PERFORMANCE EVALUATION OF DRAINAGE NETWORK USING HEC-HMS UNDER DIFFERENT CLIMATIC AND LAND USE CONDITIONS, A CASE STUDY

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ABSTRACT

Unplanned urbanization along with city's changed landscape causes urban drainage changes and also fall short maintaining its capacity. The situation gets even worse because of today's climate change. Urban drainage design and its performance depends on hydro metrological conditions. Because of climatic change, it is already evident that temperature and rainfall pattern changes with increased magnitude is a harsh reality now. So this is necessary to evaluate the consequences and to design the drainage pattern in accordance to climatic change.

This study therefore aims to evaluate the performance of drainage pattern under different land use and climatic conditions. Mahesh khal is taken as a study area, a major drainage canal connected with Karnaphuli River. This study analyses land use pattern of the study area with the data collected through field investigation and also gathered from the secondary sources using ArcGIS 10.4. Chattogram city holds monthly average rainfall of 243.26 mm and therefore totalling 2919.1 mm in a year which is about to increase 5% - 6% by 2030. Out of total 8.59 square kilometres of total land areas 5.12 square kilometres areas of land occupied as vegetation and open areas which was about 59.64% of the total area in 1988 but unfortunately within the 30 years of time span the areas lost its 28.12% of the vegetation and open. Moreover the peak discharge found for 2, 5, 10, 25, 50 and 100 years return period were 19.8, 29.4, 35.8, 44.1, 50.4 and 56.5 m^3/sec.

The study also evaluate the performances varying Curve Number (CN) value, percent (%) impervious, canal bottom materials etc. It has been found that the actual capacity of the canal is 103.85 m^3/sec of which 87.34 m^3/sec discharge contributed due to tidal effect of average peak tidal height of about 3.75 m. The peak discharge decreases with the increase of Roughness Coefficient (Manning's n) values because the canal with high n values indicates high weeds which will give more resistance than a clear canal. But peak discharge increases with the increase of CN value and percent (%) impervious as amount of direct surface runoff increases with the increase of CN value and percent (%) impervious. Rainwater harvesting, recharge well, retention pond etc. may be effectively implemented in mitigation of problematic issues related with urban drainage.

Keywords: *CN, HEC-HMS 4.2, ArcGIS 10.4, Runoff.*

1. INTRODUCTION

Hydrologic cycle is greatly affected with the growth of urbanization in many ways such as increases percent impervious areas(Lee & Chung, 2007;Schuelet, 2000), surface runoff, decreases vegetation and open space, infiltration of runoff into soils and base flow, withdrawing water (Chung, Park & Lee, 2011),water quality replacing indigenous vegetation with irrigated ornamental vegetation etc. This conversation leads to change in physical, chemical and biological disturbance of the watershed of a drainage system. Urban drainage is considered as an essential tools to human being as it contributes to prevent the floods and provides a better way to discharge the surface runoff . Moreover climate also contributes in increasing precipitation, rising temperature and sea levels resulting multiplying the effects of the events (Walega, 2013). Therefore understanding the relation between land development and climate change on storm water runoff is particularly essential from practical point of view and is socially justified (Paule-mercado, Salim, Lee & Memon, 2018; Walega, 2013). Monitoring, analysis and subsequent implementation of the preventive measures in order to integrated management of the urban drainage runoff (Paule-mercado & Lee, 2017; Tsihrintzis & Rizwan, 1998).

Chittagong city is the second largest city of Bangladesh comprising hills formed during tertiary time. Majority of the people along coastal areas living between 0 to 5 meter elevation from mean sea level. It lies at the coastal area and the most prominent natural hazards are cyclone with storm surge, water logging, landslide, earthquake and flash flood are the dominant ones. But at present water logging and landslides are the most burning issues (Islam & Das, 2014). Due to rapid urbanization along with climate change, Chittagong city dwellers are facing water logging problem in last few years. The average rainfall of Chittagong is 3378 mm which is quite high than other locations in Bangladesh. Mostly rainfall occurs between May to October. In July, the rainfall reaches its peak, with an average of 743 mm (BMD, 2017).Naturally hydrological condition of an area comes first as it directly involve in water logging events (Zhang & Pan, 2014). The land use patterns of an area have influences over the hydrological condition while the increasing urbanization reduces water body and natural streams. Chittagong city saw at least 12 canals vanish in the last 48 years, during which time the waterlogging problem accelerated. A mere 22 canals were found to be emptying into the Karnaphuli River and there was no trace of 12 canals in the premier port city where 8 of the 22 existing canals are also dying (Chowdhury, 2017). In recent years, major canals lost 42% carrying capacity due to siltation, with 87% of the existing silt traps being dysfunctional (Hussain, 2017). Over 14,000 ponds and other water bodies have disappeared is last 18 years in Chittagong. According to a survey conducted by District Fisheries Department in 1991, the number of water bodies in Chittagong city was 19,250 while the Featured Survey conducted by CDA in 2006-2007 indicated existence of 4,523 water bodies there. About 100 sq. km. water of Chittagong city is pumped out through five canals- Chaktai khal, Mahesh khal, Sub area khal, Monohar khal and Hizra khal.

