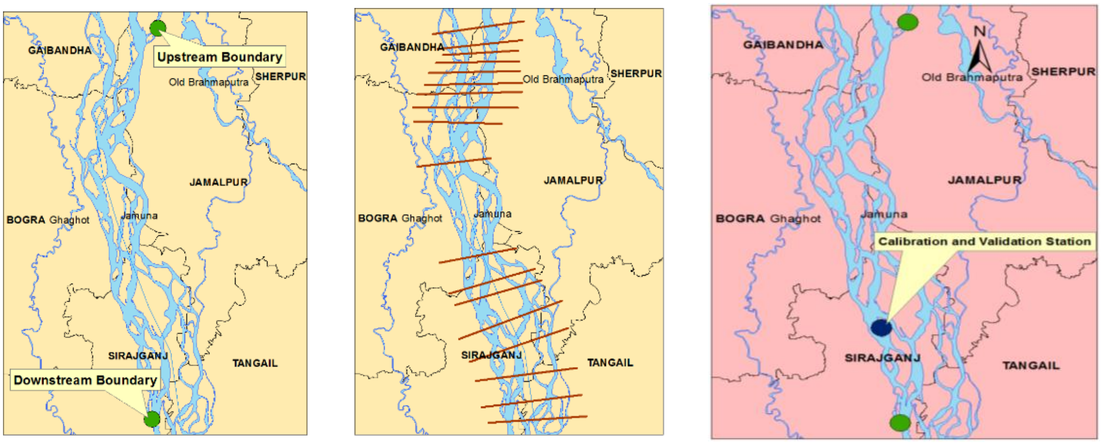


(a) **(b)** **(c)**

Figure 2: (a) Locations of discharge and water level station of Jamuna River. (b) Locations of the cross-section of Jamuna River. (c) Location of model calibration and validation station.

Model calibration and validation

In this research, the one-dimensional HEC-RAS model for the year 2004 was hydrodynamically calibrated at station Kazipur (SW49A). Then the calibrated HEC-RAS-based model was used to verify the flow for 2012 at the station (SW49A) as a validation process (Figure 2-(c))**.**

Model performance evaluation

There were two types of quantitative statistics: conventional regression and error-index. The strength of the linear relationship between simulated and measured data is determined using standard regression statistics. The variation in the units of the data of interest is quantified by error indices (Legates & McCabe, 1999). Two methodologies were employed in this study: the coefficient of determination R^2 as Standard regression statistics and the Nash and Sutcliffe simulation efficiency (NSE) as dimensionless**.**

Coefficient of determination (R2)

The degree of collinearity between simulated and measured data is described by the coefficient of determination (R^2) (Rahman, 2015). R^2 values vary from 0 to 1, with higher values suggesting less error variation, and values larger than 0.5 are normally regarded acceptable (Legates & McCabe, 1999). These statistics are oversensitive to high extreme values (outliers) and insensitive to additive and proportional variations between model predictions and observed data (Legates & McCabe, 1999). Coefficient of Correlation,

$$R = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{\{n\sum x^2 - (\sum x)^2\}\{n\sum y^2 - (\sum y)^2\}}} \quad (1)$$

Where x is the observation and y is the simulated value for the constituent being evaluated.

Nash-Sutcliffe Efficiency (NSE)

The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that compares the size of residual variance (noise) to measured data variance (information) (Nash & Sutcliffe, 1970). The NSE value reflects how closely the observed vs simulated data plot fits the 1:1 line.

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(x-y)^2}{\sum_{i=1}^{n}(x-z)^2}\right] \quad (2)$$

Where x represents the ith observation for the constituent under consideration, y represents the ith simulated value for the constituent under consideration, z is the mean of observed data for the constituent under consideration, and n represents the total number of observations. NSE has a range of -∞ to 1.0 (1 inclusive), with NSE =1 being the best number (Rahman, 2015). Values between 0.0 to 1.0 are typically regarded as acceptable levels of performance, however values 0.0 imply that the mean observed value is a better predictor than the simulated value, indicating inadequate performance (Gupta et al., 2009; Servat and Dezetter, 1991).

One-dimensional and two-dimensional coupled hydrodynamic model

The soil layer is crucial in determining hydraulic parameters (elevation volume, perimeter wetted by elevation, elevation profiles, and so on), inundation depth, and floodplain limits. Once the terrain model has been connected with the geometry and the plan, this is accomplished with RAS Mapper. This terrain is used to depict the floodplain's geometry. A digital terrain model of the research region was previously constructed in order to compute flood depths and flood restrictions using simulation data. Cross-sections should, in general, finish at the top of the embankment, hence the side structure option is used to indicate the top of the embankment along the watercourse. Using the lateral structure button in the geometry data window, two lateral structures were placed on both banks of the Jamuna River upstream. Water surface profiles for unstable flow circumstances were generated using coupled 1D and 2D hydrodynamic models for the years 2004, 1998, and 2016. The data obtained on the water surface profile were exported in GIS format to create a flood map and flood depth to create a flood danger map**.**

Hazard Mapping Phase

The Master Plan Organization (MPO) has developed a framework of flood depth distribution through a classification of land types according to flood depth in order to evaluate prospective land in terms of the kind and depth of yearly flooding (Alam et al., 1999). This is the first and most trustworthy national land type database, which is employed in any analytical task and national policy planning concerns. The MPO land type database was turned into a digital format spatial database as part of the Flood Action Plan work. Details of MPO land type classification are presented in Table 1**.**

Tabel 1: MPO land types.

