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IMPACT OF CLIMATE CHANGE ON URBAN DRAINAGE SYSTEMS IN THREE SELECTED COASTAL TOWNS OF BANGLADESH

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ABSTRACT: As urban growth is increasing in coastal zones, urban drainage system would suffer from additional stresses due to water logging. Moreover, climate change is to enhance natural disasters like floods and heavy rainfall events. So, urban drainage and its performance will be important issues in the coastal towns of Bangladesh. In this study, storm water management model (SWMM) has been used to assess the future possible drainage conditions for three selected towns of coastal areas – Amtali, Galachipa and Pirojpur. Design storm of 2-hour 10 year return period and design water level of surrounding rivers of 20 year return period were considered for simulation of drainage model. For future precipitation, high resolution climate change information has been generated using moderate emission scenarios SRES A1B derived by REGCM3 regional climate model. Sea level rise information from secondary sources has been added with 20 year return period to simulate the future scenarios. DEM of 10 m resolution has been used to delineate catchment and drainage network of the study areas. It has been found that many secondary canals are not capable to carry design storms. Also, the inundation area will significantly increase from baseline to 2030s and to 2050s in the study areas.

Keywords: *coastal zone, climate change, SWMM, sea level rise, urban drainage system.*

1. Introduction

Drainage system is a crucial issue in urban towns, especially for those in the coastal zones, where rivers adjacent to towns experience tidal effect from sea. Drainage system is also affected by the change of land use pattern and human interactions due to urbanizations (Souza et. al, 2011, Goonetilleke et. al, 2005). In addition, the impact of climate change induced sea level rise and change in precipitation pattern, will make drainage system more vulnerable and complex in future years. It is difficult to consider the whole process for solving future drainage problems. So, hydrological concept was considered useful for the assessment of future drainage problem. As hydrology is the governing backbone of all kinds of water movement (Jha, 2011), so drainage model was used to see the future drainage performance. In this context, Storm Water

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Management Model (SWMM), the widely used tool for assessing drainage problem, was considered suitable for carrying out study on drainage systems in coastal zones of Bangladesh. In this study, three coastal towns namely Pirojpur, located a bit far away from coastline, Amtali and Golachipa located closer to coastline, in the southwest coastal zone of Bangladesh, are considered. These three towns experience water logging and drainage congestion after heavy rainfall as a result of polder construction. According to IPCC (IPCC, 2007), sea level rise is a prominent issue to assess present and future condition of drainage system in the coastal zone of Bangladesh. Maintaining natural drainage system might improve water logging and address other climate change related problems. Improving drainage canal system without interrupting the hydrological cycle is a good resolution of existing and future drainage problems (Chowdhury and Bala, 2002; Chowdhury and Islam, 2005). Hence, the main goal of this research is to assess the impact of climate change on coastal drainage system and to find out an effective solution.

