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SIMULATING FLOOD RISK DUE TO CLIMATE CHANGE IN THE PADMA RIVER SYSTEM USING THE 2D HEC-RAS MODEL

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ABSTRACT

Bangladesh is in a unique geographic location with the dominance of floodplains, low land elevation, proximity to the sea and overwhelming dependence on nature. These characteristics have made the country highly vulnerable to climate change. Due to climate change, it is experiencing several consequences like irregular monsoon climate, untimely rainfall and heavy rainfall over a short period of time. This results in increased river flow and inundation during monsoon, increased frequency, intensity and recurrence of floods. Information about flood risk is usually available at the boundaries of major rivers. But it is usually unknown the flood risks at different points in the floodplain. Flood risks in the floodplain are determined using that river information. In this study, we have set up a two-dimensional hydrodynamic model called HEC-RAS for the Padma River system to simulate flood hydrographs at different locations. The Padma River and its adjoining areas are included in the model setup. Digital land elevation data from WARPO and river cross-section data from BWDB and our own survey are used to prepare the two-dimensional surface of the model. The model is calibrated and validated using observed water level (at the Padma and the Arial Khan River) and discharge (at Baruria Transit on the Padma river) data from BWDB and BIWTA. The model is calibrated for 2004 and validated for the largest flood of 1998 that occurred in the area. It is found that the model can simulate the observed variation of flood quite satisfactorily at different locations. To assess the impact of climate change on the flood, the discharge hydrographs at model boundaries (Baruria Transit on the Padma River) were changed according to climate change scenarios and the HEC-RAS model was rerun. The flood hydrographs under the base condition and changed climate were compared to assess the impact of climate change. The result reveals that the peak flood level in the Padma River can be increased by 60cm on average due to climate change.

Keywords: *Climate change, Flood, Deterministic simulation, HEC-RAS model, Padma river.*

1. INTRODUCTION

Throughout history, the global climate has been changed and its effects have already found on the environment. Climate Change has become a major issue nowadays. With a unique geographic location and geological characteristics, Bangladesh is highly vulnerable to climate change. Kreft, Eckstein and Melchior (2016) analyzed the most reliable data sets available on the impacts of extreme weather events and associated socio-economic data for the last 20 years (1996-2015) and made a Global Climate Risk Index for the year 2017. According to them, Bangladesh is in the sixth position among the world's top 10 countries most affected by extreme weather events (Kreft, Eckstein & Melchior, 2016). Among the hydro-climatic hazards, flooding is considered one of the devastating, widespread and frequent one (Teng et al., 2017). It is the most significant natural hazard in Bangladesh as the country lies on the downstream part of the GBM rivers basin. Every year Flood inundates about 20.5 percent of the country while floods with a return period of 100 years inundate more than 60 percent of the country. During1998 floods the affected area was about 70 percent of the country (FFWC, 2005).

Many Climate experts have suggested from their analysis (e.g. General Circulation Models (GCM) analysis) that flooding will be increased in future due to climate change in terms of both extent and frequency (Mirza, 1997; Mirza, Warrick & Ericksen, 2003 and Mohammed et al., 2017). Some of them also suggest an increase in monsoon rainfall (ADB, 1994). Such rainfall will play a key role in the runoff generation processes and eventually exacerbate the flooding problem. Mirza (1997) found an increase of about 69% in the mean annual flow of the Ganges River at Farakka by doubling of CO_2 scenario. He assessed a runoff-climate model with observational and GCM data for the nine sub-basins of the Ganges River basin where all basins showed an increase in runoff in the climate change scenario (Mirza, 1997). In another study, Mirza et al. (2003), have found that if temperature rise about 6^0C the mean flooded area may increase in the range of 20–40%. Depending on the general circulation model he predicted 55% of the flooded area could be deeply flooded (Mirza et al., 2003).

