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Assessment of Future Flow of Hatirjheel- Begunbari Drainage System due to Climate Change

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*Dhaka, the capital of Bangladesh, has experienced water logging for last couple of years as the storm water drainage systems are often unable to manage peak runoff volume. Moreover, precipitation intensity and pattern are expected to be altered due to climate change and such changes are likely to lead to severe flooding in urban areas of Bangladesh. This study aim*s *to* assess the effect of climate change on flow of *Hatirjheel- Begunbari Khal storm water drainage system* as it is considered *one of the major drainage channels* of Dhaka city. As H*atirjheel works as a large storm water detention area* and also a regulatory system, different scenerios are considered while assessing the future flow. The rational fromula was used to assess the flow instead of hydrologic model due to lack of observed flow data for calibration and validation. The study involves DEM based catchment delineation using GIS. The DEM was reconditioned prior to catchment delineation to *create a channelization effect intended to mimic the* existing *storm* sewer network of the city. *A future land use scenario is considered based on the analysis of land use maps of three different time interval for determining future runoff coefficient. The peak rainfall intensity is obtained from the IDF curve of Dhaka city developed considering the future precipitation data of a climate model. Although Hatirjheel is found to be an effective retention and regulatory system to minimize the flow, result of this study shows an alarming increase in flow in future which might cause severe flooding in the surrounding area.*

1. Introduction

Dhaka city is bounded by three rivers, the Buriganga in the South-West, the Turag River in the West and the North and the Balu River in the East. During rainy season the periphery of the city is inundated by backwater flow from these surrounding rivers and the storm water causes drainage congestion in the centre of the city. In addition to surrounded rivers, the city has a number of medium and small khals. Begunbari khal (also known as Rampura Khal or Banasree Khal) is one of the major drainage khals amongst these that carries storm runoff to the Balu river from catchments in eastern & central Dhaka. Three tributary khals, Shutibhola and Gojaria khals from the north and Nasirabad-Nandipara khal from the south, discharge runoff into this khal.

Hatirjheel, which is now the largest surface water body within Dhaka, also plays an important role in the inflow of Begunbari Khal. It serves very important hydrologic functions of draining and detaining storm water from a large area of Dhaka city. Although designed to carry storm water, the storm sewers discharging into Hatirjheel

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carry both storm water and dry weather flow. Hence, Hatirjheel- Begunbari Khal system is the largest and most important drainage system of Dhaka city.

Precipitation intensity and pattern are expected to be altered under a climate change regime. An increase of 4.26% was observed in the percent difference between the total annual precipitation (average of 34 meteorological station-data) of the past 20 years (1953-1972) and the recent 20 years on record (1985-2004) which represents that the annual rainfall follows an increasing trend (Rajib et al, 2011).The IPCC Special Report on the Regional Impacts of Climate Change (IPCC, 2007) indicates that there would be drastic changes in the rainfall patterns in the warmer climate and Bangladesh may experience 5-6% increase of rainfall by 2030, which may create frequent massive and prolonged floods.

Moreover, it is found that 34% area of 13 natural canals has been filled up by developers, private individuals and others. Between 1989 and 2007, area of wetland was reduced from 22.15% to 12.17% in the west Dhaka (Das and Islam, 2010). Thus, the wetlands are decreasing and on the contrary population is expanding at a rate of almost 0.8 million per year, which makes the drainage system of Dhaka City vulnerable.

2. Literature Review

There are several studies related to causes and effects of water logging, rehabilitation of canals, flood management and vulnerability of Dhaka city. Even the adequacy of Begunbari Khal have been assessed previously (Matin et al, 2010; and BRTC, 2013), but these studies are limited to 5 year return period rainfall event only and precipitation variability due to climate change was not considered. Assessing capacity of drainage canals for *extreme rainfall events* of different return period requires reliable IDF relationships. Some *IDF relationships* have been developed for Dhaka city considering observed rainfall (Tawhid, 2004; Barua and Ast, 2011; and Huq and Alam, 2003). IDF curves considering future precipitation variability due to *climate change* has been developed in a recent study (Afrin et al, 2014).

3. Material and Methods

3.1 Data collection

Spatial data for Dhaka city were acquired from a variety of sources depending on types of data. For watershed analysis following datasets was collected:

Digital Elevation Models (DEM)

In this study, a higher quality DEM from the Advanced Space-borne Thermal Emission and Reflection Radiometer instrument of the Terra satellite was used.

Storm Sewer & Drainage Network

Drainage map of Dhaka city and data regarding existing storm sewers along with their directions and outlets were collected from Dhaka WASA. Moreover, stream network data was collected from RAJUK (Rajdhani Unnayan Kartipakkha).