2. Methodology

The analysis of rainfall data using Khapupara and Barisal rain gauges was carried out in the beginning. The analysis involved separating storm events, determining return period of rainfall for a specific duration, checking inconsistency of data, etc. Daily and hourly time series rainfall data were used in the storm water model for determination of the generated runoff. The design hyetographs were developed for 2-, 5-, 10-, 25-, 50- and 100-year return periods by alternative block method (El-sayed, 2011). In this study, 10-year 2-hour hyetograph has been used as design hyetograph. For addressing climate change impact, rainfall was projected for the above mentioned two stations using RedGM3 model. Afterwards, flood flow analysis was carried out for estimation of design water level. This process involved frequency analysis with different probability distribution functions for the selected design return period. The historical data on annual peak water level were used for this purpose. There are two drainage outfalls in Pirojpur municipality. One outfall is to the Baleswar River, while the other is to the Kacha river. The drainage outfall of Amtali municipality is to the Buriswar River, while that of Galachipa municipality is to the Lohalia River. The water level gage stations close to those outfalls are Baleswar river at Pirojpur (SW 107), Kacha river at Umedpur (SW 136.1), Buriswar river at Amtali (SW 20) and Lohalia river at Galachipa (SW 185). Sub-catchments are hydrologic from where topography and drainage system direct surface runoff to a single discharge point (Wang, and Altunkaynak, 2012). Drainage catchments for the three townships were delineated using digital elevation model with spatial resolution of 10m from the Master Plan of LGED Project. This new global 10m resolution topological data has been collected for Amtali, Galachipa and Pirojpur Pourashavas. Watershed analysis has been conducted using ArcGIS spatial analysis and ArcHydro extension tools (Barco et al, 2004). Using land use map of the study areas, sub-catchments were divided into pervious and impervious subareas. Information on sub-catchment parameter such as area, width, slope in percentage, percentage of impervious zone, Manning's roughness coefficient for the pervious zone, land use category, SCS (sand clay silt) soil group and curve number, depth of depression storage, etc. are provided based on field visit and secondary literatures. Then, drainage network is determined from the spatial analysis of DEM, and has been trained using existing drainage network maps. Properties of existing drainage networks and canals are found from the cross-sectional survey of major canals and drainage structures. Drainage system data such as horizontal and vertical locations of the existing rivers, primary and secondary canals, invert elevations of junctions of flow divider storage and outlet are provided in the model. Layout plans are collected from LGED, while cross-sectional level data are collected from primary survey.

3. Results

3.1 Calibrations

Calibration of the model included the shape and timing of the hydrograph, the total flow volume under the hydrograph, and the peak discharge of the hydrograph. In the calibration process, the rating curve from the SWMM was compared and re-established with the rating curve found from the field measurements (Chowdhury, et al, 1998). This helped in elimination of inconsistency of measurements. Hydrographs of one or two storm events are used for calibration of the model. Calibrated storm water model is used for design runs. SWMM model has been calibrated for Varani Khal, Shashanhat Khal and Kumarkhali Khal of Pirojpur Pourashava, where field water level was available for comparison. These khals were chosen for calibration as they primarily drain water into the Damudor Khal – the main drainage canal of the Pourashava. Tidal hydrographs are used for both ends of the Damudor Khal. Calibration was done for cross-sections in Damudor-Varani Junction, Damudor-Shashanghat Junction and Damudor-Kumarkhali Junction. Figure 1(a) shows the locations of the junctions used for the calibration of the SWMM model. The Root Mean Square Error (RMSE) (Fang and Ball, 2011) between observed and model predicted values for Varani Khal, Shashanghat Khal, Kumarkhali Khal are 0.11, 0.12 and 0.23 respectively. Figure 1(b) shows measured and model predicted stages at Damudor-Varani junction where the red line indicates the computed water level curve. The observed water levels are shown by green squares as points. It is seen that the pattern of both computed and observed water levels are similar. Observed water levels are usually found to be lower than the computed values. Figure 1(b) shows the value R^2 is 0.965, which indicates a very good relationship between simulated and observed water level. R^2 values for Damudor-Shashanghat and Damudor-Kumarkhali junctions are 0.93 and 0.913 respectively.

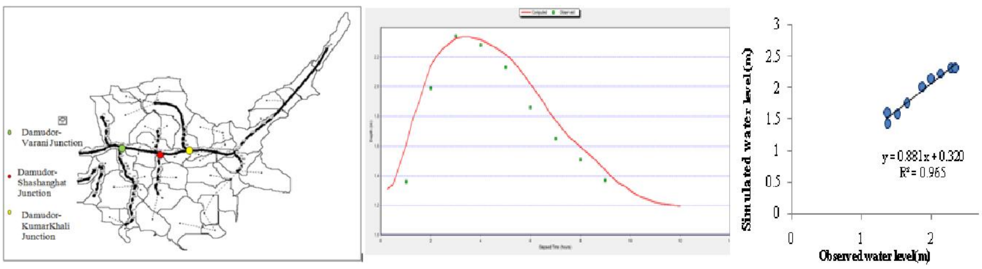

Figure 1: (a) Location for calibration point and (b) Comparison of measured and model predictedstages for Damudor-Varani Junction and R^2value between measured and model predicted

SWMM model has been calibrated for Basuki Khal at Amtali Pourashava. There is a sluice gate on Basuki Khal to regulate both drain water into the Buriswar River and vice versa as shown in Figure 2(a). Measured tidal water level has been used for boundary condition at both ends of the secondary canal, which finally meet with the Buriswar River. The RMSE between observed and model predicted values for the Basuki Khal is 0.21.