So, there is a possibility of more serious flooding in Bangladesh. Thus, it is very important to analyze flood risk in a changed climatic condition. The available information about flood risk at boundaries of major rivers can be used to simulate the risk at any point in the floodplain, also the risk under a changed climatic condition. The objective of this study is to assess the flood risk at a different point within the floodplain in terms of maximum water surface elevation, flood depth, flow velocity and direction under a changed climatic condition. For that, we have set up a two-dimensional hydrodynamic model called HEC-RAS for the Padma River along with its floodplains to simulate flood hydrographs at different locations. HEC-RAS is developed by the US Army Corps of Engineers. It is a freeware tool, basically a hydrodynamic mathematical model. This model simulates water movement by solving the Full Saint-Venant equations or the Diffusion Wave equations.

2. METHODOLOGY

The success of a 2D hydrodynamic model depends on the level of digital representation of the river and floodplain geometries through DEM. Also, the accurate description of the model parameters is needed to predict the flow magnitude and water levels accurately. In this study, digital land elevation data from WARPO and river cross-section data from BWDB and our own survey data are used to prepare the two dimensional surface of the model. In Figure 1, a schematic is showing the spatial extent of the 2D area and the river network used in this model.

2.1 Preparation of the DEM

Two dimensional (2D) hydrodynamic models require the geometric description of river bathymetry. A total of 26 cross-sections over a length of 98.7 kilometers in the Padma River, 12 cross-sections over a length of 81.4 kilometers in the Arial Khan River and 14 cross-sections over a length of 107.1 kilometers in small distributary rivers of the Padma River were used to make a Terrain surface for the river bathymetry in HEC-RAS environment. Most of the bathymetric information was collected from different projects in the Institute of Water and Flood Management (IWFM) of BUET over the last few years and some were collected from BWDB. Some bathymetries of the Padma have also been obtained very recently. River cross-sections at reasonable spacing were interpolated to satisfy the requirements of cross-section spacing. Sometimes cross-section cut lines were adjusted the better representation of the rivers, especially at junctions. This adjusted has produced a considerable improvement in the model outputs. A 20 meters spatial resolution Terrain was prepared from the river cross-section.

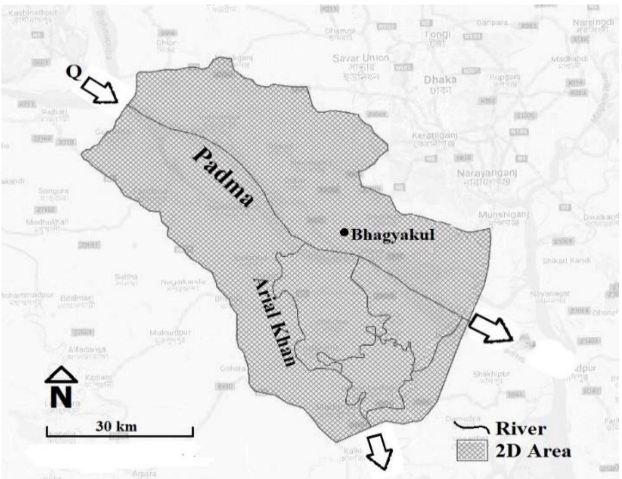

Figure 1: Model domain with 2D Mesh and River network

For floodplain bathymetry, a 500 meters DEM from WARPO was resampled into 50 meters raster file in the Arc-GIS environment through Inverse Distance Weighted (IDW) interpolation technique. The raster file was saved in float file format and then merged together with the rivers Terrain in HEC-RAS with the first priority for river Terrain and second for the raster DEM to integrate river bathymetry with the surrounding topography. The final processed DEM is shown in Figure 2. Before merging all necessary features projected into the same projection system as per HEC-RAS requirement.

