The Jahangirnagar Review: Part II: Social Science, Vol. 48, No. 2, 2024
ISSN 1682-7422 © Jahangirnagar University

Application of HEC-RAS 1D and 2D Flood Risk Modelling along the Old Brahmaputra River, Jamalpur

Muhammad Rezaul Rakib[1]

Abstract: Bangladesh is extremely susceptible to floods and experienced with massive damages to lives and properties over the years**.** The current strategy for flood control of the Old Brahmaputra floodplain region lacks implication of explicit knowledge of flood mapping which can reduce the flood-induced loss regarding lives and economy. This study generates a flood inundation model to find out the spatial extent of flood risk areas along the Old Brahmaputra floodplain in Jamalpur. Available SRTM-DEM of 2014, river discharge and water level data (1988 and 2020) of Jamalpur and Mymensingh station are used in this HEC-RAS 1D and 2D flood modelling. From the model results, it is revealed that extent of flood inundation varies according to the water level and also 1D and 2D simulation method where 1D results are more suitable to the observed water level rather than 2D results. All the unions of Jamalpur Sadar are not inundated by floods equally where Tulsir Char union is having with highest inundation experience. Besides, 1988 flood caused the maximum inundation then 2020 flood event. Moreover, DEM resolution, cross sections, mess size and Manning's coefficient (n) stimulus the model results. Along with structural flood mitigation strategies, this modelling approach is a strategic technique for better preparedness, community awareness, and strategy formulation to flood.

Key words: 1D and 2D, Flood, Modelling, HEC-RAS, Old Brahmaputra.

Introduction

Bangladesh is extremely susceptible to floods over the years and experienced with massive damages on entire 80% floodplain of the country by highest flooding 68% land (Ali et al., 2006). Flooding intensity and probability is amplifying due to rapid urbanisation, unconscious human activities on floodplain, illegal channel encroachment, and impact of climate change (Ahmed, 2006). Consequently, lives and resources are at more risk and threating the economics of the country (Islam, 2014). The Old Brahmaputra River is one of the significant rivers flowing through Jamalpur district and influencing the catchment in many ways by providing irrigation, fish resources and well balance of environment condition (Brammer, 2012). The flooding severity has increased in this River due to more meanders and braiding nature with high sedimentation, less navigability and discharge (Mohiuddin & Paul, 1998; Sarker et al., 2012). As a little excess of water during the monsoon causes peak flood almost every year, such flood events multiply the damages and sorrows of the people, especially to the poorest.

There are many studies conducted on water pollution, water quality, and channel pattern of the Old Brahmaputra River but a very few studies are found on actual assessment of flood extent. Earlier, a number of HEC-RAS flood model is used in Bangladesh by many

[1] Association Professor, Department of Geography and Environment, Jahangirnagar University, Savar, Dhaka-1342, email: mrrakib@juniv.edu

researchers for example, Masood (2011), Hossain, (2013), Mondal et.al., (2017), Tazin (2018), Rahman (2019), and Zhang et el., (2022). But, a very limited study has been conducted with HEC-RAS flood modelling application in the Old Brahmaputra floodplain.

Therefore, there is further research opportunity, and this comprehensive study of 1D and 2D flood modelling is rationale for a new study. Moreover, the mathematical models can help to reduce the catastrophic consequences of river flooding by actual flood prediction and forecasting (Anh et al., 2016). This HEC-RAS modeling approach is used to examine the riverine flood inundation pattern over the Old Brahmaputra River based on 1988 and 2020s flood's scale in Jamalpur district. Accordingly, flood inundation extents are delineated from the generated maps for better flood management plans and resource priorities.

Concept of HEC-RAS 1D and 2D Model

Hydrological Engineering Centre – River Analysis System is known as HEC-RAS, openly accessible and developed by the US Armed Force Corps of Engineers and can perform 1D and 2D hydrodynamic flood modelling and silt transport modelling for a full arrange of natural and artificial channels (HEC-RAS, 2016). The HEC-RAS one-dimensional (1D) model simulates an average flow velocity perpendicular to the cross-section and water surface elevations at individual cross-sections and visualise flood extent maps by calibration and validation (Ghimire et al., 2022; Parhi, 2012). The two dimensional (2D) model has superiority, based on grids and volume conservation, and includes both channel and floodplain to provide a spatial and temporal prediction of flooding where water depth considered as a third dimension (up and down) for better accuracy (Teng et al., 2017; Anees et al., 2016).

Aims and Objectives

The main aim of this study is to generate a model to predict the extent of flooding for flood risk assessment over the Old Brahmaputra River. The specific objectives are following below:

a) To model the extent of inundation of the major and minor flood incidents along the Old Brahmaputra River during 1988 to 2022; and

b) To determine the flood risk areas as pre-flood mitigation measures along the study area.