Land Use Maps

Land use maps of Dhaka city during 2008 & 2012 were collected from RAJUK in addition to a proposed land use map of Detailed Area Plan (DAP).

Geometric Data

Geometric data of Begunbari Khal was collected from a topographic survey conducted by the BRTC-BUET Team (BRTC, 2013).

3.2 Runoff Estimation

In this study rational method was used to estimate runoff volume.

Rational Formula

The Rational Formula is the most commonly used method of determining peak discharges from small drainage areas. It is expressed as

$$Q=(C)\,(A)\,(I)$$

Where,
Q = peak runoff
C = runoff coefficient
I = rainfall intensity
A = catchment area

The step by step procedure for determining peak discharge with the Rational Formula is as follows:

Catchment Area, A

Watershed and stream network were delineated using DEM with the help of Arc Hydro Terrain Preprocessing tools. DEM is a digital cartographic dataset of elevations in xyz coordinates which is represented as a raster. Moreover, a comparison of existing ground features affecting hydrology with the area's DEM indicated that the DEM resolution was not fine enough to depict water body, an important feature within the flood plain. To incorporate this topographic feature, prior to delineating watersheds DEM was verified and appropriately modified to match existing topography. Again in order to incorporate the existing storm sewer network the DEM was conditioned such that the presence of a storm sewer main would redefine the elevation 10 m below the original elevation. This created a channelization effect intended to mimic the storm drain system. Further terrain analysis was performed with this new conditioned DEM to generate data of flow direction, flow accumulation, streams, stream segments, and watersheds. Further analysis was performed on each outfall watershed and the percent and total area of soil type were determined with the help of Arc GIS

Runoff coefficient, C

Future land use scenario was considered while determining run off coefficient which was used to calculate future flow in the drainage system. In this study, future land use scenario was predicted by analyzing land use maps of different time interval of Dhaka city with the help of GIS. In case of considering the future land use scenario the basic assumption was that future development of eastern side would be similar to that of the land use pattern of western side (west side of Progati Sarani). Finally these maps were summarized using ArcGIS summary statistic tool according to their associated area of different land types. Based on this summary, present and future runoff coefficient was obtained from weighted average of C associated with different land types.

Rainfall Intensity, I

The IDF curves (Afrin et al, 2014) were used to determine the maximum rainfall intensity corresponding to time of concentration (Tc) and for different return periods.

3.3 Different Scenario

For determination of inflow both present and future conditions were considered.

a. Present Storm water Runoff: Considering observed precipitation and land use scenario
b. Future Storm water Runoff: Considering predicted precipitation variability due to climate change and future land use scenario

The main objective of this thesis is to assess the storm water drainage capacity of Hatirjheel -Begunbari Khal system as this system is expected to carry storm water runoff only. However, even in the dry period the storm sewers carry some flow, usually known as dry weather flow, due to illegal connection of sewage lines in the storm sewer network. Hence, in order to simulate the actual scenario and to assess the impact of this dry weather flow in the inflow of the Begunbari Khal another scenario considering both storm and dry weather flow was also generated.

Furthermore, as Hatirjheel works as a regulatory structure, it is not feasible to consider a constant contribution of Hatirjheel to the inflow of Begunbari Khal. So, based on the operational conditions two critical scenarios were considered for above mentioned scenarios.

a. Hatirjheel Crest at an Elevation of +2.5 M and Rampura Gate Open:

The crest of the Hatirjheel regulator is generally maintained at a minimum elevation of +2.5 m in the dry season to maintain a minimum water level of + 2.5m in the lake (Figure 1). By raising the elevation of crest the water level of the lake could be controlled. So, if +2.5m elevation would be maintained then storm water from entire catchment of Hatirjheel would pass through this weir and at the same time if Rampura sluice gate (Figure 2) would also open then water from SSDS-6 & 11 and water from main diversion sewers also contribute to the inflow of Begunbari Khal. In this situation the Begunbaei Khal will carry highest level inflow and this is the most critical scenario for drainage capacity assessment of the Khal.

b. Both Hatirjheel and Rampura Gates are Closed:

The Hatirjheel regulator gate is closed when the crest is raised to a maximum level and at this time all storm water coming through the SSDS's is stored in the lake. Moreover, at the same time if Rampura sluice gate is also closed then water discharging in between these structures have to pump out to discharge in the Begunbari Khal. In this situation, only the catchment of SSDS-6 & 11 and flow from main diversion sewers of Hatirjheel will contribute to the inflow of the Khal. This situation is the least critical situation and in this situation Hatirjheel plays a vital role in the storm water detention. Summary of different scenarios along with their corresponding catchments is shown in table 1.