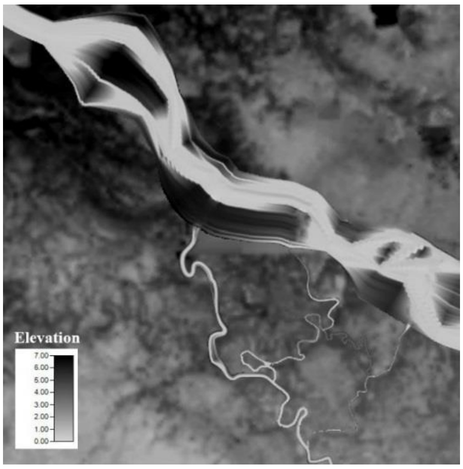

Figure 2: Image of the final processed DEM

2.2 Model Setup

In this 2D hydrodynamic model, a length of 87.4 kilometers of the Padma River spanning from Baruria Transit to down of Sureswar was modeled. The 2D area covers about 3890 kilometers^2 and a 200*200 meter^2 mesh cell size was used for the computation. The natural barriers such as roads, highways and Terrain contour lines were used as a guide to select the 2D area extent as suggested by HEC-RAS User Manual. It is found through several unsteady flow simulation that little change in 2D area vertex at floodplain have no impact in model output such as maximum water level, velocity. The model was set for 2004 and calibrated, and then validated for 1998.

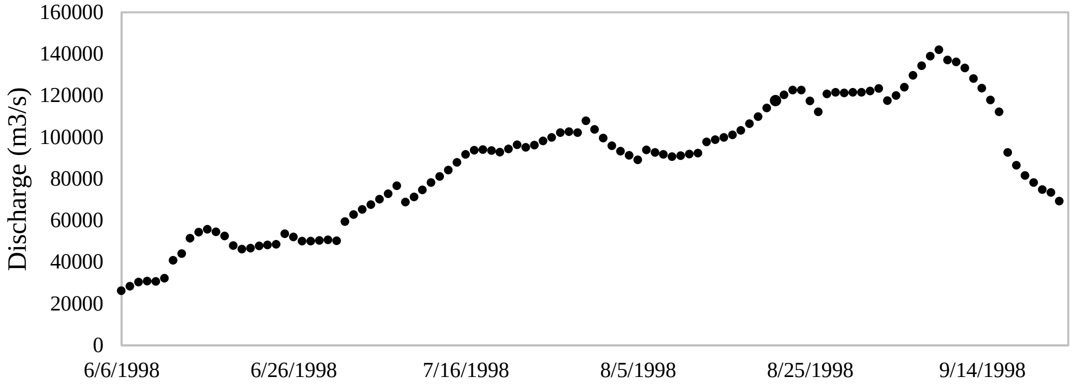

Figure 3: Mean daily discharge at Baruria Transit (SW91.9L) for 1998

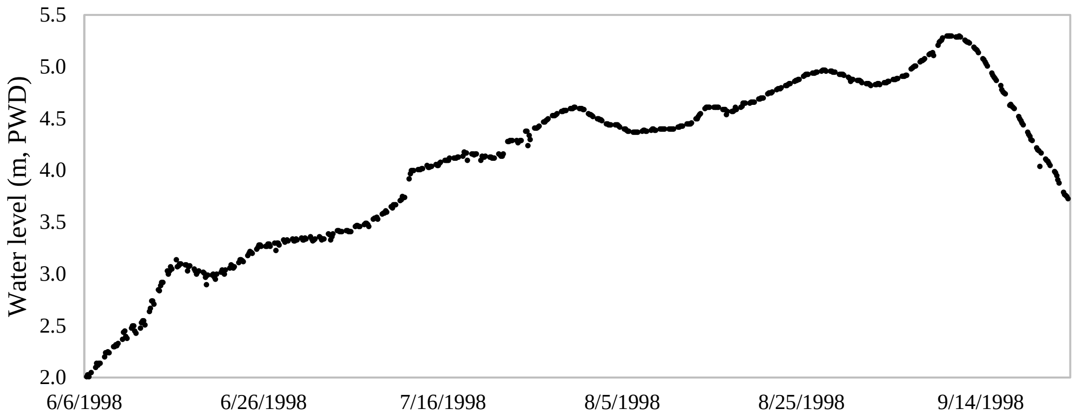

Figure 4: Water level of the downstream boundary at the Arial Khan River for 1998