Figure 2(b) shows the measured and model predicted water level of Basuki Khal. The pattern of both computed and observed water levels are similar but the observed values are found to be much closer to the computed values and R^2 value is =0.87 indicating good relationship between simulated water level and observed water level.

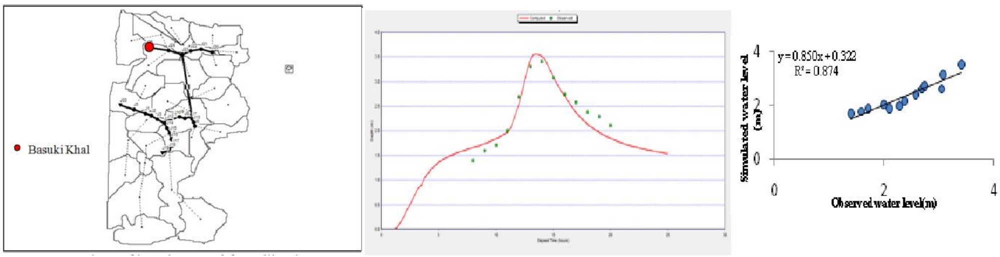

Figure 2: (a) Locations of junctions used for calibration at Amtali and (b) Comparison of measured and model predicted water level of Basuki Khal and their R^2 values

Figure 3(a) shows measured and model predicted water level of the Lohalia River at Galachipa. The pattern of both computed and observed water levels are similar but the observed values are found to be higher than the computed values. Figure 3(b) shows R^2 value (=0.785) which indicates very good relationship between simulated water level and observed water level in best fitted curve.

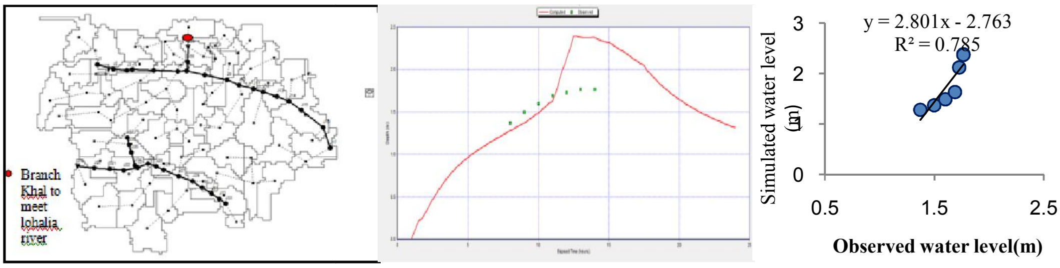

Figure 3: (a) Locations of junctions used for calibration at Golachipa and (b) Comparison of measured and model predicted water level of Lohalia khal and their R^2 values.

3.2 Overflow Condition

The sections of the natural canals, overtopped for design rainfall, have been identified through SWMM simulation run.. Table 1 shows some samples of the overtopped sections of the canal system in Pirojpur Pourashava. It is seen in the table that Chanmari Khal, Varani Khal, Palpara Khal and Shashanghat Khal are overflown. Some sections of Dhuppasha Khal and Kumarkhali khal are also overflown. Other canals of the drainage system are found capable to carry the design storm without any over topping of banks. Table 2 shows the overtopped sections of the canal system in Amtali Pourashava. It has been found that the main canal - the Basuki Khal in Amtali Pourashava has not overflown for the design storm. However, other three major canals of Amtali Pourashava, namely, Khal connecting M.U. secondary school south side to Mofiz Talukder's house, Khal connecting Badhghat Chowrasta to Shantinagar Akhrabari, and Khal connecting Pachim Chowrasta (WAPDA sluice) to R&H box culvert Chowrasta are overtopped.

