ASSESSMENT OF DRAINAGE CAPACITY OF CHAKTAI AND RAJAKHALI KHAL IN CHITTAGONG CITY AND INUNDATION ADJACENT OF URBAN AREAS

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ABSTRACT

Chittagong city is known as the business port city of Bangladesh. Water logging due to intense rainfall makes the life of Chittagong city dwellers miserable every year as the roads and lowlying areas become inundated. Proper estimation of runoff volume generated from intense rainfall is thus important. The study focuses on estimating the capacity of the existing drainage channel network of the Chittagong urban area, mainly Chaktai and Rajakhali khal and their branches which carry water from the south eastern parts of Chittagong city. This case study deals with a systematic approach for the estimation of urban runoff from the catchment area of this khals. The catchment area of Chaktai and Rajakhali khal is delineated into 10 watersheds by using ArcGIS. The existing situation of the channel drainage capacity for rainfall runoff is estimated using HEC-HMS hydrologic model for 2 different considerations -2 hour 5 year return period rainfall and 2 hour 10 year return period rainfall. Lag time and time and time of concentration variations in different watersheds are estimated from the runoff hydrographs. Afterwards, the maximum water level at different sections of the khals for the rainfall runoff are generated using HEC- RAS 1D model and urban inundation maps are produced for different scenarios. The study reveals that the geometry of major drainage channels are not adequate enough to drain out the excess rainfall runoff to the Karnaphuli river. Surplus rainfall storage spills over the channels and inundates the adjacent locality. Dredging of channel sections is an important requirement for the improvement of the scenario. The study also identifies possible solutions as an essential input towards arriving at appropriate planning decisions for the improvement of city drainage system.

Keywords: *Rainfall runoff; Drainage Capacity; Hydrologic; Inundation; Dredging.*

1. INTRODUCTION

Urban drainage congestion during monsoon due to heavy rainfall causes much inconvenience and economic losses for the Chittagong urban area residents. The reasons behind this urban flooding can be attributed to heavy rainfall, inadequate drainage system, high tide twice a day in Karnaphuli river, unplanned urban development, encroachment and congestion of channels and urban development of local water retention bodies. The various drainage channels passing throughout the city play an important role in carrying out the runoff to the Karnaphuli river (Ashraf, M.A. & Chowdhury, S.A, December 2009).The major khals passing through Chittagong urban area are Chaktai Khal, Rajakhali Khal, Moheshkhal, Jamalkhan khal and Nasir khal. All of these khals are connected to each other through interconnecting branches and finally drain out to Karnaphuli river to the south.

Both Chaktai and Rajakhali Khals, two main drainage channels of Chittagong, terminate in the river Karnaphuli traversing through this area**.** Part of the area is densely populated. Remaining part of the area is expected to be developed in the immediate future as the area falls within Bakalia earmarked as a thrust area for development in the Structure Plan for Chittagong, 1995.

14 municipality wards lie within the catchment area of Chaktai and Rajakhali and their branch khals shown in Figure 1. They are Enayetbazar, Lalkhanbazar, Alkaran, Firingeebazar, Anderkilla, Patherghata, Dewanbazar, Jamalkhan, Chawkbazar, South Bakalia, West Bakalia, Boxirhat, East bakalia & East Sholahshahar. Almost all of these areas are industrially well developing and construction of paved surfaces and residential and commercial facilities are increasing the area of impervious surfaces. Increase of imperviousness results in producing high volume of discharge, as well as short duration flood-peaks (Hassan, M.M. & Nazem, M.M, June 2016).

Water logging can be mitigated by properly designing drainage networks and facilities. The initial steps of the prospect are numerical modeling of the rainfall runoff analysis of the study area. Further, the problem can be analyzed by assessing the flood routing and highest water level to these drainage congestion flooding (Papry, I. & Ahmed, January 2015). Inundation maps of the area suggests the areas that we need to focus to plan the proper drainage and development works like retention ponds and pumping stations required for the study area. The study also determines the minimum depth and areas the channels needs to be dredged in to drain the highest magnitude of storm water safely towards the Karnaphuli river outlet.

2. METHODOLOGY

2.1 Data Collection:

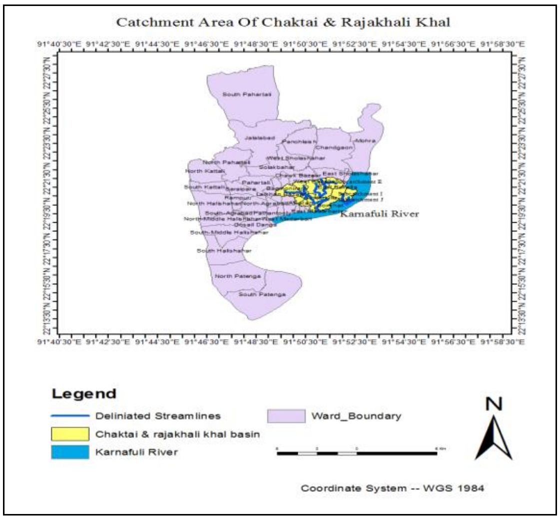


Figure 1: Ward Map of Chittagong urban area locating the Study Area

Both primary and secondary data were needed to fulfill the study. Primary data includes photographs of salient features to determine the flow paths, of the study area. Secondary data includes design rainfall data, Google earth satellite image data, cross-sectional features of channels, maps and GIS shape files.