Land Type	Description	Flood Depth (cm)
F0	High land	<30
F1	Medium high land	30 – 90
F2	Medium low	90 – 180
F3	Lowland	180 – 360
F4	Low to very low	>360

In general, flood hazard assessment is the computation of the negative impacts of flooding for a specific location. To evaluate flood danger, one or more factors such as flood duration, flood depth, flood wave velocity, and rate of increasing water level can be employed, which is mostly dependent on the region researched and the features of the flood. In this study, flood depth, velocity, and flooded regions were all taken into account when assessing flood threats. In this study, a basic and modified strategy, similar to that employed by (Dewan et al., 2007, Islam & Sado, 2000), was utilized to estimate flood hazards.

Frequency analysis

It is critical to understand historical flood data in order to assess the likelihood of such disasters in the future. Estimating the frequency of a flood is critical for quantifying the flood problem. When working with shorter records and estimating hydrological event frequencies more than twice the length of the data, frequency analysis is necessary (Viessman and Lewis, 2002). The Gumbels approach is used for frequency analysis in this study (Gumbel Distribution). In hydrologic and meteorological research, this is the most commonly employed probability distribution function for predicting flood peaks and maximum rainfalls (Chow et al., 1988). In this method, the variate X (maximum rainfall or flood peak discharge) with a recurrence interval of T is given by

$$x_T = \bar{x} + K\sigma_{n-1} \tag{3}$$

Where,

σ_{n-1} = standard deviation of the sample of size N

$$\sigma_{n-1} = \sqrt{\frac{\Sigma(x-\bar{x})^2}{N-1}} \tag{4}$$

K = frequency factor

$$K = \frac{(y_T - \overline{y_n})}{s_n} \tag{5}$$

$\bar{x}$ = mean of the variate.

y_T = reduced variate, a function of T.

$$y_T = -\left[\ln\ln\frac{T}{(T-1)}\right] \tag{6}$$

$\overline{y_n}$ = reduced mean, a function of sample size N.

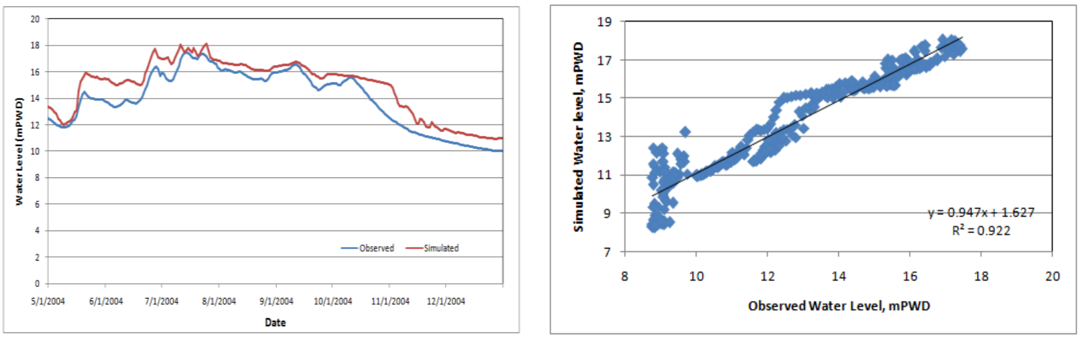
s_n = reduced standard deviation, a function of sample size N.

T = return period.

III. RESULT & DISCUSSION

Calibration and validation of the HEC-RAS Model

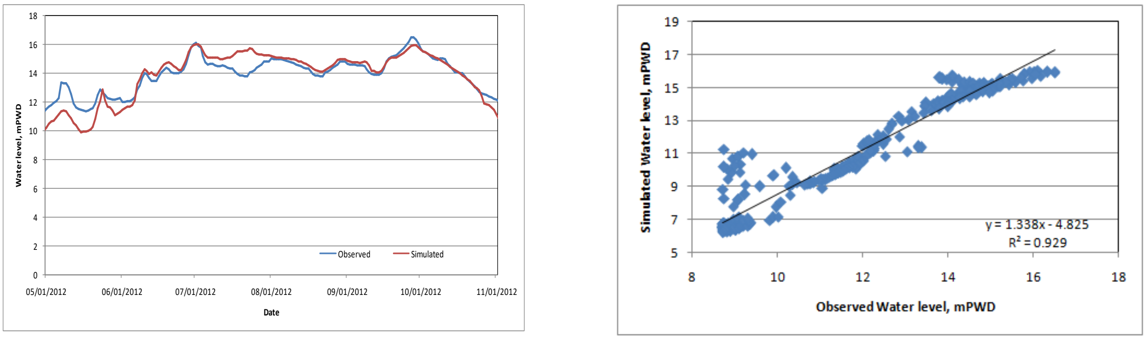
The 2004 dataset is used to calibrate the model, which is then verified using the 2012 dataset. In this work, a one-dimensional model of the Jamuna River's lengthy channel was simulated using a daily hydrograph from January to December. Various Manning roughness coefficients, n, are used in the simulations. The results reveal that raising the value of Manning's roughness coefficients raises the height of the upstream water surface. The comparison of the observed and simulated level hydrograph at the Kazipur measuring station for the Manning 'n' value of 0.026 for the main channel is shown in Figure 3-(a).



(a) **(b)**

Figure 3: (a) Observed and simulated stage hydrograph from 1st May 2004 to 31st December 2004. (b) Statistical parameters for the calibration.

The river's usual Manning's roughness coefficient 'n' is 0.026 (Chow et al., 1988), indicating that our Manning's value is adequate. Figure 3-(a) shows that the trend and form of the simulated and actual hydrographs are almost identical. There are some distinctions between November and December. The coefficient of determination R2 and Nash Sutcliffe Efficiency (NSE) in unstable calibration were found to be 0.922 and 0.46, respectively, indicating that the simulated value is closer to the observed value. Statistical parameters for the calibration are shown in Figure 3-(b).