Table 1: Summary of Different Scenarios

Criterion		Considering only storm water	Considering storm water & dry weather flow through storm sewer network
Hatirjheel crest at a elevation of +2.5 m and Rampura gate open	Upstream Catchment	Hatirjheel Lake (except SSDS 6 & 11), Gulshan-Banani Lake, Catchment of SSDS 6 & SSDS 11	Hatirjheel Lake (except SSDS 6 & 11), Gulshan-Banani Lake, Catchment of SSDS 6 & SSDS 11 and Dry weather flow through main diversion sewers of Hatirjheel
	Downstream Catchment	Hatirjheel Lake (except SSDS 6 & 11), Gulshan-Banani Lake, Catchment of SSDS 6 & SSDS 11, Sutivola, Gozaria, Nasirabad-Nandipara Khal	Hatirjheel Lake (except SSDS 6 & 11), Gulshan-Banani Lake, Catchment of SSDS 6 & SSDS 11 and Dry weather flow through main diversion sewers of Hatirjheel, , Sutivola, Gozaria, Nasirabad-Nandipara Khal
Both Hatirjheel and Rampura gates are closed	Upstream Catchment	Catchment of SSDS 6 & SSDS 11	Catchment of SSDS 6 & SSDS 11 and Dry weather flow through main diversion sewers of Hatirjheel
	Downstream Catchment	Catchment of SSDS 6 & SSDS 11, Sutivola, Gozaria, Nasirabad-Nandipara Khal	Catchment of SSDS 6 & SSDS 11 and Dry weather flow through main diversion sewers of Hatirjheel, Sutivola, Gozaria, Nasirabad-Nandipara Khal

Figure 1: Hatirjheel Regulator Gate Open (Crest at an elevation of +2. 5 m)

Figure 2: Rampura Regulator Gate Open

3.4 Capacity Assessment Using HECRAS

Hydraulic calculation for the Begunbari Khal was carried out using HEC-RAS, considering uniform flow. The basic computational procedure of HEC-RAS for steady flow is based on the solution of the one-dimensional energy equation.

4. Results and Discussion

Peak Runoff

Several small catchments were found as a result of catchment delineation. These small catchments were then grouped into seven major catchment for the convenient of further analysis (Figure 3). Area of each catchment was determined with help of GIS (Table 2). It is seen from the table that Hatirjheel lake and Nasirabad-Nandipara khal consist of larger catchments (19 km² and 22 km² respectively) compared to others. The relative proportion of each catchment is shown in figure 4. From the figure the total catchment of Nasirabad-Nandipara, Gozaria and Sutivola khals is found to be 59% depicting that Begunbari khal has a large catchment in eastern side in addition to western side.

Table 2: Summary of Catchment Areas

Catchment	Area(km^2)
Hatirjheel Lake	19.00
Gulshan-Banani Lake	8.27
Sutivola Khal	14.76
Gozaria Kkal	4.87
Nasirabad-Nandipara Khal	22.00
Catchment of SSDS 6	0.65
catchment of SSDS 11	0.44