2.2 Design Rainfall data:

The design rainfall data was generated from IDF curves of Chittagong City for the interval 1984-2016. (Rimi, S,S & Matin, A, M, 21-23 December 2016)

2.3 Watershed Delineation :.

30m x30m Landsat satellite DEM was used for watershed delineation of the study area. Arc hydro tools were used in the process. GeoSWMM was used to delineate the streams of the watershed using the Agree Dem raster of the Catchment Area – and the digitized polylines of the urban area channel network. The watershed polygon Raster was produced and – 18 watersheds were found for the digitized channels, among which- 10 watersheds lie within the study area. The 10 sub catchments were then imported as GIS shape files for the HEC HMS basin analysis The area is delineated into 10 sub catchments from where rain and storm water runs off to the river. The sub catchments are named respectively as Sub catchment A, Sub catchment B, Sub catchment C, Sub catchment D, Sub catchment E, Sub catchment F, Sub catchment G, Sub catchment H, Sub catchment I & Sub catchment J.

2.4 Calculation of Lag time And Time of Concentration for All the Sub catchments

NRCS developed the following equation (NRCS lag formula.) for watersheds with areas of less than about 8 km^2 (2000 ac) and Curve Number CN between 50 and 95 (Haan, C.T., Barfield, B.J. and Hays, J.C, 1994).

$$\mathrm{tL} = \frac{l^{0.8}(1000-9\mathrm{CN})^{0.7}}{1900\mathrm{CN}^{0.7}\, y^{0.5}} \tag{1}$$

$$\mathrm{tL} = \frac{l^{0.8}(2540-22.86\mathrm{CN})^{0.7}}{1410\mathrm{CN}^{0.7}\mathrm{Y}0.5} \tag{2}$$

The lag t_L is in hours. The hydraulic length l from the outlet to the most hydraulically remote point in the watershed is in feet (Eq. 1) or meters (Eq 2). CN is a dimensionless parameter between zero and hundred, CN = 0 represents an infinitely abstracting catchment with maximum potential retention, S= ∞, and a CN value of 100 represents a condition of zero potential retention (i.e. impervious catchment). Y is the average land slope of the watershed in percent.

The hydraulic length, l is obtained from ArcGIS 10.4.1, by taking the lengths of the flow paths in the different sub catchments. The corresponding land use types were obtained from ARCGIS supervised image classification on Google earth satellite images. The average basin slope, Y (%), was determined from the equation (Chow, 1964).

$$\mathrm{Y} = \frac{100(\mathrm{C\,I})}{\mathrm{A}} \tag{3}$$

Where, Y= average land slope, %
C= summation of the length of the contour lines that pass through the watershed drainage area on the quad sheet, ft
I= contour interval used, ft
A= drainage area, ft^2 (1 acre = 43,560 ft^2)

2.5 Design Rainfall Depths:

The equation of IDF curves of Chittagong City for the interval 1984-2016 (Figure 2) was obtained as--

$$I = \frac{1122 T_r^{0.213}}{T_d^{0.673}} \tag{4}$$

Here, I= intensity in mm/hr
Tr = Return Period, in Years
Td= Duration, in minutes

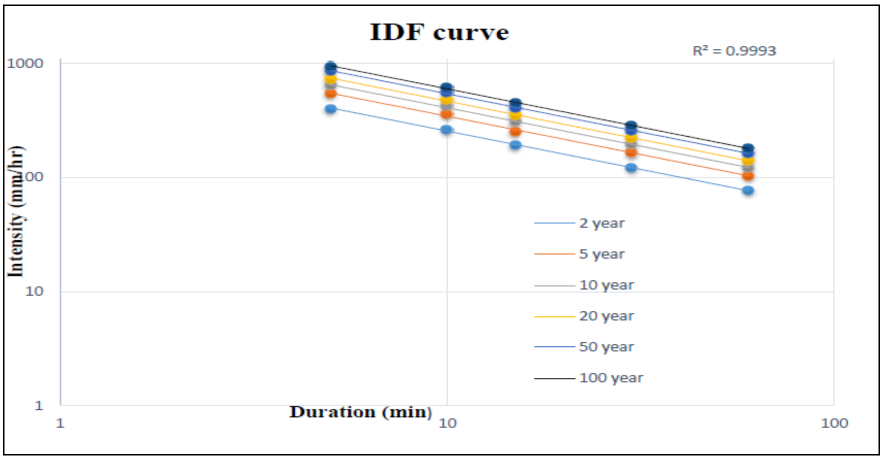
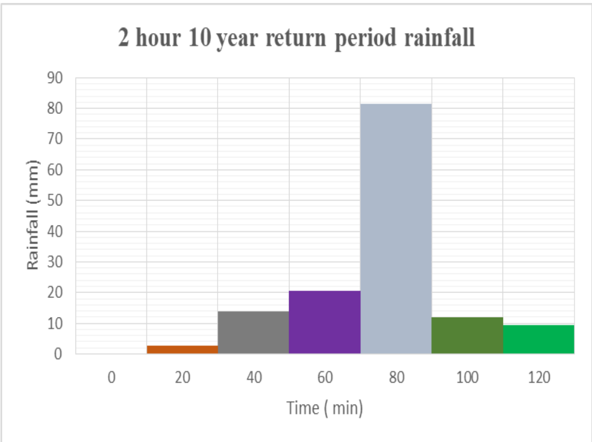