(a) **(b)**

Figure 4: (a) Observed and simulated stage hydrograph from 1st May 2012 to 1st November 2012. (b) Statistical parameter of unsteady flow validation, 2012.

Validation for the model was completed in 2012 using the calibrated Manning's roughness coefficient (n) value. Validation results have also demonstrated satisfaction. The comparison of observed and simulated stage hydrographs at Kazipur gauging stations is shown in Figure 4-(a).

It demonstrates that the simulated stage hydrograph closely matches the observed hydrograph. The coefficient of determination R2 and Nash and Sutcliffe Efficiency (NSE) in unstable validation were found to be 0.929 and 0.66, respectively, indicating that the validated value is closer to the observed value (Figure 4-(b)).

Analysis of Flood Event

To do unstable simulation, the flow hydrograph from the 2004 rating curve was utilized at Bahadurabad station, and the stage hydrograph from 2004 was employed at Sirajganj station as a boundary condition. From May through September, the simulation was run. It was carried out in order to analyze how flood patterns change over time. A simulated water profile is used to create flood inundation and flood depth maps for 2004 on the different dates supplied and explained in the subsections that follow.

Every century, the Bengal delta was visited by over a half-dozen floods. Floods in 1987, 1988, and 1998 were devastating, causing extensive devastation, suffering, and loss of life. In this study, an inquiry was undertaken into flood scenarios from the 1998 flood occurrence in the study region. In 1998, about two-thirds of the country's total land was inundated. In terms of flooding extent, it is comparable to the terrible flood of 1988. A combination of severe rains from within and outside the country, synchronization of main river peak flows, and a very strong backwater effect culminated in the greatest flood in recorded history. The flood of 1998 lasted more than two months. To execute an unsteady flow simulation, a flow hydrograph from a rating curve from 1998 was utilized at Bahadurabad station, and a stage hydrograph from 1998 was used as a boundary condition at Sirajganj station. It was carried out to analyze the shifting flood patterns throughout time.

The 2016 flood was one of the most severe floods in recent memory. This topic has been researched in terms of flood scenarios on flood events in 2016 in the studied area. To carry out an unstable simulation, a flow hydrograph from a scoring curve from 2016 was utilized at Bahadurabad station, and a degree hydrograph from 2016 was employed at Sirajganj station as a boundary scenario.

Flood inundation map analysis

The comparative maps of the inundation area for particular dates of May to September of 1998,2004 and 2016 are shown in Figure 5. On August 11, 2004, the maximum and minimum inundation areas were 22.06% and 4.39%, respectively. The percentages of flooding area on various dates of 11 June 2004, 11 July 2004, and 11 September 2004 are 6.11%, 12.17%, and 21.25%, respectively. The overall area of the floodplain is approximately 9382 square kilometers (sq km). The flood inundation areas for 11 May 2004, 11 June 2004, 11 July 2004, 11 August 2004, and 11 September 2004 are 412, 573, 1142, 2069, and 1993 square kilometers, respectively. The picture shows that the flooding area grows from May to August 2004 and then decreases, with the highest inundation occurring in August 2004.

Maximum and minimum inundation areas in 1998 were 50.17% on September 9, 1998, and 4.47% on May 9, 1998, respectively. On other days, the percentages of inundation area are 6.98%, 9.38%, and 23.79% on 09 June 1998, 09 July 1998, and 09 August 1998, respectively. The overall area of the floodplain is approximately 9382 square kilometers (sq km). The flood inundation areas for 09 May 1998, 09 June 1998, 09 July 1998, 09 August 1998, and 09 September 1998 are 419, 655, 880, 2232, and 4706 sq km, respectively. The inundation area steadily expands from May to July, then rapidly increases in August and September. In September 1998, the maximum flooded area was discovered.