Figure 3: Catchment of Hatirjheel-Begunbari Khal

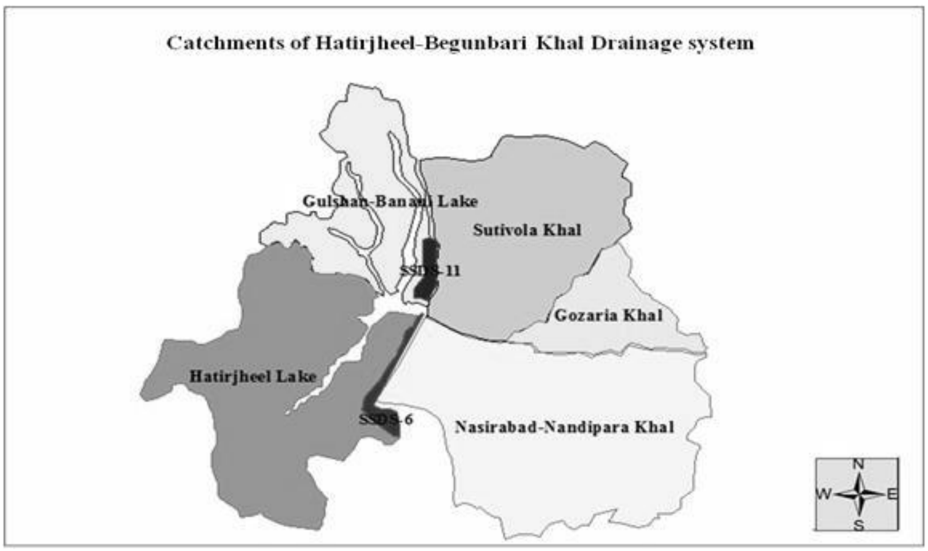
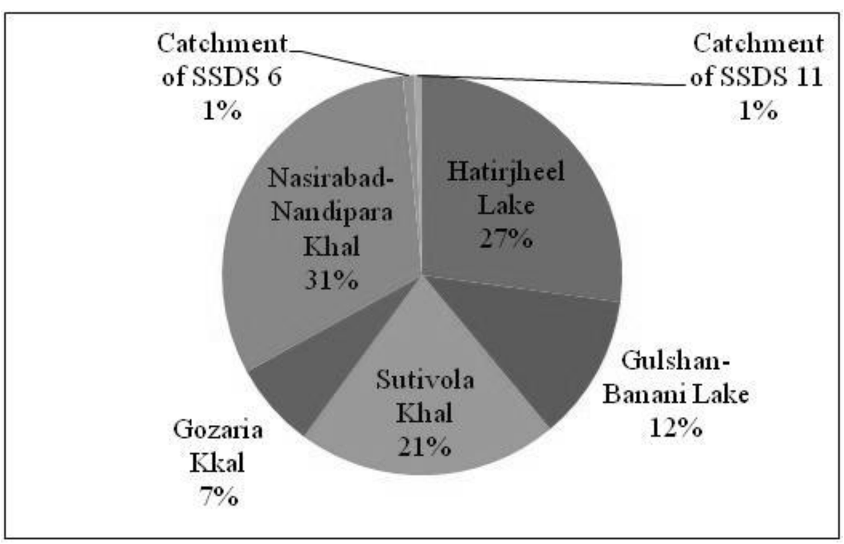


Figure 4: Relative Proportion Catchments



From the summary statistics of present land use map it can be depict that the eastern side of Dhaka is not still developed enough (table 3). On the other hand, in the western side, built up area is 75.52% and there is actually no scope of further development in future. So for future land use pattern of east side it was considered that the water body will remain unchanged as present (i.e. 6.56%) and at the same time other land use categories will tend to approach to those of west side. And for future land use pattern of west side it was considered that it will be same as present. Based on these assumptions the proposed land use pattern for future was determined and summarized in table 4. The weighted average runoff coefficient of the study area was determined for both present and future scenarios and it was found to be 0.53 and 0.63 respectively.

Table 3: Summary of Present Land Use Scenario

Land use categories	West Side		East Side	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Built up	21.42	75.52	12.65	30.39
Open & cultivated land	1.77	6.25	21.34	51.27
Water body & Wetlands	1.45	5.10	6.56	15.75
Transportation & Communications	3.73	13.13	1.08	2.60

Table 4: Summary of Proposed Land Use Scenario

Land use categories	West Side (Area %)	East Side (Area %)	Total study area (Area %)
Built up	75.52	70	72.23727829
Open & cultivated land	6.25	6.65	6.486778351
Water body & Wetlands	5.10	15.35	11.19532811
Transportation & Communications	13.13	8	10.08061525

The following intensity duration frequency relation (Afrin et al., 2014) were used for determination of rainfall intensity, where rainfall intensity (I) is in mm/hr, T is the return period in year and d is the duration of storm in hour. For peak flow analysis time of concentration Tc was used as duration.

Considering present scenario, $I_{d,T} = \frac{69.536-23.457\ln(-ln(1-1/T))}{d^{0.686}}$

Considering future scenario, $I_{d,T} = \frac{168.92-102.88\ln(-ln(1-1/T))}{d^{0.686}}$