Figure 2: IDF Curve obtained from Gumbel Distribution method for Chittagong city (1984-Recent)

The model was simulated with the following rainfall events:

- ✓ 2h 5-Year Return Period
- ✓ 2h 10-Year Return Period

The design rainfall hyetographs are shown in Figure 3.



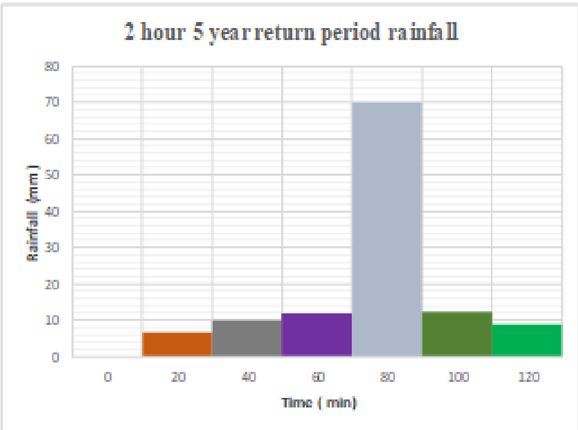


Figure 3: Precipitation hyetographs obtained from IDF curve of Chittagong City

2.6 HEC HMS runoff model

The SCS Unit Hydrograph was used as Transform Method. SCS Curve Number was chosen in Loss Method. Surface Method and Canopy Method were chose as “none”. Also it was assumed that there was no base flow infiltrated through the ground. A meteorological model manager was created. A precipitation gauge was added under time-series data manager. Finally, a control specification was set up.

Model Specific data: In the rainfall-runoff model of HEC-HMS, area, initial abstraction, curve number, imperviousness (%), lag time were given as inputs of catchment parameter. In time-series data manager, rainfall values were input in precipitation gauge as input hyetographs of 20 minute interval, as shown in Figures.

Model Simulation: A fixed time stem of 20 minute has been used as simulation period. 2 different return period rainfalls were used as design rainfall and control specifications time was selected as 12 hours. So the 12 hour runoff model was computed for the catchment area.

2.7- HEC-RAS 1D Flood Routing Model

2.7.1 Processing of Geometric Data

Cross Section Geometry: Width and elevations at the mouth of Chaktai and Rajakhali khals were observed from previous studies. The other location cross sectional width was calculated from the latest google earth satellite image of the study area. The cross section data of all the reaches were then interpolated at 20 m interval. The 1D model layout is illustrated in Figure 2.

Downstream reach length: The downstream cross section reach lengths describe the distance between the current cross section and the next cross section downstream are calculated from Google Earth.

Manning's n value: Initially roughness coefficient is assumed to be 0.025.

2.7.2 Unsteady Flow Data

At the beginning of the simulation, initial flow and boundary conditions at all of the external boundaries of the river reach is provided.

Boundary Conditions: For unsteady flow model, the boundary conditions are as follows:
HEC-HMS model output inflow hydrographs for Chaktai channel outlet was provided as Chaktai khal upstream boundary.
HEC-HMS model output inflow hydrograph for Rajakhali channel outlet was provided as Rajakhali khal upstream boundary.

At downstream boundary—stage hydrograph of Karnaphuli upstream at Sadarghat station and khal 18 station was provided.

2.7.3 Bed slope calculation:

Let the average cross sectional dimension of the channel is respectively 50m top width & 7m depth (Google earth image observation)
So, the trapezoidal area

$$A = (b + zh)h \tag{5}$$

Where b = bottom width of channel (assume 20 m)
z= side slope of channel = 7/15 =0.47 (assume 0.5)
h= channel depth = 7m

The wetted perimeter of the channel section

$$P = b + 2h\sqrt{1 + z^2} \tag{6}$$

From above calculation A=374.5 m^2
P=65.65 m
Hydraulic radius $R = \frac{A}{P}$ **(**7)
So, R= 5.70 m

Manning's equation for discharge calculation-

$$Q = \frac{1}{n} * AR^{\frac{2}{3}} * Sf^{0.5} \tag{8}$$

Where n= Manning's roughness coefficient considered 0.025
S_f = bed slope of channel

From above calculation, S_f = 0.0000026.

2.7.4 Performing Unsteady Flow Computations

After the geometry and unsteady flow data have been entered, unsteady flow analysis is performed from 7 December 2016 12.00 P.M to 8 December 2016 12.00 A.M. From the 12 hour model simulation, various water levels measurements at different cross sections were observed.