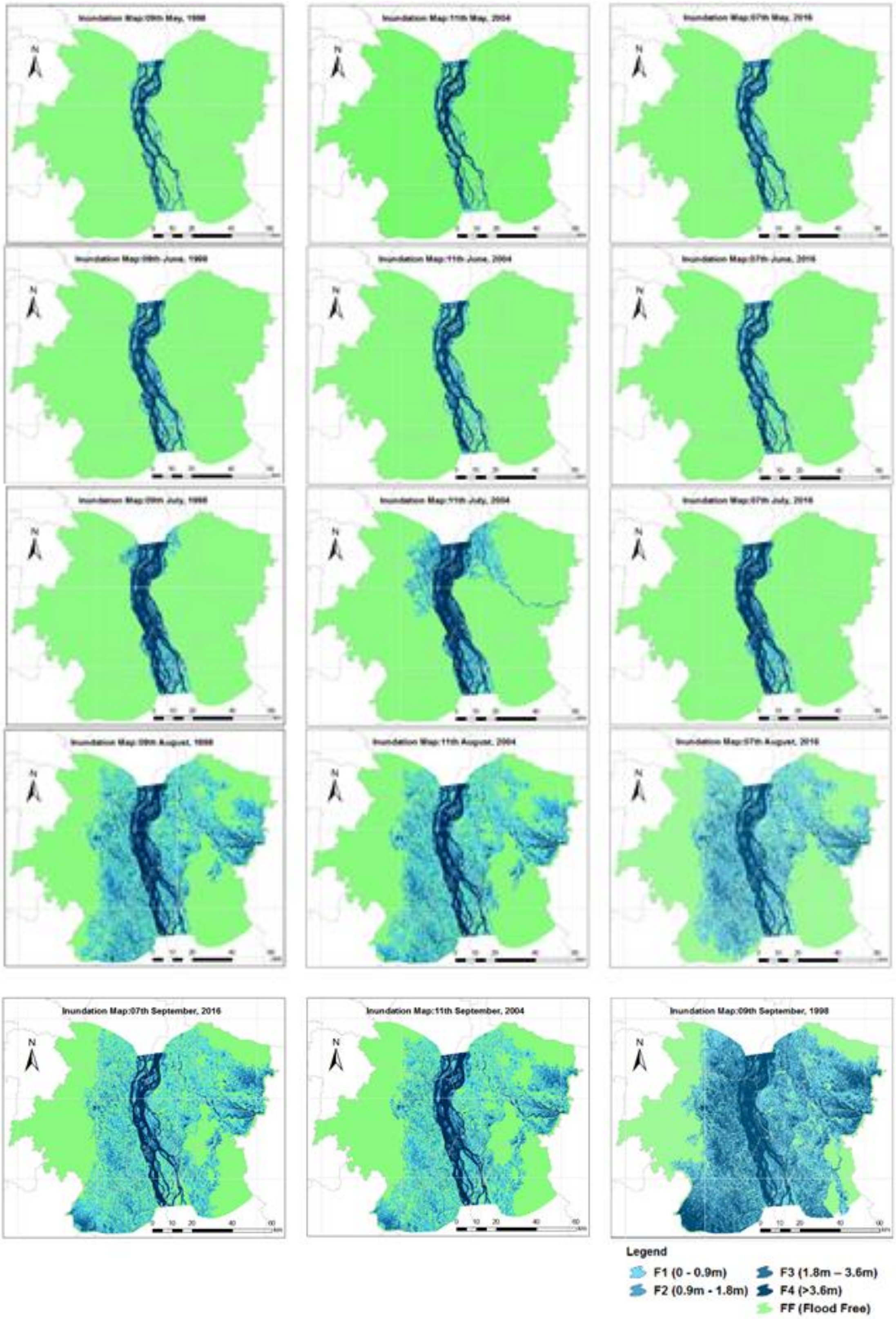


Figure 5: Flood inundation map developed by model simulation at Jamuna River.

In 2016, the maximum and minimum inundation areas were reported to be 25.42% on 07 August 2016 and 5.55% on 07 May 2016. The percentages of inundation area on other days of 07 June 2016, 07 July 2016, and 07 September 2016 are 5.66%, 8.42%, and 22.25%, respectively. The overall area of the floodplain is approximately 9382 square kilometers (sq km). The flood inundation areas for 07 May 2016, 07 June 2016, 07 July 2016, 07 August 2016, and 07 September 2016 are 520, 531, 790, 2384, and 2088 square kilometers, respectively. The flooding area grows from May to August 2016 and starts to diminish thereafter, with the highest inundation occurring in August 2016.

In this study, inundated regions are classified into four qualitative inundation depth classes: F1 (0.0m - 0.9m), F2 (0.9m - 1.8m), F3 (1.8m - 3.6m), and F4 (>3.6m). Table 2 summarizes the outcomes of this examination. According to the categorization of flood depth areas, during the monsoon seasons of 1998, 2004, and 2016, The overall flooded area rose from 92 sq km to 470 sq km, with water depths ranging from 1.8 m to 3.6 m. Water depths of up to 0.9m have swamped an average of 280 sq km and 277 sq km regions, respectively. During the monsoon season, water depths of more than 3.6 m are common in areas ranging from 207 to 507 sq.km.

According to observations from 2004, the total area inundated by water depths ranging from 0.9m to 1.8m, 1.8m to 3.6m, and more than 3.6m increased significantly with the intensity of flooding and tends to diminish after August. The overall area covered by water with a depth of less than 0.9 m was little, but it increased fast in August.

The area of F1 rose from 51 sq km to 868 sq km in 1998, with a significant surge in August and September. F2's area grows from 54 square kilometers to 915 square kilometers, F3's area grows from 70 square kilometers to 1501 square kilometers, and F4's area grows from 245 square kilometers to 1422 square kilometers.

In 2016, the overall flooded area rose from 98 to 589 square kilometers, with water depths ranging from 1.8 to 3.6 meters. Water depths of up to 0.9m have swamped an average of 317 sq km and 243.4 sq km areas, respectively. Water depths of more than 3.6 m are common from 286 sq km to 615 sq km during the monsoon season. When compared to the other simulated days in 1998, the flooded region on September 9, 1998 is the most significant. All four flood depth classifications F1, F2, F3, and F4 have also been seen to grow with time.

Tabel 2: Calculation of flood area according to inundation depth of 1998, 2004 and 2016.

Date	Flood type	F1	F2	F3	F4	Total	Inundated area
	Water depth (m)	**0.0 – 0.9**	**0.9 – 1.8**	**1.8 – 3.6**	**> 3.6**		**%**
1998							
09 May	Area (sq. km)	51	54	70	245	420	4.47
09 Jun		95	80	118	362	655	6.98
09 Jul		113	109	178	480	880	9.38
09 Aug		650	492	520	570	2232	23.79
09 Sep		868	915	1501	1422	4706	50.17
2004							
11 May	Area (sq. km)	55	58	92	207	412	4.39
11 Jun		82	66	99	326	573	6.11
11 Jul		0	368	242	532	1142	12.17
11 Aug		632	467	470	500	2069	22.06
11 Sep		632	424	430	507	1993	21.25
2016							
07 May	Area (sq. km)	72	64	98	286	520	5.55
07 Jun		75	60	99	297	531	5.66
07 Jul		97	96	156	441	790	8.42
07 Aug		659	521	589	615	2384	25.42
07 Sep		682	476	475	455	2088	22.25