Materials and Methods

Study Design

This study is based on mainly secondary sources of data. DTM image, base map, water level and discharge data of the Old Brahmaputra River were gathered and also reviewed various academic journals and documents for modelling flooding extent (Table 1). Extensive field observations were also undertaken to explain the topography of the areas. HEC-RAS (6.0) 1D and 2D model has been run for the extreme 1988 flood event and 2020 low flood event with the upper gauge data (Jamalpur Town), and validated with the lower station (Mymensingh town) and available flood maps of Flood Forecasting and Warning Center. From the model results, extent of flood inundation areas were generated then interpreted, and analyzed by spatial analysis R. Finally, mapping was done by ArcGIS (10.3) to accomplish a fruitful study (Fig. 1).

Table 1: Data sources for 1D and 2D flood modelling.

Data Type	Source
SRTM- DEM (30m resolution) of the study area in 2014	United States Geological Survey (USGS)
Water level data of the Old Brahmaputra river (1988- 2022)	Bangladesh Water Development Board(BWDB)
Discharge data of the Old Brahmaputra river (1988-2022)	Bangladesh Water Development Board(BWDB)

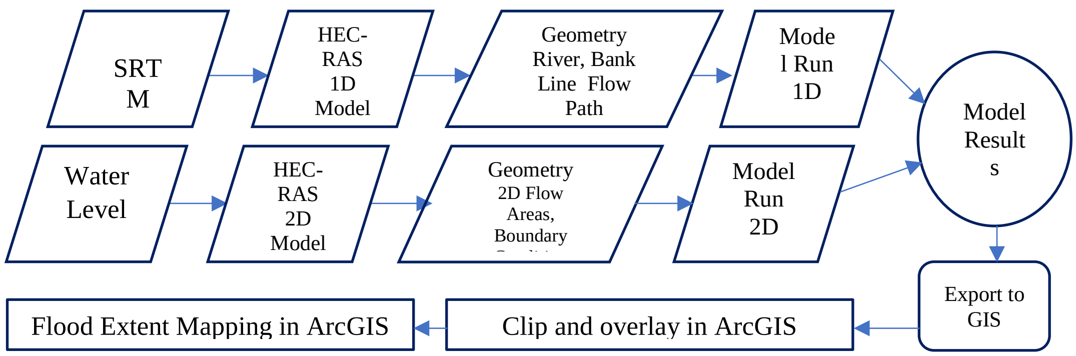


Figure 1: Methodological flow chart for the HEC-RAS 1D and 2D flood modelling along the Old Brahmaputra.

Processing of Digital Elevation Model (DEM)

First of all, SRTM DEM image of the study area was downloaded, then re-projected as projected coordinated system of Bangladesh Transverse Mercator (BTM) and clipped for the study area using subset tool of Erdas Imagine (2014). Then a project file of UTM zone 45N was used for processing and re-projecting the DEM image in HEC-RAS which was collected from the Spatial Reference (https://spatialreference.org/).

Processing in 1D Model

A center line, two bank lines of the river and two flow path lines along the both bank of the river were drawn for 1D model setup (Fig. 3a). Then, a total 41 cross sections were drawn by crossing flow path, bank line and center line of the river as perpendicular direction with average interval of 550 meters from the upstream (Jamalpur) to downstream direction (Mymensingh).

Processing in 2D Model

150m×150m resolution mesh size is determined while initial Manning's roughness coefficient is used 0.03 for 2D model. A river center line is also drawn to recalculate the meshes related to the river channel and input boundary at the upper gauge, and output boundary line are also drawn at the downstream (Fig. 3b). For model calibration and validation mesh size is re-calculated and also changed the roughness value for the main channel as well as floodplain.

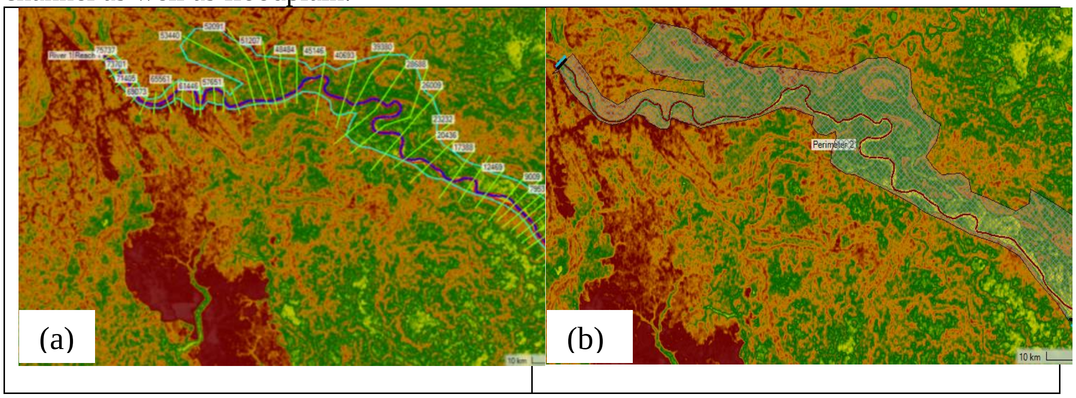
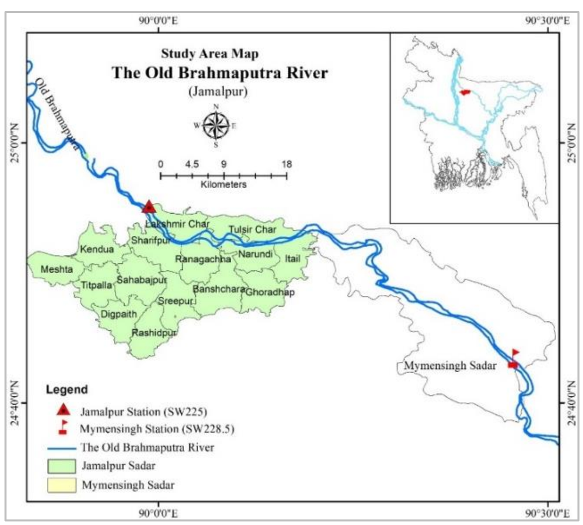