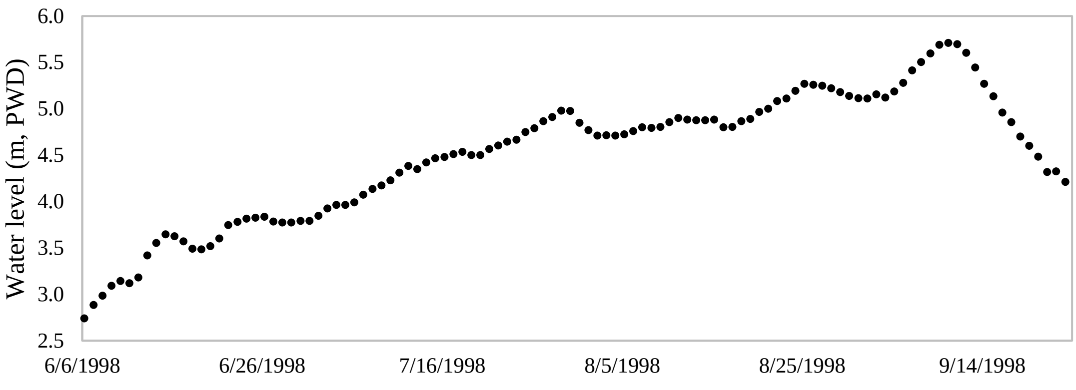

Figure 5: Water level of the downstream boundary at the Padma River for 1998

As it is an unsteady flow simulation, the model requires boundary and initial conditions. The upstream boundary condition of this model was set with a flow hydrograph at Baruria Transit (SW91.9L) on the Padma River with mean daily discharge (MDD). Figure 3 shows the flow hydrograph at the upstream boundary for 1998. For the downstream boundary condition, such as Madaripur (SW5) on the Arial Khan and Sureswar (SW95) on the Padma River, the water levels were used. The model boundary at the Arial Khan river is about 18 kilometers downstream of the Madaripur station. The water level at this location is determined from Madaripur station by water-surface slope analysis of the Arial Khan River. Figure 4 shows the water level of the downstream boundary at the Arial Khan River. Figure 5 shows the water level of the downstream boundary at Sureswar in the Padma River for 1998. Observed discharge at Baruria Transit and water level at the Padma and Arial Khan were used as an initial condition.

2.3 Model Simulations

After the model setup, the simulation was performed from 5 June to 23 September for the year 2004 and then for 1998 to simulate the flood peak with a computational interval of 30 munites. As the model calculates water level at all points within the 2D area, we have compared the simulated water level with the observed water level at Bhagyakul river station (SW 93.4L) in the Padma River to calibrate the model for 2004. Manning roughness coefficient is used as a calibration and validation parameter. A land-use data layer with different Manning's n values is incorporated to define the surface resistance to flow using the RAS Mapper and Geometric window. Then, the model was rerun multiple times using different sets of Manning's n values for rivers and floodplains to get a proper matching in water levels. After the calibration, the model was rerun by changing the boundary conditions to simulate the flood of 1998 keeping other things the same. The validation was done by comparing the simulated water level and the observed water level at Bhagyakul river station for1998. A final fine-tuning in Manning's n values were done to get a satisfactory calibrated and validated model.