Table 1: Drainage capacity and conditions of different canal in Pirojpur

a) Chanmari Khal

XS	Chainage (m)	Roughness	Allowable Depth (m)	Max Depth (m)	Comment
1	0	0.035	1.81	3.16	Overflow
2	200	0.035	1.45	3.02	Overflow
3	405	0.035	1.51	2.79	Overflow
4	600	0.035	1.59	2.46	Overflow
5	800	0.035	1.58	2.12	Overflow
6	1000	0.035	1.44	1.44	

Table 2: Drainage capacity and conditions for different canal in Amtali

a) Khal connecting M.U. secondary school south side to Mofiz Talukders house in Amtali

XS	Chainage (m)	Roughness	Allowable Depth (m)	Max Depth (m)	Comment
1	0	0.035	1.72	3.42	Overflow
2	100	0.035	1.71	3.42	Overflow
3	200	0.035	1.67	3.42	Overflow
4	300	0.035	1.72	3.80	Overflow
5	345	0.035	1.76	3.80	Overflow

3.3 Climate change Condition

Model has been simulated under climate change conditions and possible change of land use patterns of the three Pourashavas for two future time slices during 2030s (2026-2035) and 2050s (2046-2055). It has been found that due to sea level rise and increase of precipitation and urbanization, the inundation areas are increased for the all three Pourashavas. Figure 4 shows inundation area of Pirojpur during 2030s and 2050s for 2-hour 10-year design storms. It has been found that inundation will be higher during 2050s than 2030s. Similar situations are observed for Amtali Pourashava.

Percentage of change of inundation areas for different land types are calculated for the three selected Pourashavas. Floodplain land is classified into five types based on the depth of flooding in each month. Table 3 shows land types and flooding depth and duration.

Percentage of changes of flooding for each of the land class type has been quantified. Table 4, 5 and 6 present results of percent of inundation of Ward for design flood during present and future climate change conditions for Pirojpur, Amtali and Golachipa respectively.