Figure 3: (a) Cross sections with the river centerline, bank lines, flow paths for 1D model, and (b) upstream and downstream boundary condition with 150×150-meter mesh for 2D model (Source: USGS, 2014; Analysis by Author, 2023).

Study Area

Sadar Upazila of the Jamalpur district with an area of 489 km^2 is chosen for this flood inundation modelling. This study area is located between 24^{0}42' N to 24^{0}55' N latitudes and 90^{0}13' E to 90^{0}28' E longitudes (Map 1). The Old Brahmaputra River is the main water course which flows from the southwestern corner of the Garo Hills to the eastern rim of the Madhupur Tract. The relief is as broad and narrow flood-plain ridges with lower ridges and depressions (Brammer, 2012; Rashid, 2009). Although the higher ridges are only shallowly flooded only during the monsoon, all the basins are at least 0.91m deep. Soils with heavily developed ploughman are difficult to drain (Rashid, 1991). This floodplain's soil is rich in fertility, and a variety of agricultural crops are flourishing and a good place to raise animals.



Map 1: Geographical location of the Old Brahmaputra River (Source: BCA, 2009; Prepared by Author, 2023).

Results

Annual flow of water level varies significantly in the Old Brahmaputra River at Jamalpur Station during the study years 1988 to 2022 (Fig. 3). The water level at Jamalpur tends slightly downwards where the highest water level was 17.83 meters in 1988 and the lowest, 9.34 meters in 2021.