Due to climate change, the streamflow in different rivers would be changed as the rainfall pattern and intensity changes. There are literature based on modeling, give predictions about the amount of streamflow increase in different rivers in Bangladesh. It has been analyzed that the flow peak would increase due to climate change (Mondal et al., 2018). In this study, to simulate the climate changed scenario, the upstream flow at Baruria Transit was changed by increasing the flow of the 1998 flood as summarized by Mondal et al. (2018). Then the HEC-RAS model was rerun by changing the upstream boundary flows of the Padma River at Baruria Transit keeping other things the same as the year 1998. After the simulation, the climate change impact on the water level in different locations within the 2D area has been analyzed.

3. RESULT AND DISCUSSIONS

3.1 Model Calibration and Validation

The model was calibrated using the water level data at Bhagyakul river station (SW 93.4L), an intermediate gage station on the Padma River for the year 2004 and validated for the year 1998. In both years, there were floods in the study area and the 1998 flood was the most extreme one. The comparison of model-simulated and the observed water level is shown in Figure 6 and Figure 7. A Manning's n value 0.017 for the Padma River, 0.025 for the Arial Khan River and other distributary rivers, and 0.030 - 0.035 for the floodplain, from low elevation to high elevation, is used for the final setup. It is found that the model captures the variation in the stage hydrograph at Bhagyakul reasonably well.

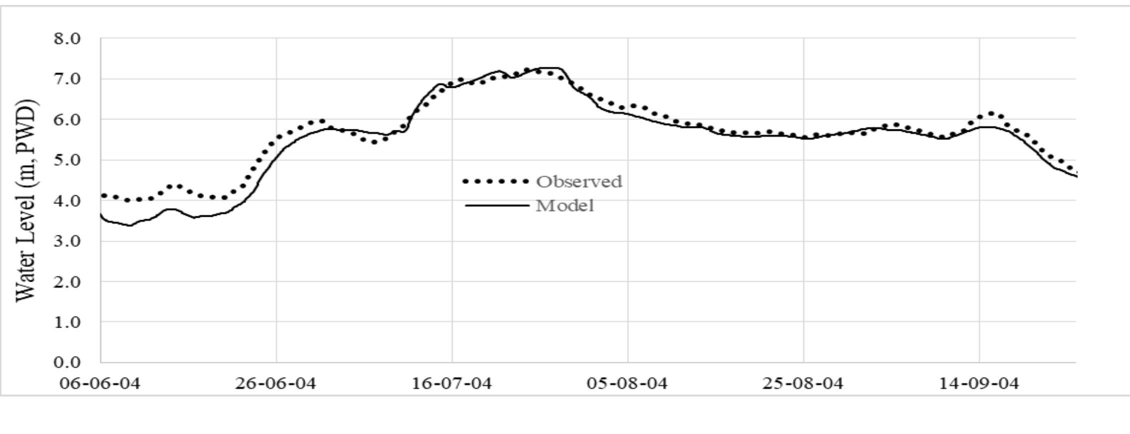

Figure 6: Comparison of model-simulated and observed water level at Bhagyakul on the Padma River for 2004