Development of Hazard Map

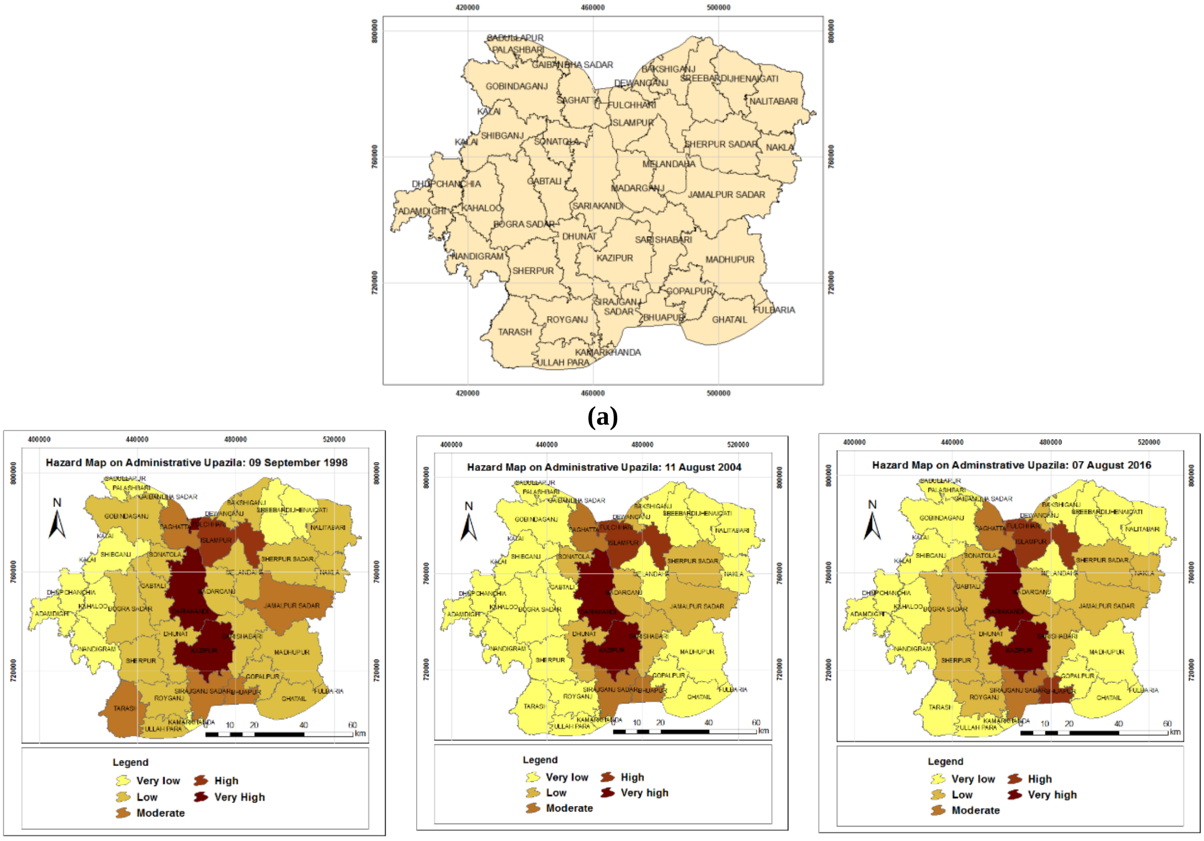
One or more parameters, such as flood frequency, flood depth, flood wave velocity, and rate of water level rise, can be used to estimate flood risk, which is primarily determined by the studied area and flood characteristics. In this study, the submerged area, flood depth, and speed were all considered in the estimation of the map of the administrative unit of risk Upazila flood and agricultural land use map. To assess the risk map, all factors are assessed for the corresponding Upazila administrative unit and culture pattern. all factors are normalized to calculate the cumulative risk. From this cumulative danger, the danger score is calculated. From these five classes, an Upazila administrative unit map and a culture pattern map are prepared. These risk maps were prepared for 1998, 2004, and 2016.

Hazard map on administrative unit

There were forty-two Upazilas in the study area in the administrative unit map of Upazila which is shown in Figure 6-(a). Based on this map, a hazard map for 1998, 2004 and 2016 has been developed (Figure 6-(b)). In 2004, all Upazilas were assessed to be more or less vulnerable to floods. On August 11, 2004, the Upazilas and the Jamuna River were discovered to be more dangerous flood zones. The danger score for the western and northwestern parts of the research region is extremely low.

In 1998, It was found that most of the Upazila except the western part of the study area was affected due to flooding. Sariakandi and Kazipur are the most two hazardous Upazila of all Upazilas. Several Upazilas such as Adamdighi, Nandigram, Dhupchachia, Shibganj, and Kahaloo were less affected by this flood. In the north-eastern part of the study area, Sreebardi and Jhenaigati were less affected too.

In 2016, It was found that most of the Upazila near Jamuna was affected due to flooding. Sariakandi and Kazipur are the two most hazardous Upazila of all Upazilas. Several Upazilas in the western part of the study area and the northeastern and north-western parts of the study area were less affected by this flood event.