The study has undertaken three objectives to know the changes of the urban drainage under different changed climate and land use pattern.

a. To evaluate the changes of drainage network in different land use and climatic conditions
b. To simulate the existing drainage network by using primary data to replicate real scenario.
c. To evaluate the performances of the existing drainage network in different land use and climatic conditions.

2. METHODOLOGY

2.1 Study Area

Mahesh Khal, one of the major khal in Chattagram city connected with the Karnaphuli River is taken as study area as shown in Figure 1. The catchment lies between latitude ($22°17'49.751"N - 22°20'22.2612"N$) and ($91°46'30.6948"E - 91°48'45.2412"E$) and occupies the area about 8.578 Km^2 (857.8 ha) with 16.37% inclination. The canal is located between Sadarghat and Khal 10 station. The study area is classified in 17 catchment (Sub-Basin) and these area is mainly used for commercial and residential purposes. 31.52% of the area is vegetation and open space, 14.97% is water body and 53.51% is build up area. The length of the canal is about 6.3 Km considered for this study and divided into 6 reaches.

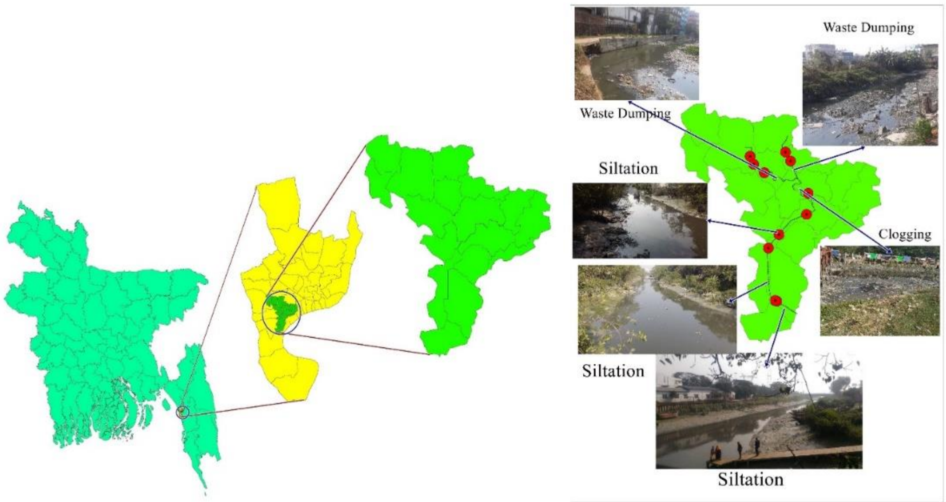

Figure 1: Area showing Mahesh Khal and its physical conditions in different places.

The canal collects the natural flow along with water draining from Sub-Basin area at the upstream and finally discharges into Karnaphuli River at downstream. Total 11 points have been selected for collecting data i.e. cross section, bottom materials, tide table, discharge etc.

2.2 Analogous of Methodology

The methodology as shown in Figure 2 starts with collection of primary and secondary data. Primary data include cross section, side slope, bottom slope, bottom materials, tide level, discharge of the canal also types of land use land cover (LULC), flow path etc. Due to lack of data, the cross sections of the canal were taken manually. Total 11 study points were selected for data collection. The bottom width of the canal was divided into several strips and depth of the bottom of the canal was determined by a rope with a mass attached at the bottom of the rope.