2.7.5 Calibration of Model:

Calibration is the adjustment of a model's parameters, such as roughness and hydraulic structure coefficients, so that it reproduces observed data to an acceptable accuracy. Calibration of model was done by checking the model water level value at the boundary cross section of Chaktai and Rajakhali channels with the observer tidal stage hydrograph of Karnaphuli river upstream measured by CDA.

2.8. Inundation Map from ARCGIS

The flood inundation map for the selected catchment was prepared using Arcgis 10.4.1 The DEM of the study area was reclassified using the highest water level observed in the channel reaches from WGS 1984 datum. The DEM initially had class value ranges from -3 to 52. That indicates the low and high land topographies respectively. By using a break point at the highest water elevation found for simulation of 2 year return period rainfall and 5 year return period rainfall the raster was reclassified into two segments.

Inundated Area (Raster grids having value below highest flood level) Uninundated Area (Raster grids having value above highest flood level) The reclassified raster was then exported as GIS maps using layout view of ARCMAP.

3. RESULT AND DISCUSSION

The final delineated catchment area and the streams are shown in the Figure 4. 10 intersecting watersheds were found to lie within the region of the study area channels. That indicated that, Storm water or rainwater from this catchment pass through this drainage networks and streams and discharges to the outlet. Table 1 and 2 represents the geometric and hydraulic characteristics of the catchments.

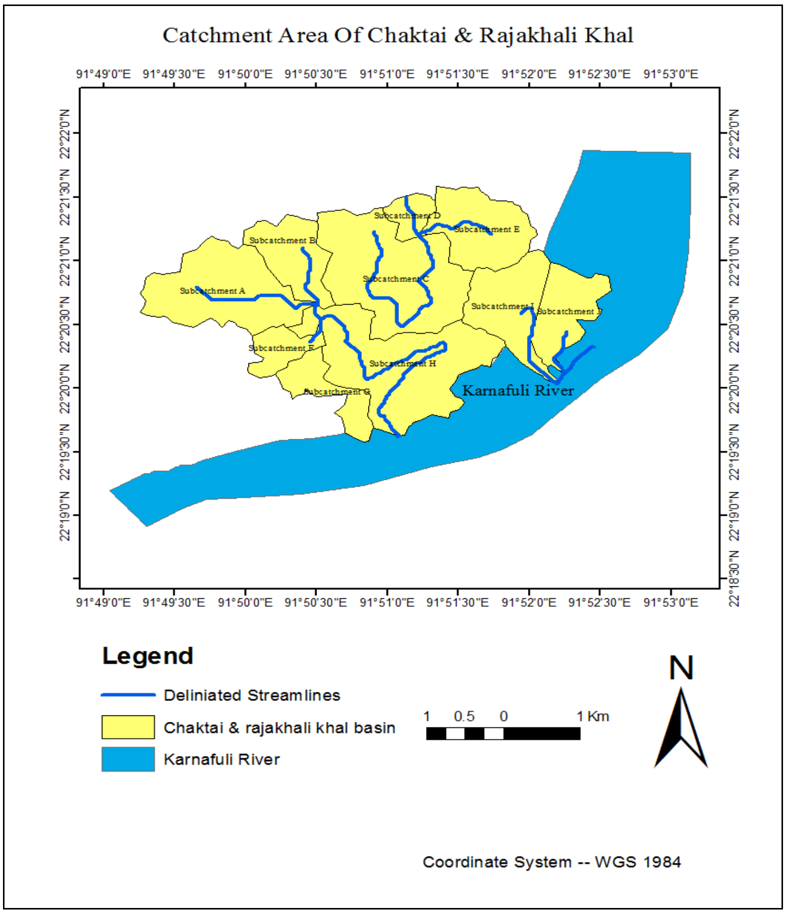


Figure 4: Watershed delineation of Catchment area

Table 1: Area of Delineated watersheds

Sub catchment Name	Area (km^2)
A	0.99
B	1.327
C	2.81
D	0.335
E	1.326
F	0.472
G	0.667
H	2.886
I	1.289

Table 2: Calculation of Lag Time and Time of Concentration

Catchment	Summation Of Length Of Contours (ft)	Area Of basin (ft^2)	Contour interval I (m)	Contour Interval (ft)	Average Land Slope Y (%)	Weighted Curve Number	Initial Abstraction (mm)	Hydraulic Length (L)	Lag Time TL (hr)	Lag time TL (min)	Time Of Concentration (Tc)
Sub basin A	1456744.22	22286880.94	0.30	0.98	6.43	77.25	14.96	1812.34	0.57	34.04	56.73
Sub basin B	543250.47	10661402.56	0.30	0.98	5.01	71.78	19.97	1063.46	0.49	29.42	49.04
Sub basin C	954257.57	30248904.20	0.30	0.98	3.10	75.20	16.75	3768.50	1.56	93.44	155.74
Sub basin D	123631.50	3606246.40	0.30	0.98	3.37	77.18	15.02	668.45	0.35	21.21	35.34
Sub basin E	554502.08	14279803.35	0.30	0.98	3.82	76.97	15.20	1174.44	0.52	31.47	52.45
Sub basin F	261241.86	5082462.14	0.30	0.98	5.06	85.02	8.95	429.93	0.16	9.46	15.77
Sub basin G	228339.23	7172317.60	0.30	0.98	3.13	75.01	16.92	886.99	0.49	29.40	49.00
Sub basin H	893504.98	31065742.41	0.30	0.98	2.83	77.65	14.62	4707.84	1.81	108.82	181.37
Sub basin I	383468.12	13874210.62	0.30	0.98	2.72	50.89	49.02	1573.82	1.56	93.71	156.18
Sub basin J	59318.40	10489005.13	0.30	0.98	0.56	0.00	---	779.44	---	---	----