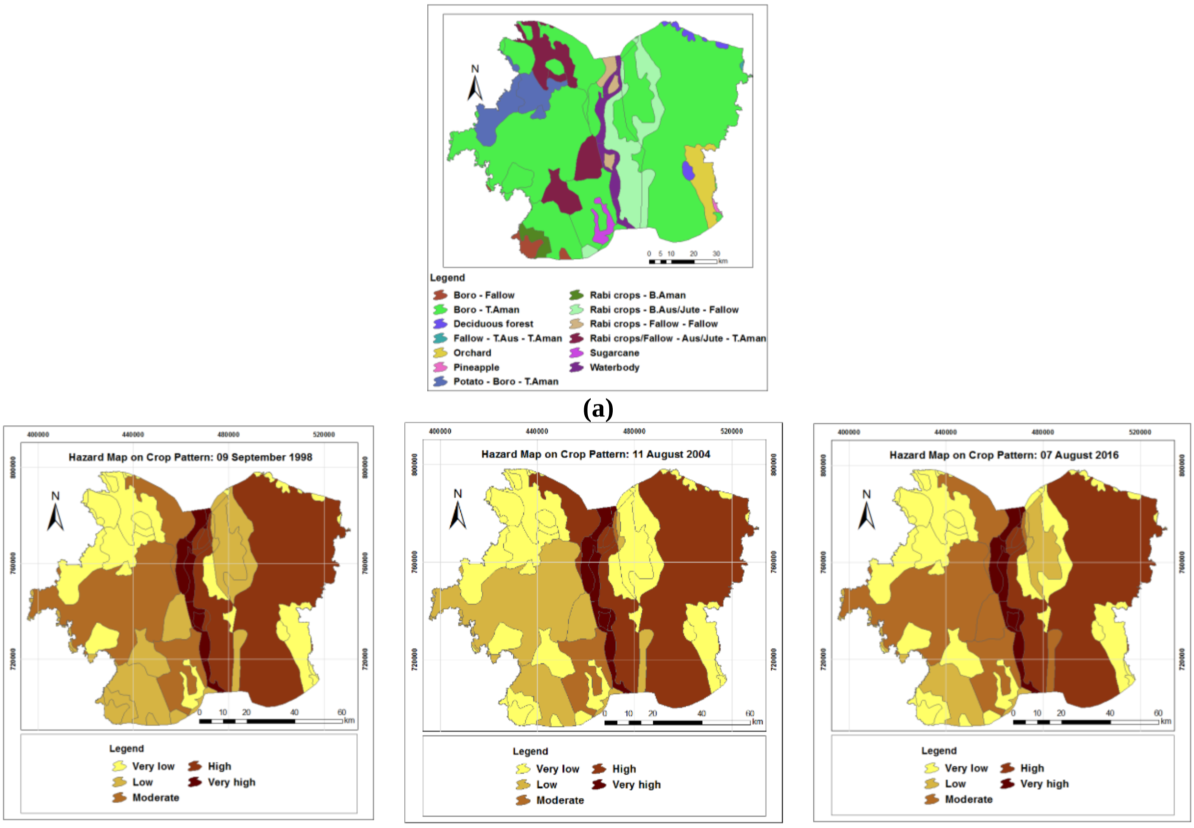
(a)

(b)

Figure 6: (a) Upazila map of the study area. (b) Hazard map on the administrative unit on 09 September 1998, 11 August 2004, and 07 August 2016.

Hazard map on agricultural land use type

Floods caused serious damage to the agriculture sector, including crop losses of the key food staple rice, with the majority of the impact concentrated in Bangladesh's northern regions. Crop hazard management, as a non-structural approach, can be used to avoid or reduce the impact of flooding on various agricultural development operations. Essentially, it involves controlling cropping and other land use in order to lessen crop, livestock, fisheries, forestry, people, and property vulnerability. To serve the purpose the crop pattern of the study area is abstracted from the map of the existing crop pattern of Bangladesh. Figure 7-(a) shows the existing crop pattern of the study area. There are thirteen different types of crop patterns in the research region, as may be shown. The crop pattern Boro - T.Aman dominates the research area. It depicts the crop pattern danger map in the research region for 1998, 2004, and 2016. According to the hazard map, the most vulnerable crop pattern in the research region is Boro - T.Aman in Sariakandi Upazila and Rabi crops - Fallow - Fallow in Islampur and Fulchhari Upazila. The Boro - T.Aman crop pattern in the research area's east is likewise prone to floods. In 2004, the western section of the research region had the lowest flood risky crop pattern to floods. In 1998, the northwestern section of the research region had the lowest flood risky crop pattern to floods. In addition, a flood danger map for 2016 has been created utilizing the model simulation flood inundation depth map.



(a)

(b)

Figure 7: (a) Crop pattern of the study area. (b) Hazard map on crop pattern in the study area in 1998, 2004, and 2016.

Flood Frequency Analysis

Following model calibration and validation, future flows were anticipated for various return durations and flood extents, and inundation maps were created for those estimated flows. The findings of a 2, 5, 10, 25, 50, and 100 year return period flood frequency study based on maximum flow observed at Bahadurabad (Station ID 46.9L) between 1985 and 2018, omitting 2007. The discharge at the Jamuna river gauge station at Bahadurabad is rising.

Assembling the peak discharge data of 1985 to 2018, the peak discharge for the 2, 5, 10, 20 year return periods were calculated. Plotting the peak discharge data with their corresponding return period in a semi-log graph (Figure 8), a relation was established. From that graph, peak discharge for 25, 50, and 100-year return periods was calculated (Table 3) using the extrapolation method.

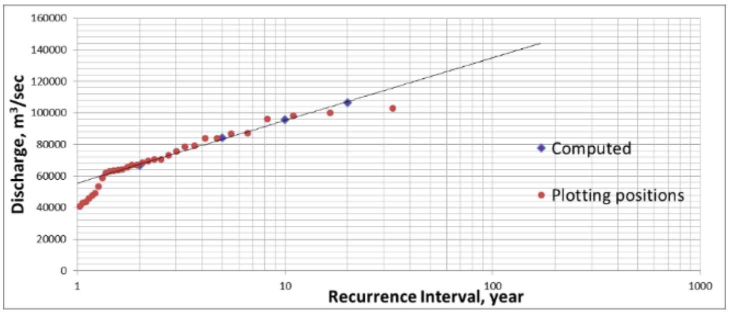


Figure 8: Flood probability analysis by Gumbel's distribution.

Tabel 3: Peak flood discharge for different return periods.