Table 5: Summary of Present Runoff of Begunbari Khal

Catchment		Hatirjheel Lake	Gulshan-Banani Lake	Sutivola Khal	Gozaria Kkal	Nasiraba-Nandipara Khal	Catchment of SSDS-6	Catchment of SSDS-11
Present C		0.53	0.53	0.53	0.53	0.53	0.53	0.53
I (mm/hr) for different Return periods	2 yr	25.25	35.09	32.36	57.21	25.38	53.92	72.01
	5 yr	33.85	47.03	43.37	76.67	34.02	72.27	96.52
	10 yr	39.54	54.94	50.66	89.56	39.74	84.42	112.74
	15 yr	42.75	59.40	54.77	96.83	42.96	91.27	121.89
	25 yr	46.73	64.93	59.87	105.85	46.96	99.76	133.24
	40 yr	50.35	69.96	64.51	114.05	50.60	107.50	143.57
	100 yr	57.35	79.69	73.49	129.92	57.64	122.45	163.54
Area (km^2)		19.00	8.27	14.76	4.87	22.00	0.65	0.44
Present Q (m^3/sec)	2 yr	70.38	42.56	70.05	40.86	81.90	5.14	4.60
	5 yr	94.32	57.05	93.89	54.77	109.76	6.89	6.17
	10 yr	110.18	66.64	109.67	63.97	128.21	8.05	7.21
	15 yr	119.12	72.05	118.58	69.17	138.62	8.70	7.79
	25 yr	130.21	78.75	129.61	75.60	151.53	9.51	8.52
	40 yr	140.31	84.86	139.66	81.46	163.27	10.25	9.18
	100 yr	159.83	96.66	159.09	92.80	185.99	11.68	10.46

Table 6: Summary of Future Runoff of Begunbari Khal

Catchment		Hatirjheel Lake	Gulshan-Banani Lake	Sutivola Khal	Gozaria Kkal	Nasirabad-Nandipara Khal	Catchment of SSDS-6	Catchment of SSDS-11
Future C		0.63	0.63	0.63	0.63	0.63	0.63	0.63
Futurte I (mm/hr) for different Return periods	2 yr	66.79	92.80	85.58	151.29	67.12	142.60	190.44
	5 yr	104.48	145.17	133.87	236.67	105.00	223.07	297.91
	10 yr	129.43	179.85	165.85	293.20	130.08	276.35	369.07
	15 yr	143.51	199.41	183.89	325.09	144.23	306.41	409.22
	25 yr	160.96	223.66	206.25	364.62	161.77	343.66	458.98
	40 yr	176.85	245.73	226.60	400.60	177.73	377.58	504.28
	100 yr	207.57	288.42	265.97	470.20	208.61	443.18	591.88
Area (km^2)		19.00	8.27	14.76	4.87	22.00	0.65	0.44
Future Q (m^3/sec)	2 yr	222.07	134.31	221.05	128.94	258.42	16.23	14.53
	5 yr	347.39	210.10	345.79	201.70	404.25	25.38	22.73
	10 yr	430.36	260.28	428.38	249.88	500.81	31.44	28.16
	15 yr	477.17	288.60	474.98	277.06	555.28	34.86	31.22
	25 yr	535.20	323.69	532.74	310.75	622.80	39.10	35.02
	40 yr	588.02	355.64	585.31	341.41	684.27	42.96	38.48
	100 yr	690.17	417.42	687.00	400.73	803.14	50.43	45.16

Finally runoff volume in m^3/sec for different catchment of Begunbari Khal was determined using rational formula and these values are summarized in table 5 & 6.

These discharges are further categorized into different scenarios according to their corresponding catchment area and represented in table 7.

Adequacy Check using HECRAS Model

Existing condition of Begunbari Khal was modeled using HECRAS assuming a roughness value of 0.03 for the channel bed. The developed reach of the Begunbari Khal is shown in Figure 5, where station 6363.855 represents the most upstream cross section and 241.2447 represents the most downstream cross section. Only few upstream sections were found adequate to meet the peak flow when both Hatirjheel and Rampura regulator gates are closed (Figure 6). But in all other cases, the sections appeared to be overflowed. Figure 7, 8, 9 show the condition of some of the sections of Begunbari Khal under different flow conditions.

Table 7: Flow of Begunbari Khal under Different Scenarios for 5 Year Return Periods

Different Scenario		Considering only storm water		Considering storm water & dry weather flow	
		Present Discharge (m3/sec)	Future Discharge (m3/sec)	Present Discharge (m3/sec)	Future Discharge (m3/sec)
Hatirjheel crest at a elevation of +2.5 m and Rampura gate open	Upstream Catchment	164.44	605.60	170.96	612.12
	Downstream Catchment	422.85	1557.34	429.37	1563.86
Both Hatirjheel and Rampura gates are closed	Upstream Catchment	13.06	48.11	19.58	54.63
	Downstream Catchment	271.48	999.85	278.00	1006.37

Figure 5: Reach of Begunbari Khal with Different Cross Section.