After inputting the precipitation data observed from the IDF curve of Chittagong city, the rainfall runoff model was simulated for 12 hours. The runoff hydrographs showing the peaks for different catchments obtained from the model are detailed in Figure 5-8.

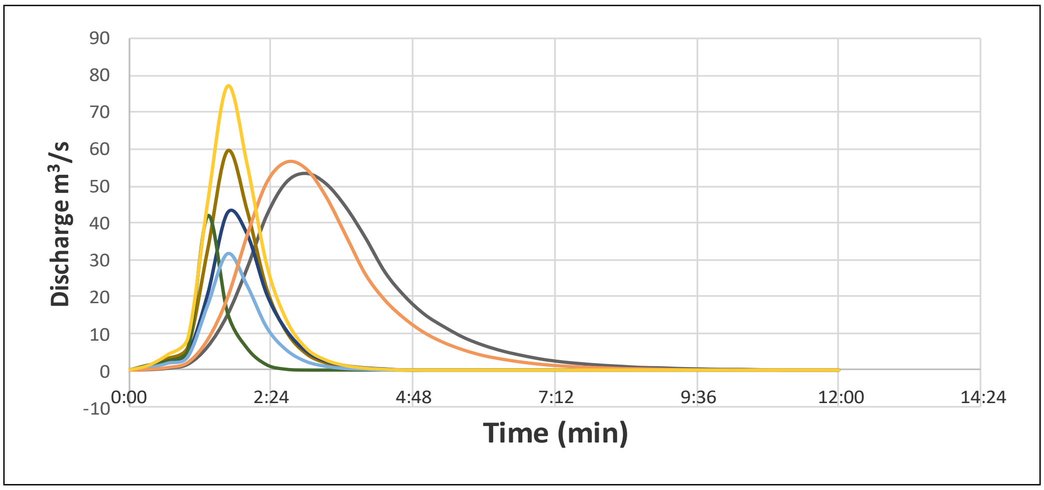


Figure 5: Runoff Hydrographs for 2h 10 year return period rainfall

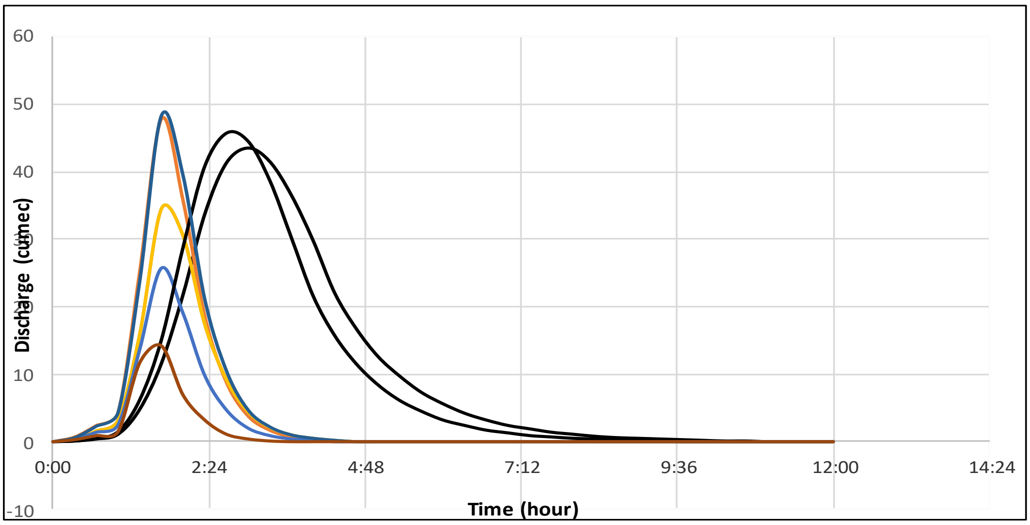


Figure 6: Runoff Hydrographs for 2h 5 year return period rainfall

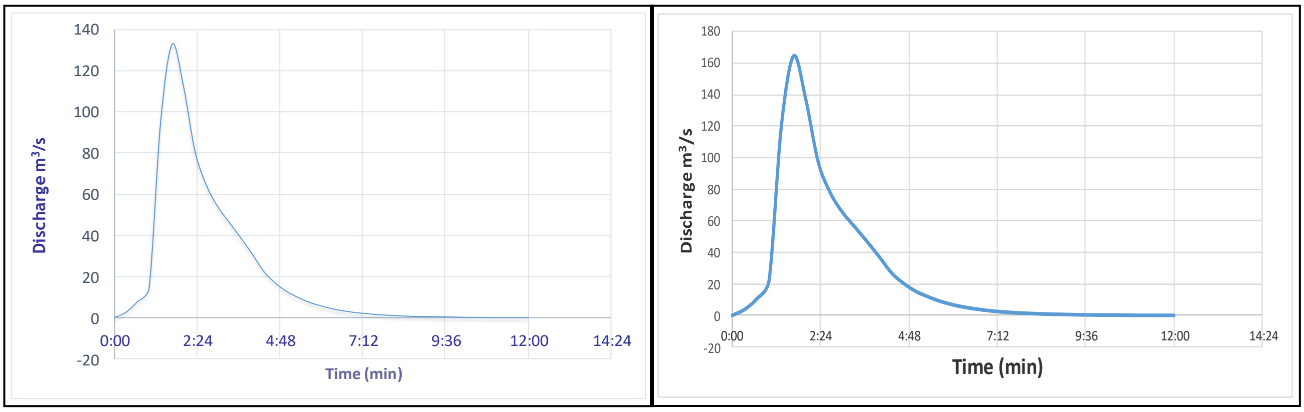


Figure 7: Inflow hydrographs at Chaktai outlet for 2h 5year and 2h 10 year return period rainfall