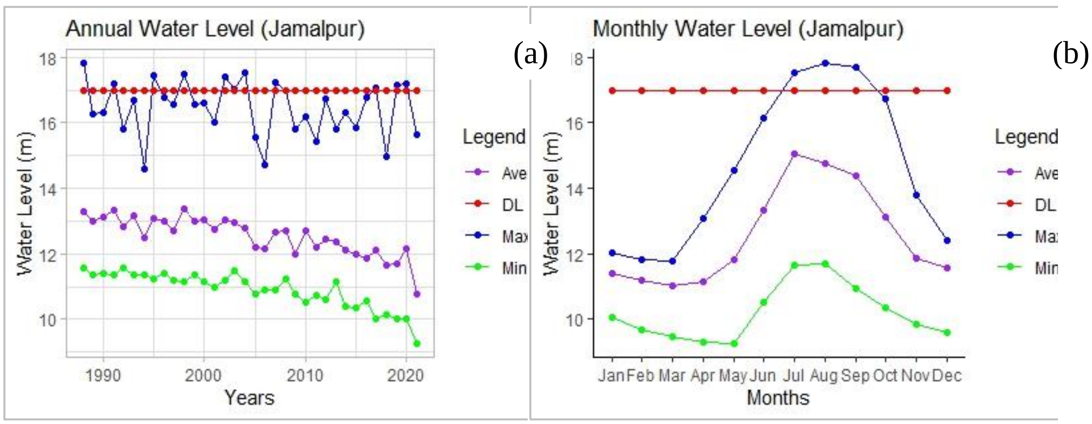
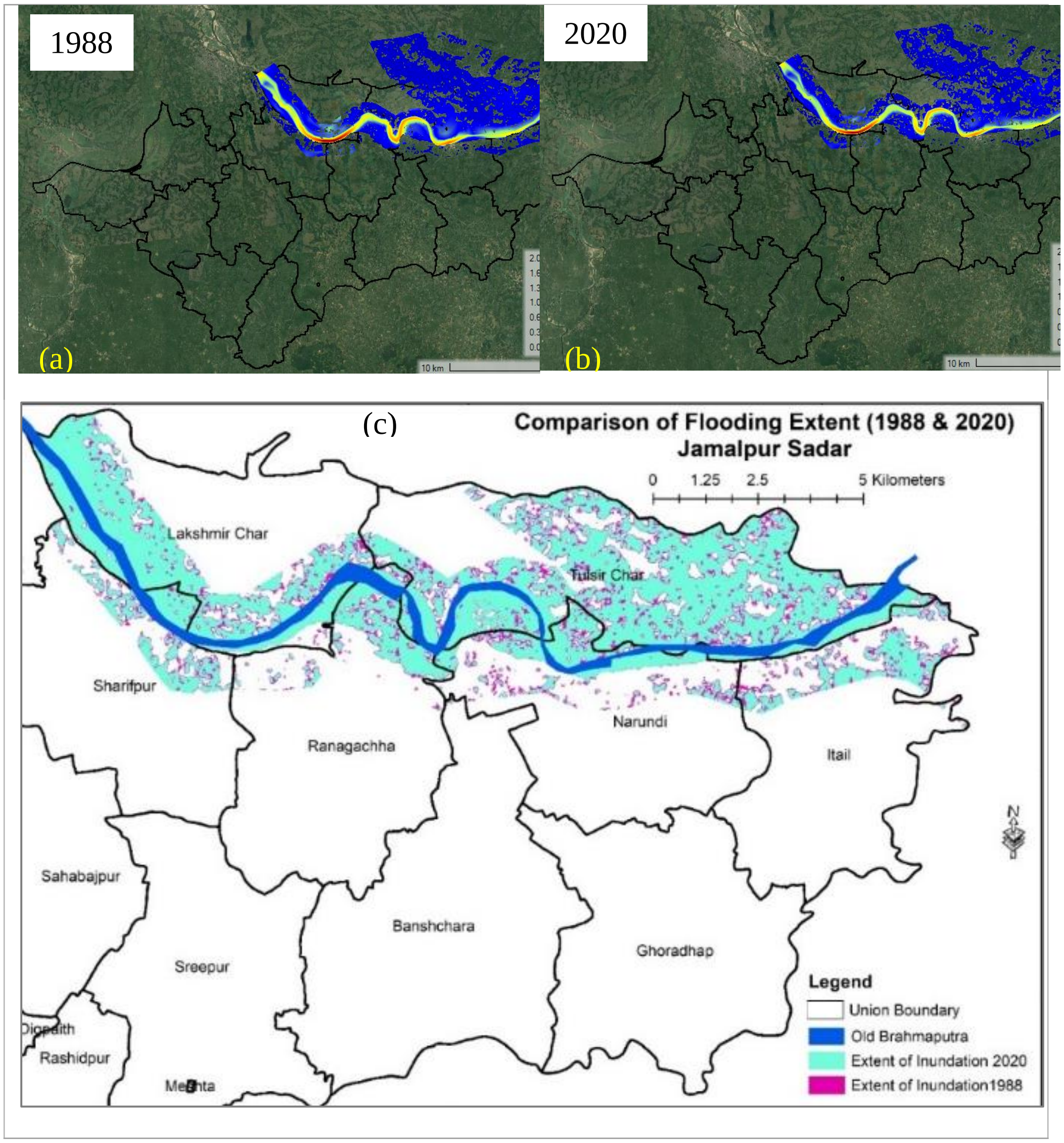


Figure 3: (a) Annual and (b) monthly water level of the Old Brahmaputra River at Jamalpur Station of SW 228.5 (Source: BWDB, 2022).

The danger level of Jamalpur station is 17 meters and crossed the danger level from the threshold at Jamalpur in 1987, 1988, 1991, 1998, 2002, 2004, 2007, 2010, 2015, and 2017. Moreover, the maximum water level 17.83 meters was observed in the month of July while the minimum water level was 11.04 meters observed in March at Jamalpur. Overall, as a general trend, water level gradually increased from April to October and decreased from November to March.