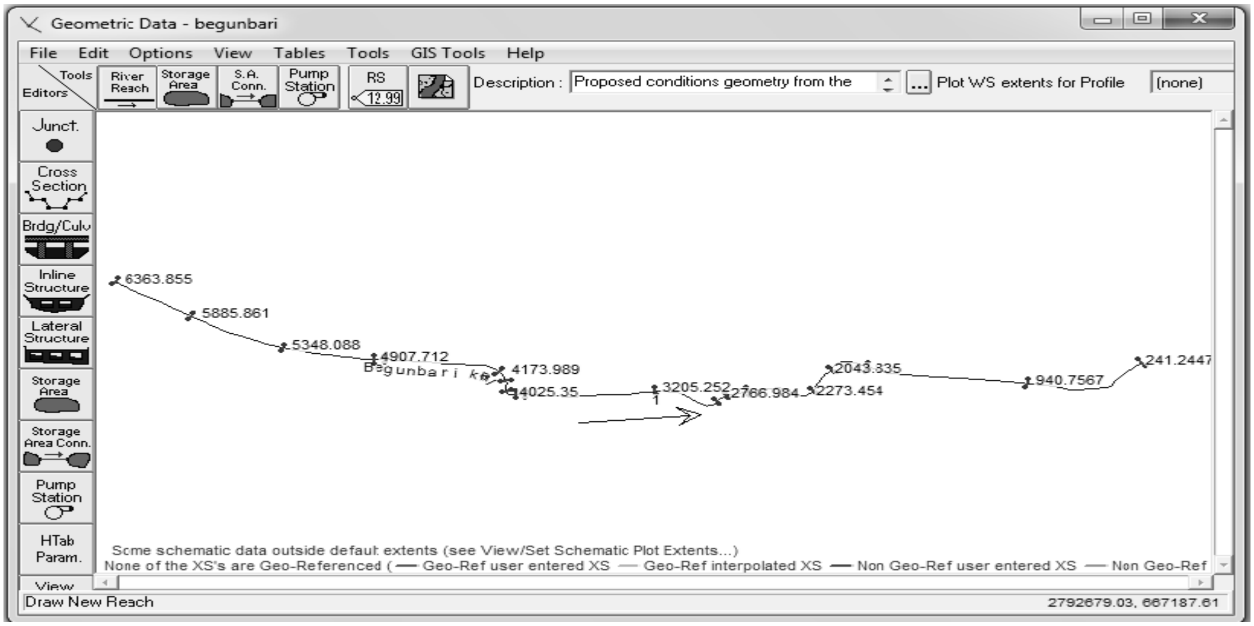


Figure 6: Upstream Cross Section of Begunbari Khal under Different Flow Conditions.

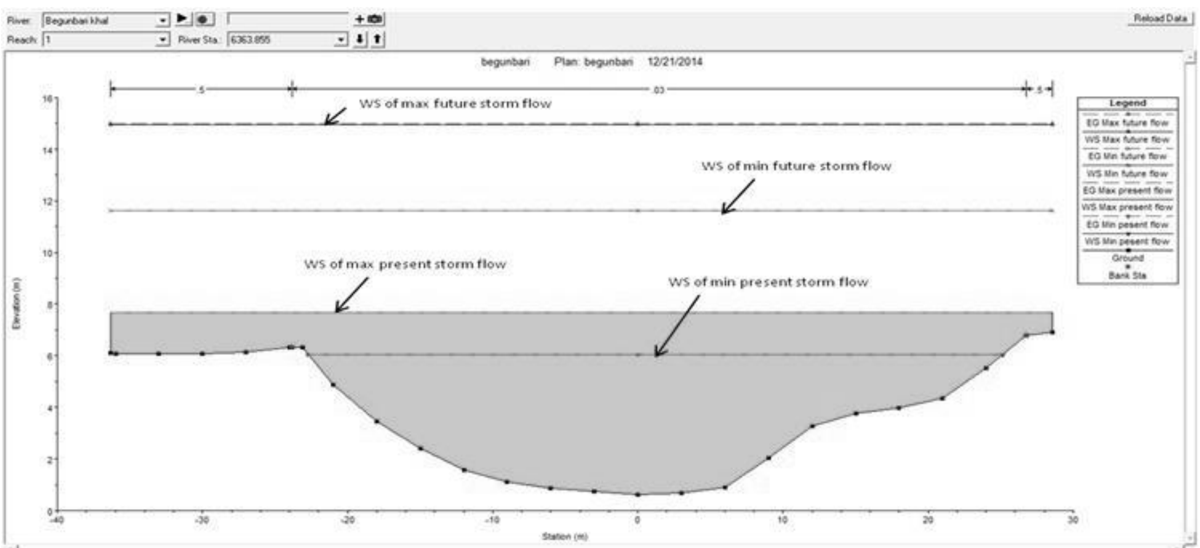


Figure 7: Cross Section Just Downstream of Tri-Mohini under Different Flow Conditions