Return period (years)	**Peak flood (m^3/sec)**
2	66863
5	84151
10	95598
20	106577
25	110000
50	123500
100	134000

Maps of the inundation area for the 10-year return period and 20-year return period are shown in Figure 9. The inundation area and the percentage of inundation area with those return periods are shown in Table IV. For the 10-year and 20-year return periods, the maximum flooded areas are 28.39% and 51.62%, respectively. The overall area of the floodplain is approximately 9,382 square kilometers (sq km). The flood inundation areas are 2,663 and 4,843 square kilometers for the 10-year and 20-year return periods, respectively.

Tabel 4: Inundated area on different return periods.

Return Period	Inundation area (km^2)	Inundated area (%)
10 year	2663	28.39
20 year	4843	51.62

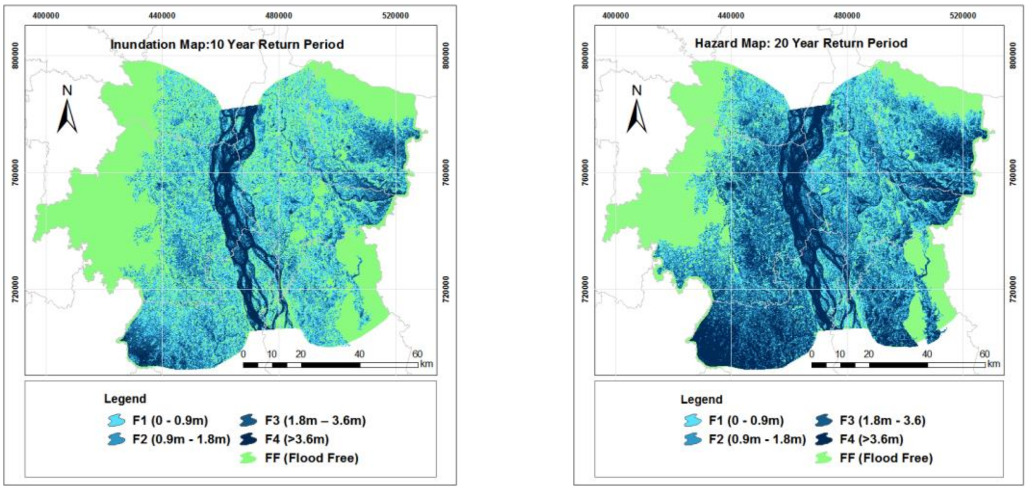


Figure 9: Flood inundation map developed by model simulation at Jamuna River flood plain for 10-year return period and 20-year return period.

In the study, inundated regions are classified into four qualitative inundation depth classes: F1 (0.0m - 0.9m), F2 (0.9m - 1.8m), F3 (1.8m - 3.6m), and F4 (>3.6m). The findings of this evaluation are summarized in Figure 10. Here it can be observed that the inundated area of F1 for both the return periods is quite similar, but the inundated area in other flood types increases incredibly for the 20-year return period. Moreover, it is noted that the flood-free area decreased incredibly for the 20-year return period.

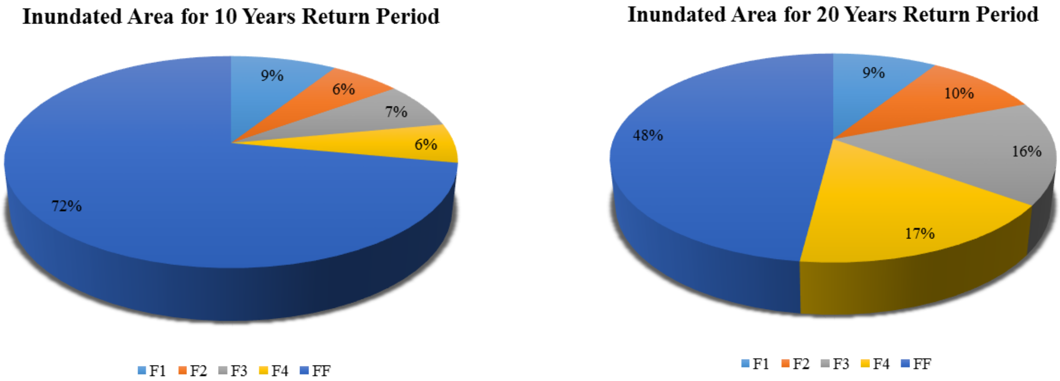


Figure 10: Inundated area according to inundation depth, 10-year return period, and 20-year return period.

To assess the hazard map, all elements for the respective administrative unit and Upazila agriculture pattern are considered. The cumulative exposure is then calculated by normalising all parameters. This cumulative risk is used to determine the risk assessment. The hazard score is classified into five levels: very low, low, medium, high, and extremely high. These five classifications are used to construct an administrative unit map of Upazila and a circumcision pattern map. These risk maps are created for 10-year and 20-year return periods.

Based on the Upazila map, two risk maps were created for the 10-year return period and the 20-year return period (Figure 11). Flooding was found to have affected most of Upazila near Jamuna. Sariakandi and Kazipur are the two most dangerous Upazila of all Upazila. Over a 20-year return period, most Upazila is affected. Bakshiganj, Sreebardi, and Jhenaigati are the three least affected Upazila in the northeastern part of the study area. The northwestern Upazilas are also less affected areas in the study area.