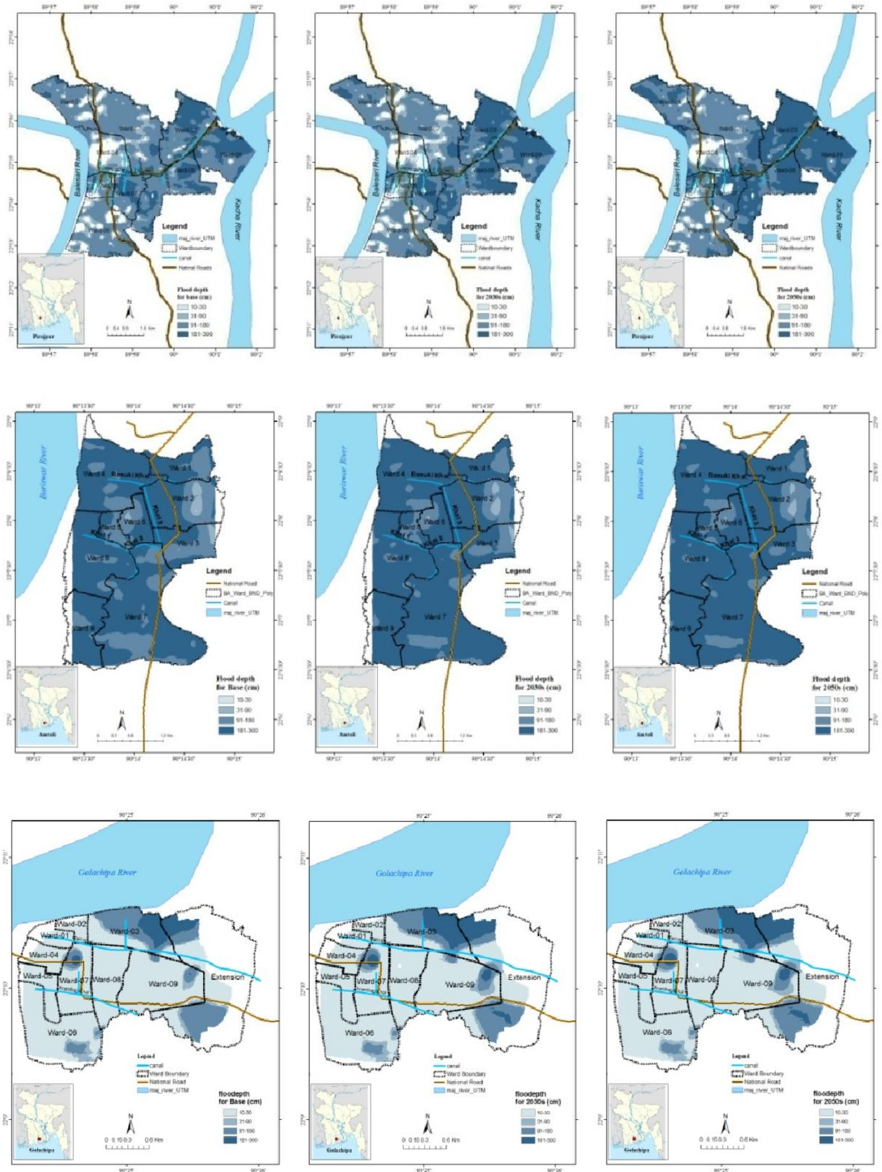

Figure 4: Inundation map for base line, 2030s and 2050s at Pirojpur, Amtali and Golachipa

It has been found that for Pirojpur Pourashava, the depth of inundation will be higher for the larger areas of the Wards during 2030s and 2050s. Climate change is to worsen the present inundation situation. Inundation during 2050s will higher than that for 2030s. Similar situation was found for the Amtali Pourashava. Inundation depth and duration was found higher under climate change conditions for future conditions. Almost all the areas of the Wards show increasing trends of flood inundation for Amtali Pourashava.

It is also noteworthy to mention that during 2050s, flood inundation will be higher than that for 2030s. For Golachipa, the condition of flood inundation is slightly different than other two Pourashavas. The condition of flood inundation has been increased almost for all the Wards under climate change conditions during 2030s than present condition.

Climate change conditions will increase inundation depth for the Golachipa Pourashava but not like as Amtali and Pirojpur. During 2050s, the situation is supposed to be worse for some Wards, while to be improved for some other Wards. Though the changes of inundation areas within different Wards are observed, they are not uniform under climate change conditions.

Table 3: Flood land types defined on the basis of flood depth

Category	**Flood Depth**	**Land Type**	**Flooding Condition**
F0	0-30 cm	Land above normal flood level	Intermittent flooding up to 30cm
F1	30-90 cm	Medium highland: Land	Seasonally flooded up to 90 cm deep
F2	90-180 cm	Medium lowland: Land	Seasonally flooded between 90-180 cm deep
F3	180-300 cm	Lowland	Land seasonally flooded more than 180 cm deep.
F4	Greater than 300 cm	Perennial deep water body	Permanent backwater lakes (beels).

Source: MPO, 1987.

Table 4: Comparison of the percentage of inundated area under different land use classes for various Wards of Pirojpur Pourshava

Wards	**Baseline**				**2030s**				**2050s**			
	F0	F1	F2	F3	F0	F1	F2	F3	F0	F1	F2	F3
Ward 1	3	9	75	5	2	7	74	12	1	5	57	34
Ward 2	5	16	70	6	6	19	61	9	2	12	67	17
Ward 3	1	3	53	42	0	2	35	62	0	0	11	88
Ward 4	8	22	32	2	10	16	31	2	8	17	32	10
Ward 5	6	14	58	4	4	15	50	8	4	12	44	22
Ward 6	6	16	59	3	6	16	56	6	5	15	58	8
Ward 7	1	6	58	31	1	4	46	45	1	4	30	54
Ward 8	0	4	62	32	0	2	44	53	0	1	26	72
Ward 9	0	1	54	43	0	1	42	56	0	0	12	87

Table 5: Comparison of the percentage of inundated area under different land use classes for various Wards of Amtali Pourashava