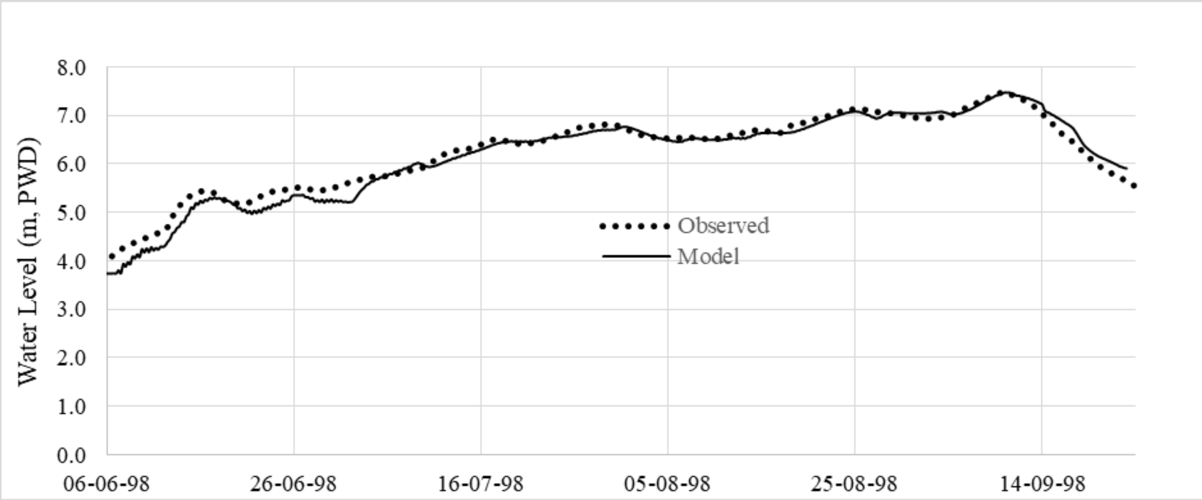

Figure 7: Comparison of model-simulated and observed water level at Bhagyakul on the Padma River for 1998

In the year 1998, the highest measured water level was found to be 7.50 m, PWD on the 10th of September and the highest simulated water level was 7.47 m, PWD on the same day. However, a closer view of the simulated hydrograph revealed that the model can simulate flood peak very well but underestimate the water level in low flow conditions at initial stages. From this model, such stage hydrograph is available at any point within the 2D area. Thus, flood risk can be easily determined at any point in both rivers and floodplains. But, at the edge of the 2D mesh, the results are not representative sometimes. So, it is suggested to keep the 2D mesh boundary away from the location of interest.

A survey was conducted by IWFM on maximum flood level in 1998 in Shariatpur and Madaripur district in two locations covering an area about 80-kilometer square. Age-old people who have experienced the flood in 1998 were asked about the highest flood level by showing some references. Those points are within this model domain. A relation between the surveyed maximum flood level and model maximum flood level is shown in Figure 8.

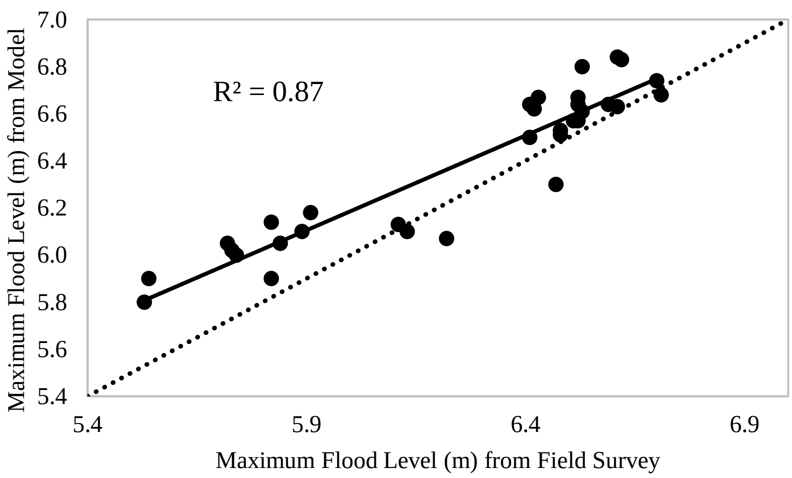

Figure 8: Correlation between maximum flood level from field survey and model

This surveyed area only covers a small portion of the total floodplain modeled in this study. But, it requires huge resources to collect such information about flood levels at such a huge scale. With this limited information, it is found that the model simulated maximum flood water level is 15cm higher on average than the survey data.