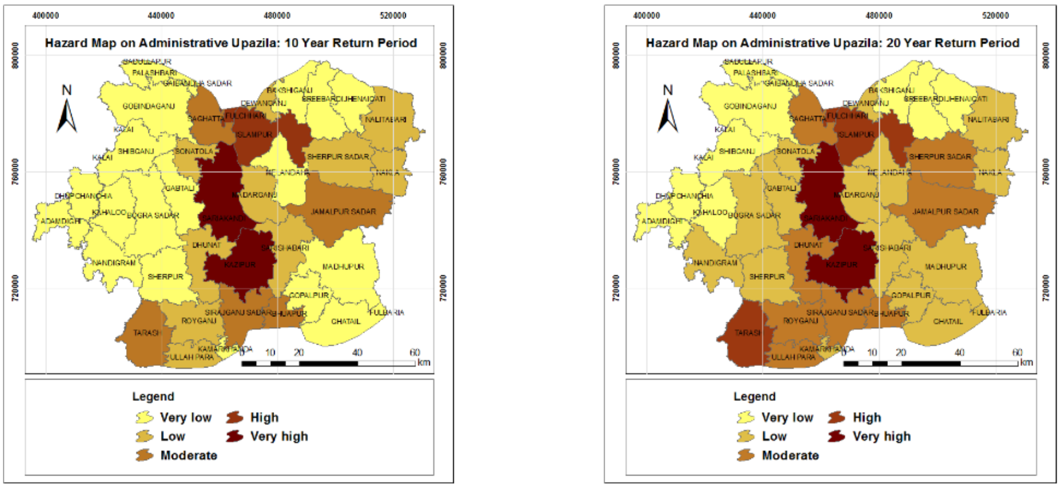


Figure 11: Hazard map on crop pattern in the study area for 10-year return period and 20-year return period.

A flood danger map illustrating the pattern of agricultural land use in the Jamuna River floodplain was created using the simulated model results for a 10-year and 20-year return period. An agricultural land use map was created in the research region using a compiled map of agricultural land use throughout Bangladesh, revealing thirteen different cropping patterns. Three factors are normalised to get the cumulative hazard, which is then used to calculate the hazard score. For a 10-year and a 20-year return time, two flood danger maps were created using the flood simulation flood depth map model.

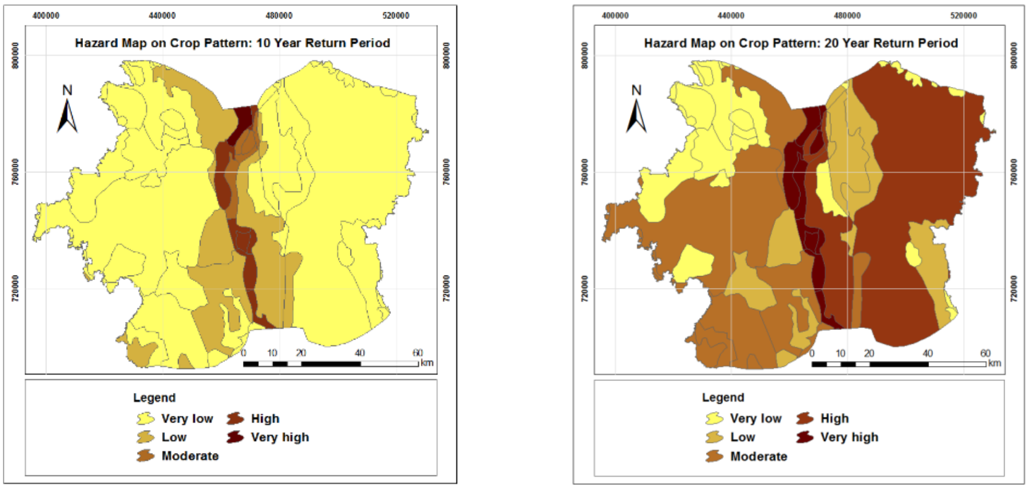


Figure 12: Hazard map on crop pattern in the study area for 10-year return period and 20-year return period.

From Figure 12, it is observed that for the flood event of a 10-year return period, the hazard score is very low for the study area. Moreover, it could be predicted that most of the crop patterns in the study area would be affected by the flood event during the 20-year return period.

IV. CONCLUSIONS

The coupled 1D/2D hydrodynamic model was utilized in this work to create an inundation model of the Jamuna River floodplain. The floodplains were considered 2D flow areas and the Jamuna River was considered a 1D flow. Subsequently, the model was simulated for 2004, 1998, and 2016. An analysis of flooded surface and depth was carried out and the corresponding flood maps were classified. It was discovered that the flooded area of the Jamuna River floodplain rises with time. Floodwaters swamped 22.07%, 50.17%, and 25.42% of the whole studied area in 2004, 1998, and 2016, respectively. The evolution of flood hazards in the Jamuna River floodplain was studied using an integrated flood map model and a GIS technique. The findings of this study give a method for estimating possible flood risk in the study region, which may be utilized to reduce the detrimental effects of future floods. The findings of this study are valuable for flood control planning, as well as for the building and development of flood-prevention measures in the Jamuna River basin. It was noted in the hazard map on the administrative unit map that the most flood prone Upazila in the study area is Sariakandi.

From the threat map on land use patterns, it has been observed that the Boro–T. Aman withinside the Sarikandi to be the maximum dangerous crop sample. The Boro–T.Aman crop sample withinside the jap a part of the look at the place and Rabi crops–B.Aus/Jute–Fallow had been additionally observed as a dangerous crop pattern. The crop sample withinside the north-western part of the look-at place became observed to be much less dangerous. The north-jap and south-jap elements of the look at the place also are much less dangerous due to their topography.

From flood frequency analysis, using Gumbel’s extreme value distribution for 10 years and 20-year return period, it could be noted that the effect on the floodplain is almost double for 20-year return period. About 51.62% of the study area could be inundated if an event of a 20-year return period occurs.

In comparison to the extensive study undertaken in other flood-prone nations, research on the present condition of the flood map in Bangladesh is quite scarce. According to the current state of knowledge, few works on Jamuna River floodplain inundation mapping using a 1D/2D coupled model have been identified, but no studies on hazard assessment have been found. This investigation was carried out in a basic manner utilizing the GIS application. This strategy might be quite successful for preliminary flood prevention measures. The use of GIS techniques for flood mapping has been proven to be quite beneficial.

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