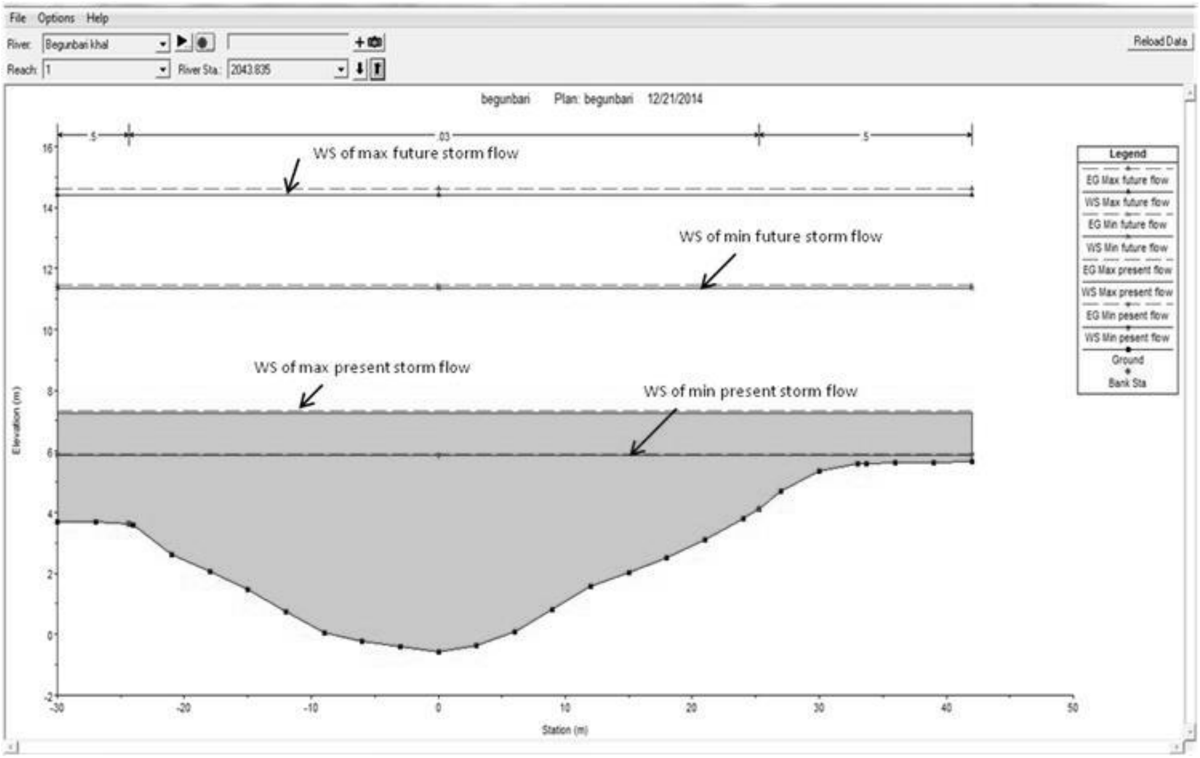


Figure 8: Cross Section Just Downstream After Connecting with Gozaria Khal under Different Flow Conditions.