1D Model Results

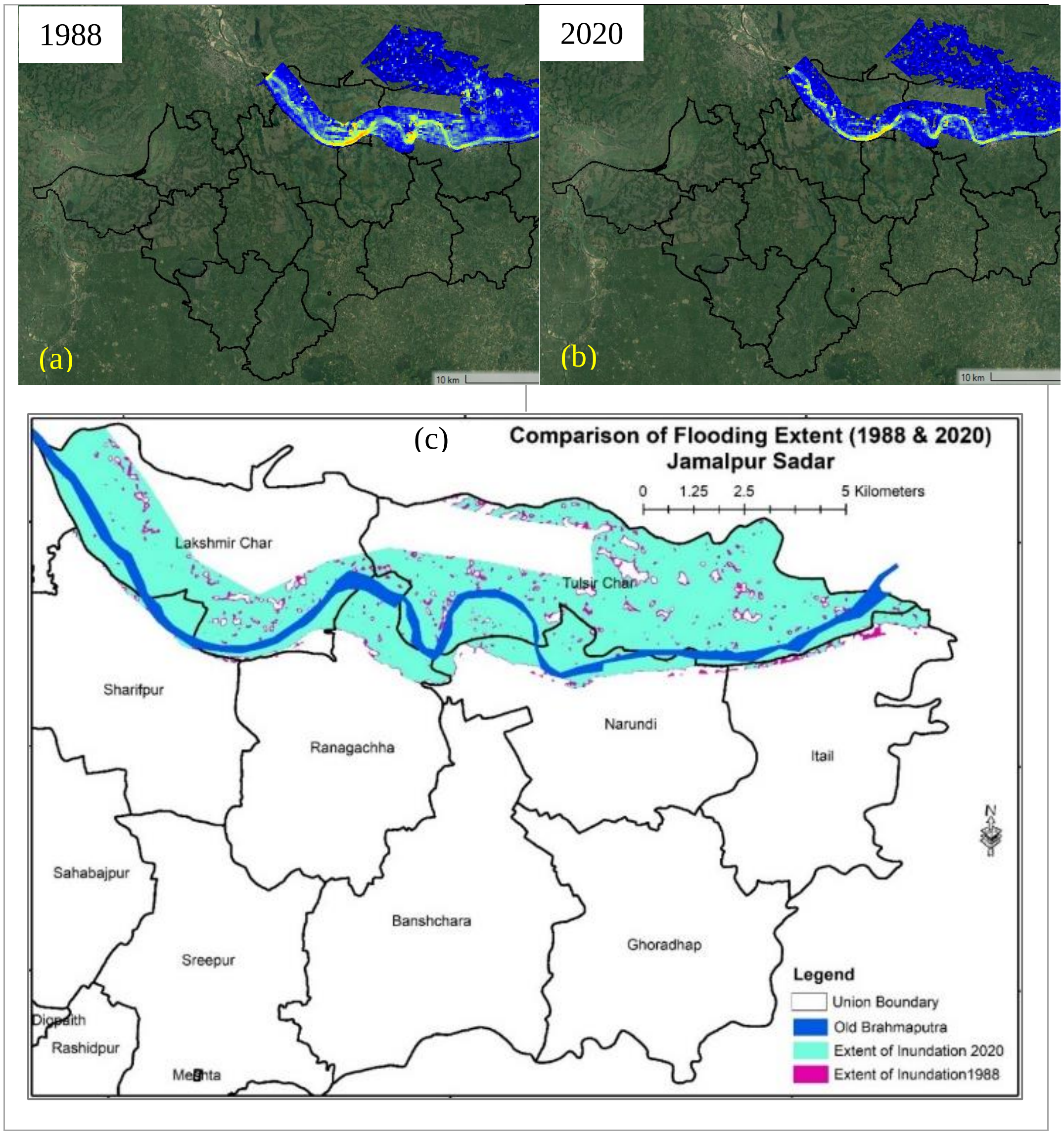
1D model results demonstrated the flood extent and velocity along the Old Brahmaputra River at Jamalpur (Map 2). In 1988, the Old Brahmaputra river and associate floodplain, flooded away by maximum water level. The lower stream was heavily inundated while the city embankment served as a protection on the right side of the river at upper stream. Overall, the left bank and its floodplain is comparatively more flooded rather than the right bank. On the other hand, almost similar trend of flooding pattern was found with lower extent in 2020. Almost similar trend of flood velocity is seen in both the modelled flood events where the highest velocity is located in the main channel. Overall, the flood velocity is comparatively higher in 1988, than 2020 with nearly similar pattern.



Map 2: 1D model results showing the flood velocity (a, b) and flood extent (c) along the Old Brahmaputra River.

2D Model Results

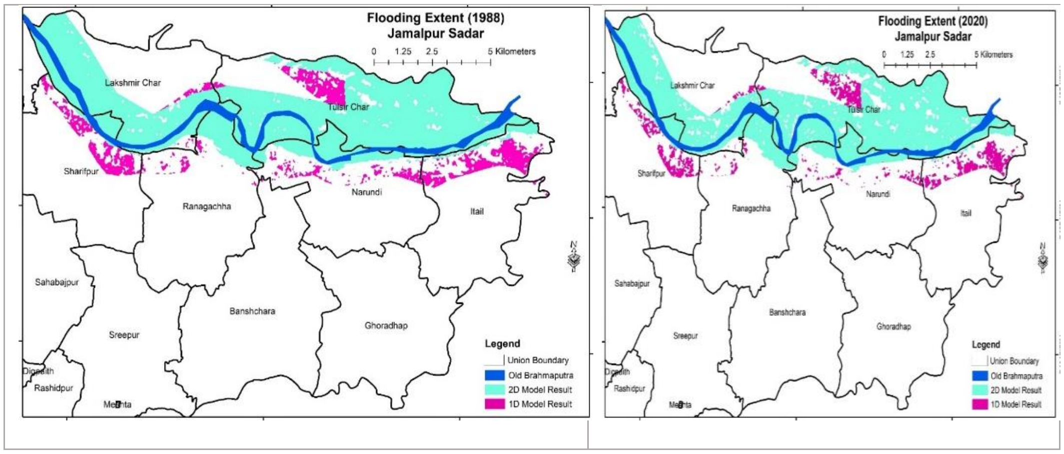
HEC-RAS 2D flood simulation result shows the inundation extent for the modelled flood events in the map 3. Overall, flood inundation is more extended in relation to the 1D model output for the Old Brahmaputra floodplain. The flood of 1988 was the worst flood in Bangladesh and in this flood the left side of the Old Brahmaputra river was severely flooded with greater impact in the rural areas of the lower stream rather than upper stream. Due to the flood protection embankment of the city, the right side was not flooded. The water velocity of the River was higher in the main channel compared to the floodplain and 1988 flood shows higher velocity rather than 2020 flood event.