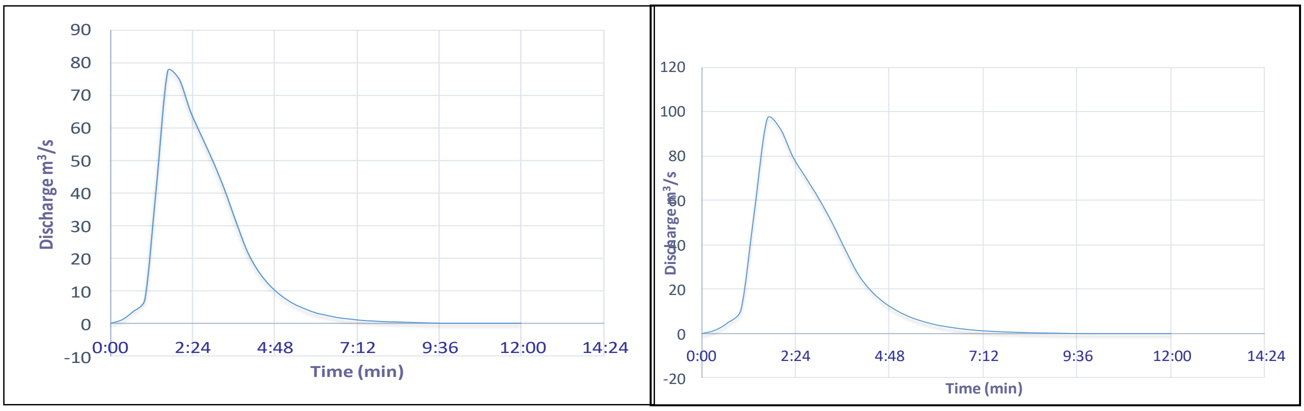


Figure 8: Inflow hydrographs at Rajakhali outlet for 2h 5year and 2h 10 year return period rainfall.

From Hec Ras 1D flow routing for 5 years and 10 years return period of rainfall- the comparison in maximum water level at different sections for both the model runs are given in Table 3. It is observed that the maximum spilling water level at different sections of khals increase 0.3-0.5 m due to tidal surge effect at downstream of khals.

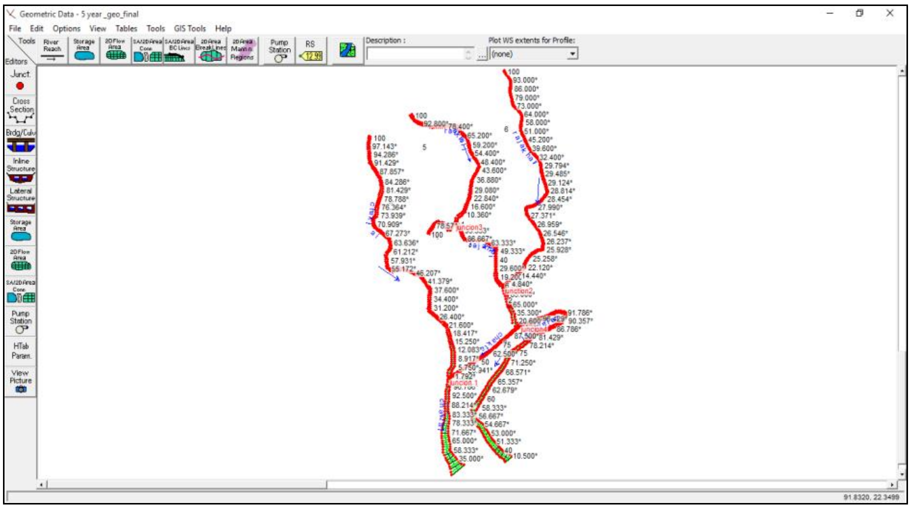


Figure 9: Geometric Data window of Hec Ras 1D (Major Drainage Channels of Chittagong)