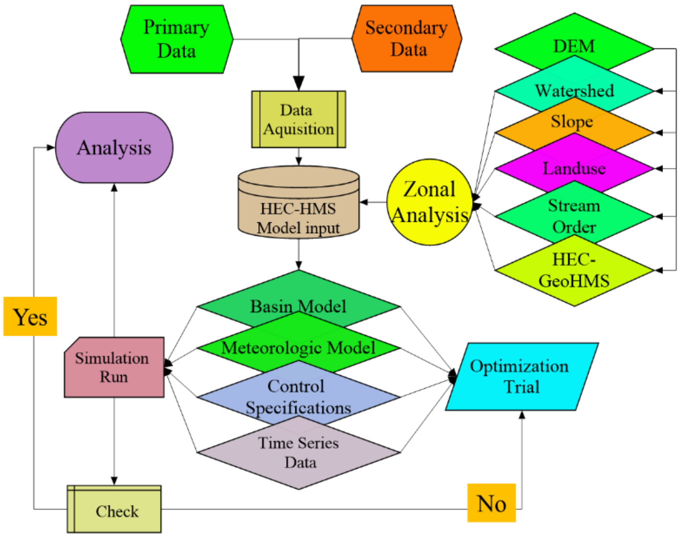

Figure 2: Details Methodology

The length of the canal was determined by ArcGIS 10.4 using field calculator. The average bottom slopes were determined using GPS and adjusted with data found from HEC-GeoRAS. Bottom materials were investigated physically and recorded for the selection of Manning's n. Field land use and land cover data were recorded in different locations for accuracy assessment of the land use map prepared from DEM by ArcGIS 10.4. Field investigation was done for problem identification, flow pattern of the canals, causes of overflow etc. Secondary data are collected from different sources. Digital Elevation Model (DEM), Land use map, soil data map, precipitation, tide tables, discharge etc. are the main secondary data used for the study. Secondary data and their sources are given in Table 1.

Table 1: Necessary Data Sources of the Study

Data	Source	Address	Resolution /Periods /Others
DEM	United States geological Survey (USGS)	https://earthexplorer.usgs.gov/	30m
Land Use Map	GlobeCover	http://due.esrin.esa.int/page_globcover.php	1 : 500000
Soil Data Map	Food and Agricultural Organization (FAO)	http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116	1000m
Precipitation	National Aeronautics and Space Administration (NASA) Bangladesh meteorological department (BMD)	https://earthdata.nasa.gov/ www.bmd.gov.bd	2018
Water tide table	Chittagong Port Authority (CPA) Bangladesh Navy Hydrographic & Oceanographic Centre (BNHOC)	http://www.cpa.gov.bd/site/view/commondoc/Tide%20Table/ http://bnhoc.navy.mil.bd/?pageid=77	2017, 2018
Discharge	Bangladesh Water Development Board (BWDB)	https://www.bwdb.gov.bd/	2018

The USDA Natural Resources Conservation Service (NRCS) method previous known as SCS has been used for the computation of storm water runoff rates, volumes and hydrograph. The NRCS Curve Number (CN) is the key component of NRCS method which depends on soil permeability, surface cover, hydrologic condition etc. The most commonly used are the June, 1986 Technical release 55 – Urban Hydrology for small watershed (TR-55)(USDA, 1986).

3. RESULTS AND DISCUSSION

3.1 Land Use Analysis

Remote sensing and GIS technique is the most important tool for studying the land use and land cover analysis. Large land area can be mapped with low cost and rapidly with high accuracy. Major three land use classification have been identified for the study area and results are presented in the Table 2 and Figure 3.

The classification process was repeated for respective year. The generated classified land cover map was verified using ground truth data and Google earth. The Figure 3 shows the Land use maps of the Mahesh khal watershed area from the year 1988 to 2018 with different interval. Results obtained from the land cover classification of three types of land use analysis have been shown in Table 2. The results clearly shows that built up areas are increasing in an alarming rate whereas open and vegetation areas are decreasing day by day.

Table 2: Land use analysis of the study area

Type of land use	Area-1988 (%)	Area (sq Km)	Area-2008 (%)	Area(sq Km)	Area-2012 (%)	Area(sq Km)	Area-2018 (%)	Area (sq Km)
Vegetation & open area	59.64	5.1219	48.85	4.19	36.71	3.15	31.52	2.7072
Water	15.34	1.3176	14.37	1.2339	14.41	1.24	14.97	1.2852
Built up	25.02	2.1483	36.78	3.159	48.88	4.20	53.51	4.5954