Map 3: 2D model results showing the flood velocity (a, b), and flood extent (c) along the Old Brahmaputra River.

Variation of Flood Extent

Flood extent varies according to the model results of 1D and 2D. From the simulated results of without channel modification, it is evident that the flood extent is greater in the 2D model outcome rather than in the 1D model for both the year 1988 and 2020 (Map 4). Moreover, this difference of flood extent is more noticeable for the floods of 1988 flood. The highest extent of flood is occurred due to the 1988 flood. The flood extent is much higher scale in the upper stream of the Old Brahmaputra floodplain but variance of extent is seen higher in the lower stream rather than the upper stream.



Map 4: Variation of flood extent by 1D and 2D model results along the Old Brahmaputra River.

Flood Risk Areas

All the unions of Jamalpur Sadar Upazilla are not affected by floods equally, where flood extent areas varied based on topography, water level, and the location of union relative to the river distance (Table 2). Tulsir Char union is flooded with highest inundation areas of around 25 square kilometers and Lakshmir Char union also showed higher inundation areas, respectively. Banshchara union is not flooded according to 1D model, however, including Banshchara, Itail, Sharifpur, Ranagachha and Narundi unions demonstrated lower flood risk areas (Fig. 4). Overall, 1988 flood caused the maximum inundation and flood risk areas compared to the 2020 flood event (Fig. 5).

Table 2: Flood risk areas at Jamalpur Sadar Upazilla.

Union Name	**1D 1988**		**1D 2020**		**2d 1988**		**2d 2020**	
	Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%
Banshchara	0.01	0.0	0.01	0.01	0.00	0.0	0.00	0.0
Itail	3.29	6.2	2.39	5.30	0.93	1.8	0.63	1.3
Lakshmir Char	12.89	24.4	11.67	25.89	15.12	28.7	14.37	29.1
Narundi	4.86	9.2	3.86	8.56	4.19	8.0	3.94	8.0
Ranagachha	3.39	6.4	2.85	6.32	3.34	6.3	3.19	6.5
Sharifpur	3.35	6.3	2.76	6.11	1.41	2.7	1.31	2.7
Tulsir Char	25.08	47.4	21.55	47.80	27.65	52.5	25.99	52.6
Total	**52.87**	**100**	**45.08**	**100**	**52.63**	**100**	**49.44**	**100**

Source: USGS, 2014; Analysis by Author, 2023

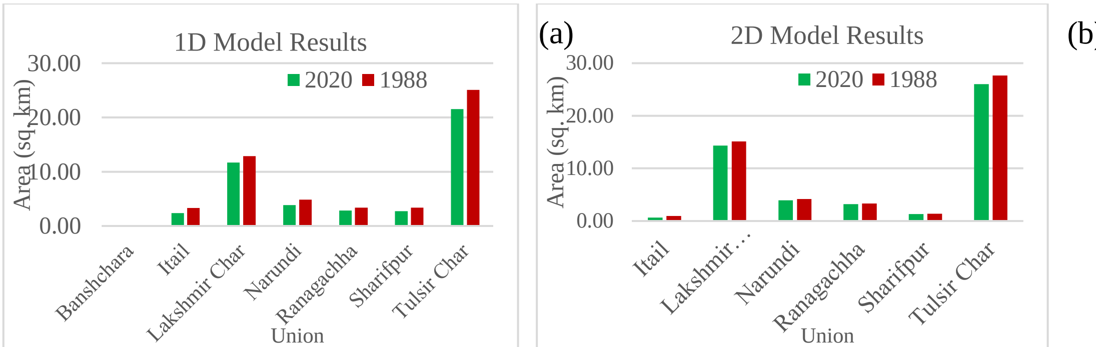


Figure 4: Union wise flood extent area (a and b) by 1D and 2D model at Jamalpur Sadar Upazilla.