Wards	Baseline				2030s				2050s			
	F0	F1	F2	F3	F0	F1	F2	F3	F0	F1	F2	F3
Ward 1	0	0	31	67	0	0	21	77	0	0	15	82
Ward 2	0	8	30	54	0	6	29	58	0	4	28	60
Ward 3	0	5	47	44	0	3	31	63	0	1	24	71
Ward 4	0	0	16	79	0	0	9	86	0	0	9	86
Ward 5	0	0	62	38	0	0	48	52	0	0	32	67
Ward 6	0	3	42	55	0	1	31	68	0	0	30	70
Ward 7	0	0	28	71	0	0	13	86	0	0	10	89
Ward 8	0	0	11	78	0	0	8	81	0	0	5	84
Ward 9	0	0	10	71	0	0	3	78	0	0	1	81

Table 6: Comparison of the percentage of inundated area under different land use classes for various Wards of Galachipa Pourashava

Wards	Baseline				2030s				2050s			
	F0	F1	F2	F3	F0	F1	F2	F3	F0	F1	F2	F3
Ward 1	100	0	0	0	100	0	0	0	100	0	0	0
Ward 2	85	10	5	0	85	10	5	0	100	0	0	0
Ward 3	0	5	47	44	0	3	31	63	32	7	41	20
Ward 4	99	1	0	0	98	2	0	0	87	8	4	0
Ward 5	29	6	32	33	28	5	31	35	100	0	0	0
Ward 6	99	1	0	0	99	1	0	0	85	10	5	0
Ward 7	84	4	9	3	82	4	9	5	82	4	9	6
Ward 8	100	0	0	0	100	0	0	0	99	1	0	0
Ward 9	89	5	5	0	81	8	9	2	79	9	9	3
Extension	45	7	36	12	39	8	33	19	39	8	33	21

4. Conclusion

In this study, urban drainage modeling study has been conducted using open source and community model, SWMM developed by EPA for three selected coastal towns of Bangladesh. SWMM has been calibrated using the rainfall and water level data of the major canals and outfall of the three Pourashavas during monsoon season of 2012. Due to limitations of the data, it is only possible to calibrate model with one or two single storm events. The model seems reasonably capture the shape of the hydrographs constructed using observed water levels of canals and of the surrounding rivers. Various sections of the natural canals in three selected Pourashavas are overtopped under the design storms at present and under climate change conditions in future.

It is essential to consider both structural and non-structural measures to improve drainage conditions. Considering the limited scope of this study, improvement of X-sections of major canals is tested under design storms for both present and future climate change conditions. It has been found that in many cases, improving the existing canals by deepening, changing of bed slope or side slope can improve the drainage capacity. Except a few sections of the major canals of the three Pourashavas, improvement of canals can provide viable solutions to the existing drainage problem. Some of the non-structural measures such as raising awareness among the people about the protection of canals, proper cleaning of debris, putting boundaries or fence, remove any artificial obstructions in the canals, improving flood forecasting and sluice gate management, etc. can also improve the performance of the drainage system.

Several lessons learned in the study are listed below:

- It has been found that high resolution DEM data is necessary to delineate catchment of the study area. The DEM provided in the Master Plan is based on very old topographic maps which are changed due to the change of land use of the Pourashava. The high resolution DEM can provide sufficient and updated information about the catchments and it may help to develop most realistic drainage network. Total station survey for the whole catchment area is highly necessary to construct high resolution DEM for the study area.

- Continuous hourly rainfall and water level data for major canals should be collected for a number of storms during the monsoon season for all the study area. It is also essential to install automatic water level and flow measuring devices in the major canals and operate for the whole season. Automatic rain gauges should be installed to collect hourly rainfall data during the storms. This might assist for precise calibration of the model.

- In this study, SWMM has been successfully applied to capture the urban runoff though the major canals of the three Pourashavas under study. However, converting results of inundation depth from 1D water depth to 2D spatial distribution of inundation for the study area are challenging and suffers for accuracy. Although open source software has been used in this study, commercial software which couples both 1D and 2D would improve inundation maps.

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