Table 3: Maximum Water level observed from model

Channel Name	Reach	5 years return period WL (m)	10 years return period WL (m)
Chaktai	1	4.94	5.39
Chaktai	2	5.04	5.70
Chaktai	3	6.30	6.30
Rajakhali	1	4.94	5.70
Rajakhali	2	5.24	6.11
Rajakhali	3	5.73	6.59
Rajakhali	4	6.17	6.77
Rajakhali	5	6.32	6.94
Rajakhali	6	6.07	6.65

For determining the peak discharge of subcatchments theoretically, the rational formula (Eq 9) for peak discharge is used. The comparison is shown in Table 4.

$$Qp = \frac{CIA}{3.6} = 0.2778CIA \qquad (9)$$

Where, I= rainfall intensity in mm/hr

A= drainage area in km^2

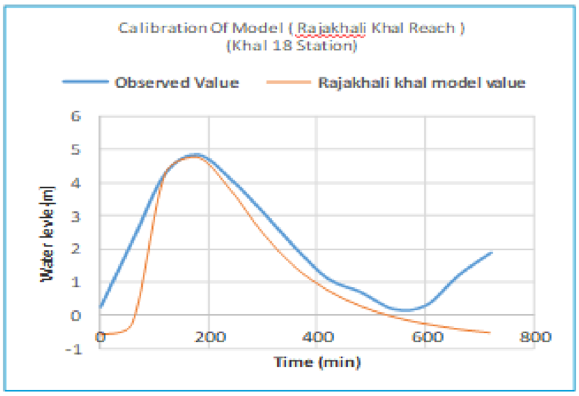
Q_p= Theoretical peak discharge in m^3/s

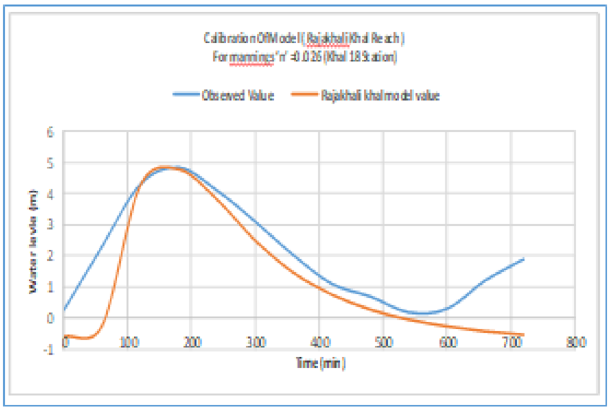
C= Run off Coefficient

Table 4: Comparison of Model Discharge and Rational Discharge (Q= CIA)

	Subcatchment Name	Model peak discharge	Rainfall Intensity mm/hr	Area (km^2)	Theoretical peak discharge
5 year return period	A	34.5	126	0.99081	34.68112427
	B	47.8	126	1.327	46.4487156
	D	14.2	126	0.335	11.725938
	E	48.3	126	1.326	46.4137128
	F	34.8	126	0.472	16.5213216
	G	25.7	126	0.667	23.3468676
10 year return period	A	42.7	146	0.99081	40.18606463
	B	59.5	146	1.327	53.8215276
	D	17.3	146	0.335	13.587198
	E	59.8	146	1.326	53.7809688
	F	41.9	146	0.472	19.1437536
	G	31.6	146	0.667	27.0527196

As the Khal 18 station records the extreme water levels of Karnaphuli river upstream, the model was calibrated –for sadarghat station observed tidal water level for 5 year return period rainfall & Khal 18 data for 10 year return rainfall. The calibration graphs are shown in Figure 10.





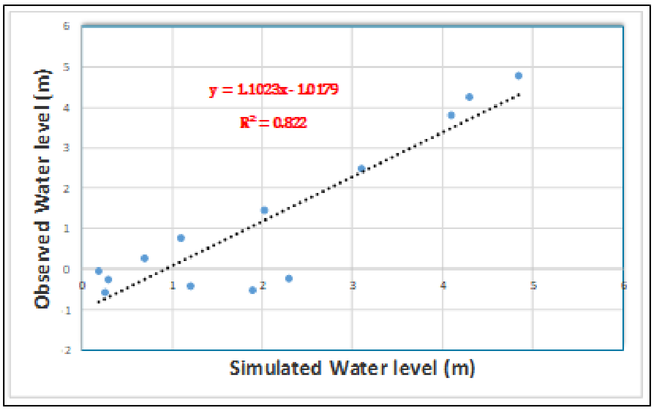


Figure 10: Model Calibration with observed water level of khal 18 station

From the simulated peak water level value, the catchment area was inundated over the Digital elevation model of the area. The low-lying areas in the DEM are flooded due to the spilling and inadequacy of the canal to pass away the drainage water to Karnaphuli. The Inundation maps for different conditions prepared from Arcmap 10.4.1 is illustrated in Figure 11.