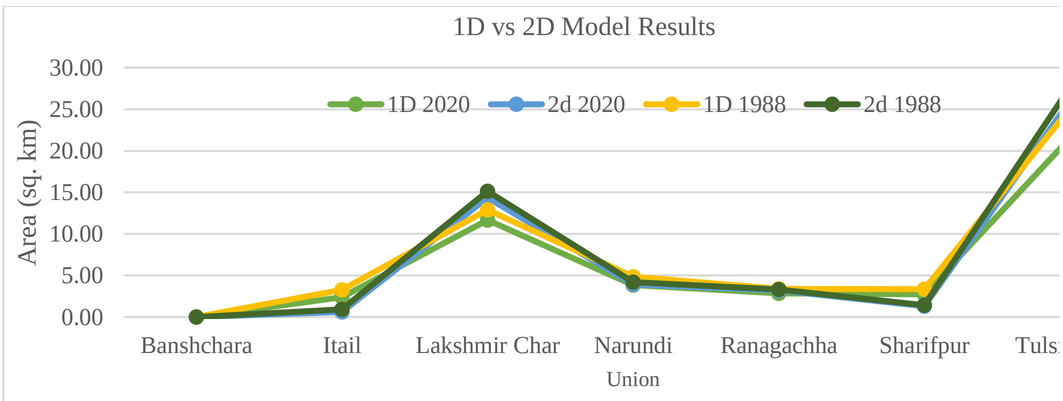


Figure 5: Union wise comparison of yearly total flood inundation area by 1D and 2D model.

Discussions

HEC-RAS 1D and 2D both model is very sensitive for various factors including DEM resolution, number and spacing of cross sections, mesh size and coefficient of manning's roughness value (Bomers et al., 2019; Ghimire et al., 2022; Liu et al., 2015). Accuracy and availability of the observed data and location of upper gauge station and lower gauge station are important phenomenon for the HEC-RAS modelling. In this study, lower gauge is located around 60 kilometers outside of the study area.

Both of the HEC-RAS 1D and 2D model generates similar trends of flooding but 1D model is more accurate to the observed water levels while 2D model displays comparatively excess flooding. This floodplain experienced with severe flooding whenever the country experienced that magnitude of flooding remarkably in the year of 1988, 1991, 1998, 2002, 2004, 2007, 2009, and 2020. The flood extent in 1988 was highest compared to other floods events. The flooding extent is higher on the left bank of the river relative to the right bank. The extent of flood-prone areas relatively high in the lower stream of the river.

Both structural and non-structural mitigations measures are being implemented in the Old Brahmaputra floodplain. Flood modelling is a non-structural mitigation measures which is a powerful technique for the engineers, planners and flood risk managers for optimizing costly investments in flood risk mitigation measures, support emergency relief measures, price insurance premiums or to design flood-resistant infrastructure (Brunner, 2016; Waghchaure et al., 2020). As flood is an inevitable hazard, for this reason actual flood prediction is crucial to engineers and flood risk managers for detailed understanding flood risk areas to further response and recovery. Moreover, flood modelling application has the provision of the hydro-system operation, flood alert and warning, risk quantification and decision making for the design and planning of flood mitigation measures (Zhang et al., 2022) and this study is one of the significant example.

Conclusion

Overall, the Old Brahmaputra River is experiencing different magnitude of floods over the years. Flood frequency curve depicts that 1988 is the highest inundated flood in this particular region. This study reveals flood inundation maps of Jamalpur Sadar Upazilla for the years of 1988 and 2020 which depict the extend of flood with the help of 1D and 2D modelling approach where both models shows almost alike extent of flooding. Almost all the model outcomes illustrate that 2D model results shows more flow of water with excess inundation rather than 1D model. 1D model results are approximately close to the Flood Forecasting and Warning Center (FFWC) inundation map. As this study area is the Old Brahmaputra floodplain so the lower magnitude of flood also shows almost similar extent of flooding though flood depth varies based on water level data. Although 1D and 2D model has some uncertainties and sensitivities to bring out accurate results but this model results can help the policy makers to take precaution measures, and local people also can be aware about their location relative to flood risk area. This study recommends that more accurate simulation result is possible with recent LiDER 1-meter DTM and discharge data because high resolution DEM is the main concern of this 1D and 2D flood modeling. Moreover, a structured questionnaire survey can carry out to find out the people's perception about their flood mitigation strategies.

Acknowledgement

This work was supported by the Jahangirnagar University Research Project's 2022-2023, Savar, Dhaka, Bangladesh.

References

Ahmed, A.U. 2006. Bangladesh, Climate Change Impacts and Vulnerability. A Synthesis, Climate Change Cell, Department of Environment, Dhaka.

Ali, M. M. Haque, M.M. Rahman, R. & Rashid, S. 2006. Bangladesh Floods view from home and Abroa, University press Limited.

Anh, T. N. Kha, D. D. Duc, D.D & Thanh, N. 2014. Hydraulic modelling for flood vulnerability assessment. Case study in river basins in North Central Vietnam.

Anees, M. T., Abdullah, K., Nawawi, M.N.M., Rahman, N. N. N. A., Piah, A.R.M., Zakaria, N.A.Z, Syakir, M.I., Omar, A.K. M. 2016. Numerical modeling techniques for flood analysis. Journal of African Earth Sciences, Elsevier Ltd. http://dx.doi.org/10.1016/j.jafrearsci.2016.10.001

Aziz, M.A. et al. 2022. Delineating Flood Zones upon Employing Synthetic Aperture Data for the 2020 Flood in Bangladesh, Earth Systems and Environment, 6(3), 733–743. Available online: https://doi.org/10.1007/s41748-022-00295-0.