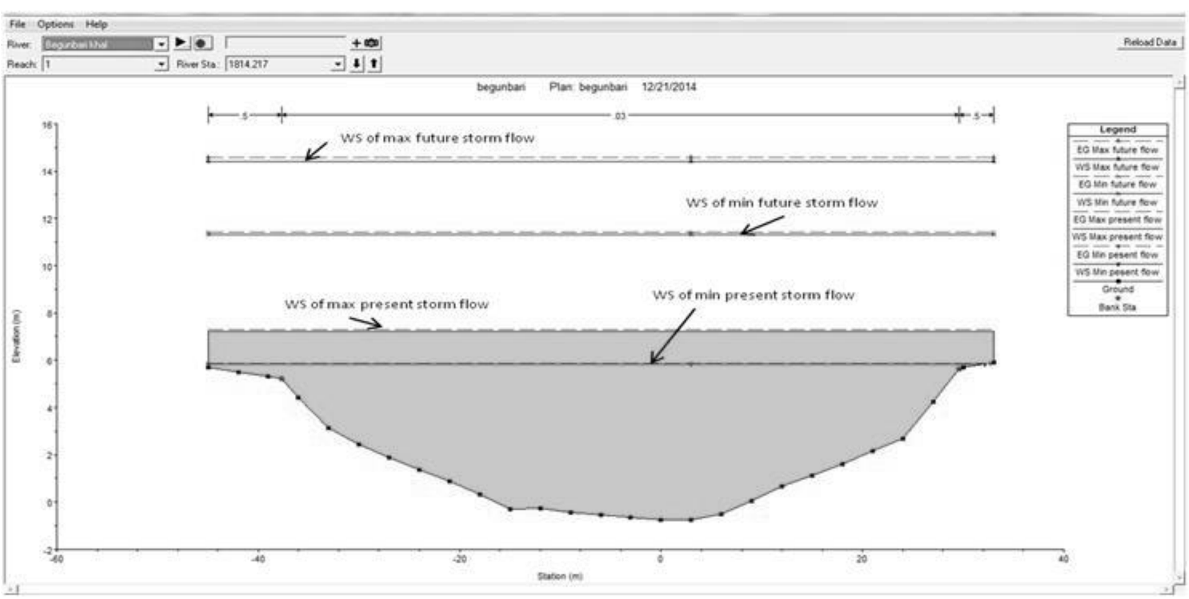
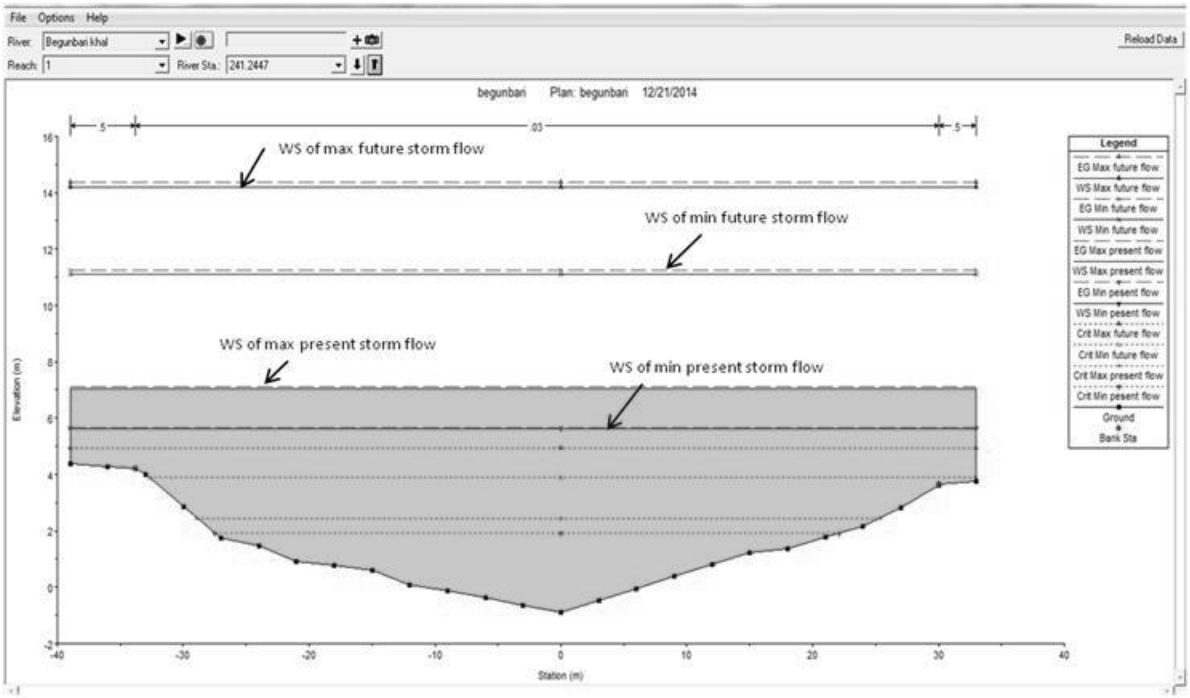


Figure 9: Downstream Cross Section of Begunbari Khal under Different Flow Conditions



5. Conclusions

In this study, catchment of a major drainage khal (Begunbari Khal) of Dhaka was delineated not only based on DEM but also on existing storm sewer network. It was found that Begunbari khal has a large catchment in eastern side in addition to western side. Future land use scenario of the catchment was also developed based on some assumptions and future flow was calculated based on this land use scenario. Finally HECRAS model was used for checking the adequacy of Begunbari Khal under present as well as future climatic conditions. All the sections appeared to be inadequate except some upstream cross sections for historical extreme rainfall event when both Hatirjheel and Rampura regulator gates are closed. It implies that Hatirjheel plays a very important role in the conveyance capacity of Begunbari Khal. It was also found that under future climatic scenario there is a possibility of about significant overflow which is alarming. It needs to be mentioned that while developing HECRAS model, tidal effect and back water flow during wet period were not considered due to lack of bathymetric and discharge data of Balu river. Hence a future study is recommended considering these effects.

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