3.2 Impact of Climate Change

It is expected that future streamflow would change due to climate change. Mohammed et al. (2017) have used the SWAT model to generate daily streamflow time series for three major transboundary rivers (the Ganges, the Brahmaputra and the Meghna). In that study, 11 different streamflow time series were available for 1980-2099 based on 11 climate projections. The simulated streamflows varied from one projection to another projection. A representative projection was identified by comparing the highest observed and modeled flows during the base period (1980-2009) for every river. From the analysis, a 29% increase in flow peak of the Ganges, 10% in the Brahmaputra and 22% in the Meghna are indicated by comparing the highest flow of the 2080s (1970-2099) with that of the base condition (1980-2009) (Mondal et al., 2018). The climate change condition was simulated in this model by adopting this increase in streamflow. The results are summarised through the comparison of the maximum water level at different locations in Table 1. The maximum water level is found on 10th September for both 1998 and climate changed condition.

Table 1: Comparison of maximum water level at different locations

Location	**Observed maximum water level in 1998 (m)**	**Model maximum water level in 1998 (m)**	**Maximum water level due to climate change (m)**	**Increase in water level due to climate change (m)**
Bhagyakul	7.50	7.47	8.09	0.62
Arial Khan Offtake	7.58	7.55	8.20	0.65
Mawa	7.14	7.05	7.63	0.58

After the simulation with climate changed condition, it is found that the peak flood level of 1998 magnitude has increased by 65cm at Offtake of the Arial Khan, 62cm at Bhagyakul and 58cm at Mawa in the Padma. The magnitude of flood level also increased in the floodplain by 41cm to 64cm with an average of 53cm in previously mentioned surveyed locations. From this model, flood levels at different locations of the Padma River system are available under the climate changed condition.

The model sensitivity has been tested by changing the Manning's n value for the Padma River and comparing the change in maximum water level at Bhagyakul river station. The relation between Manning's n value and corresponding maximum water level at Bhagyakul is shown in Figure 9. A change in Manning's n value of 0.001 of the Padma River results on average 0.083 meters change in maximum water level at Bhagyakul. Also, the change in water level reduces for a higher Manning's n value.

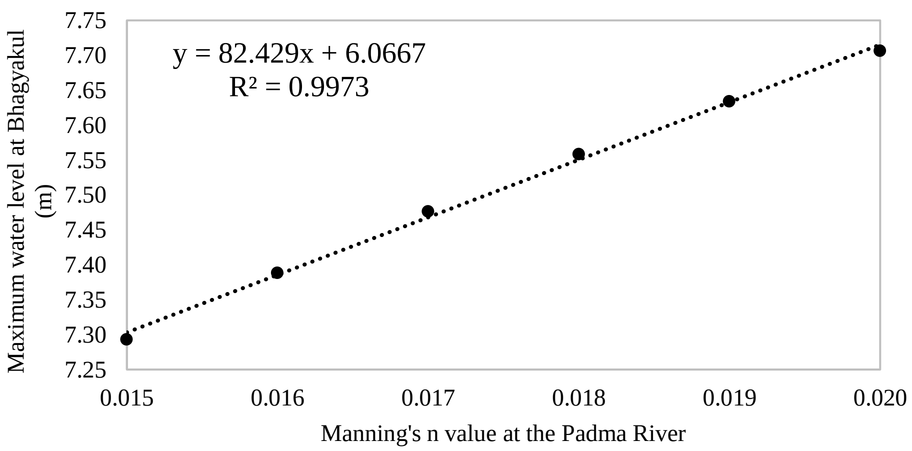

Figure 9: Water level change due to change in Manning's n value at the Padma River

4. CONCLUSIONS

In a country like Bangladesh, where data is very limited and scarce, different modeling approaches can give reasonable predictions of required scenarios. Flood risk in the Padma River along with its distributaries and floodplains due to climate change impacts were evaluated using the HEC-RAS model in this study. The flood peaks might increase by approximately 60cm in the Padma River system under a changed climate condition. The flood peaks might be higher if the potential rise in sea level is considered. As the model can provide stage hydrograph at any point within the 2D mesh, it would be useful in infrastructural planning and design, such as economic zone, power plant, airport, bridge, flood control embankment, river training work and road, in the floodplain of the rivers modeled.

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