BCA. 2009. Bangladesh Country Almanac. BCA v. 3.0: CIMMYT.

Brammer, H. 2012. The Physical Geography of Bangladesh.

Bomers, A., Schielen, R. M. J., Hulscher, S. J. M. H. 2019. The influence of grid shape and grid size on hydraulic river modelling performance. Environmental Fluid Mechanics, Springer 19:1273–1294. https://doi.org/10.1007/s10652-019-09670-4.

Brunner, G. W. 2016. HEC-RAS River Analysis System: Hydraulic Reference Manuals:U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center, 609 Second Street, Davis, CA 95616.

BWDB (Bangladesh Water Development Board), 1999. Annual Flood Report 1998, Flood Forecasting and Warning Centre.

Ghimire, E. Sharma, S. & Lamichhane, N. 2022. Evaluation of one-dimensional and two-dimensional HEC-RAS models to predict flood travel time and inundation area for flood warning system, ISH Journal of Hydraulic Engineering, 28(1), 110–126. Available online: https://doi.org/10.1080/09715010.2020.1824621.

HEC-RAS, 2016. HEC-RAS River Analysis System Hydraulic Reference Manual, Hydrologic Engineering Center.

Islam, M.S. 2014. Flood Risk Assessment in Bangladesh and People` s Adjustment Scenarios : A Case Study in Brahmaputra-Jamuna Floodplain, Department of Geography and Environment, University of Dhaka.

Liu, Q., Qin, Y., Zhang, Y., Li, Z.W. 2015. A coupled 1D-2D hydrodynamic model for flood simulation in flood detention basin. Nat. Hazards 75 (2), 1303-1325.

Mohiuddin, M. & Paul, B.K. 1998. Flood problems in Bangladesh: is there any indigenous solution?: Environmental Management, 11(2), 155-173.

Mondal, M.S. Islam, M.R. & Biswas, S. 2017. Simulation of Flood Risk Due To Climate Change in Major Rivers of Bangladesh Using a Hydrodynamic Model, (November), 1–5.

Neelz, S., Pender, G. 2013. Benchmarking the Latest Generation of 2D Hydraulic Modelling Packages. DEFRA/Environment Agency, UK. http://evidence.environment-agency.gov.uk/FCERM/Libraries/FCERM_Project_Documents/SC120002_Benchmarking_2D_hydraulic_models_Report.sflb.ashx.

Parhi, PK. 2012. Calibration of Channel Roughness for Mahanadi River, (India) Using HEC-RAS Model, Journal of Water Resource and Protection 04(10):847-850. DOI:10.4236/jwarp.2012.410098.

Rahman, A. 2019. A Study on Monsoon Flood Hazard and Vulnerability.

Rashid, H. 2019. Geography of Bangladesh. 1st edn. Taylor and Francis.

Rhoads, B.L. 1991. A continuously varying parameter model of downstream hydraulic geometry. Water Resour. Res. WRERAQ 27 (8), 1865-1872.

Sarkar, A. Garg, R.D. & Sharma, N. 2012. RS-GIS Based Assessment of River Dynamics of Brahmaputra River in India, Journal of Water Resource and Protection, 04(02), 63–72. Available online: https://doi.org/10.4236/jwarp.2012.42008.

Tazin, T. 2018. Flood Hazard Mapping of Dharla River Floodplain Using Hec-Ras 1D / 2D Coupled Model Flood Hazard Mapping of Dharla River Floodplain Using Hec-Ras 1D / 2D Coupled Model, 157.

Teng, J., Jakeman, A.J., Vaze, J., Croke, B.F.W., Dutta, D., Kim, S. 2017. Flood inundation modelling: A review of methods, recent advances and uncertainty analysis. Environmental Modelling & Software. Elsevier Ltd. http://dx.doi.org/10.1016/j.envsoft.2017.01.006

USGS (The United States Geological Survey), 2018. Floods and Recurrence Intervals by Water Science School. Available online: https://www.usgs.gov/special-topics/water-science-school/science/floods-and-recurrence-intervals.

Waghchaure, A. Aarti Patil, A. Bachhav, P.A. Bodhai, R. and Patil, G. 2020. Flood Modeling and Flood Forecasting Using Hec-Ras, 5(6), 54–61.

Zhang, K. Shalehy, M.H. Ezaz, G.T. Chakraborty, A. Mohib, K.M. & Liu, L. 2022. An integrated flood risk assessment approach based on coupled hydrological-hydraulic modeling and bottom-up hazard vulnerability analysis, Environmental Modelling and Software, 148(November 2021). Available online: https://doi.org/10.1016/j.envsoft.2021.105279.