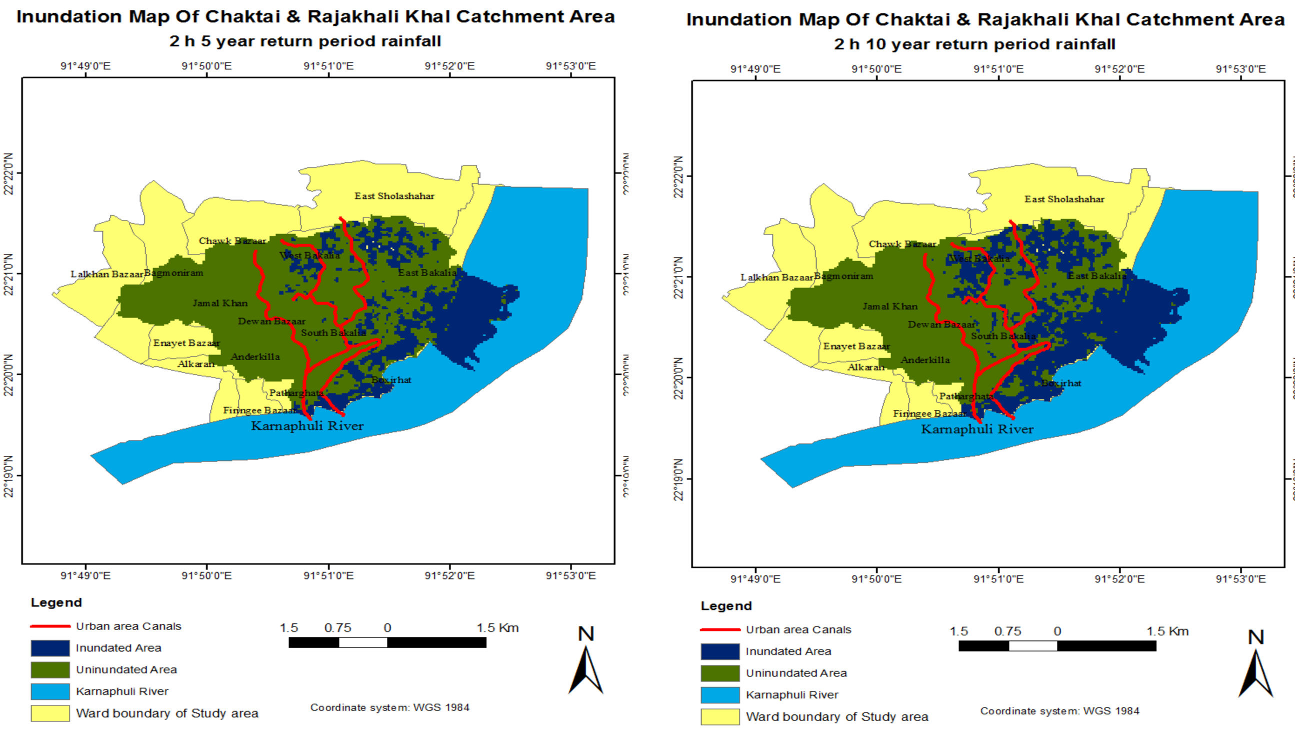


Figure 11: Inundation maps for 2h 5 year and 2h 10 year return period rainfall

4. CONCLUSIONS

The larger sub catchments drain out water from both the channel branches and so the outflow divides into two drainage channels. The dominant channels are Chaktai and Rajakhali khal. This channels and their branches drain storm runoff from 10 sub catchments of area about 14 km^2. Chaktai khal discharges more water to the Karnaphuli river than Rajakhali khal. Hydrodynamic model calibration was done by using Manning's roughness values ranging between 0.025 and 0.033.

The total peak runoff to Chaktai khal for 5 year return period rainfall is found to be 132.7 m^3/s and for Rajakhali khal is 77.5 m^3/s. The total peak runoff to Chaktai khal for 10 year return period is 164.4 m^3/s and for Rajakhali khal is 64.7 m^3/s.
The maximum water level for 5 year return period rainfall in the khals was found to be 6.32 m. The maximum water level for 10 year return period rainfall in the khals was found 6.94m.

The HEC-HMS model output yields slightly higher values of peak discharge, and in undeveloped sub catchments, the rational method produces higher values of peak discharge.

The inundation maps have been generated for peak rainfall runoff and highest high water (spring tide) level near Sadarghat station. It was found that almost 2.15 km^2 of the low lying areas get inundated for 2h 5 years return period rainfall and about 3.5 km^2 area gets inundated for 2h 10 year return period rainfall.

To some extent, it is hoped that the results obtained from the study will be useful for the planners and engineers for the proper design of drainage infrastructure in Chittagong urban area.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the cooperation of Chittagong City Corporation (ChCC), Chittagong Port Authority (CPA) and Chittagong Development Authority (CDA), for providing necessary information and master plans of the city.

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