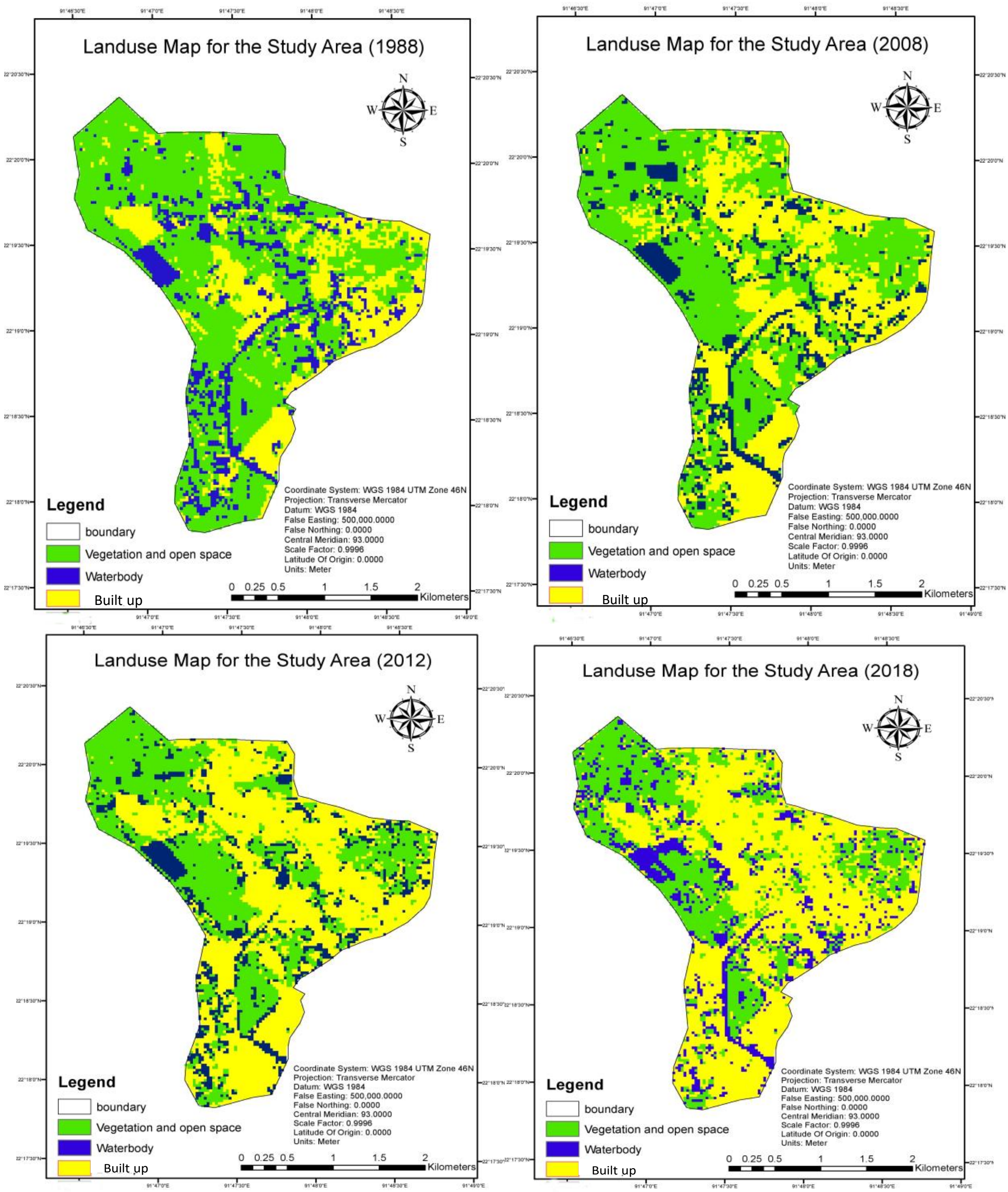

Figure 3: Land use maps of the study area (1988-2018)

From the year 1988 to 2018 the build-up area increased about 28.49%. Initially in the year of 1988 the build-up area was about 2.15 square kilometres which was 25.02% of the total area of 8.59 square kilometres. The trend of change in build-up areas was slower up to 2008 as compared with the changes found later years. The build-up area was about 3.16, 4.20, 4.60 square kilometres for the year of 2008, 2012 and 2018 which is 36.78%, 48.88% and 53.51% of the total area. Out of total 8.59 square kilometres of total land areas 5.12 square kilometres areas of land occupied as vegetation and open areas which posed the highest portion of the total area and was about 59.64% of the total area in 1988. Within the 30 years of time span the areas lost its 28.12% of the vegetation and open areas which can be termed as alarming.

3.2 Data Preparation

The basin and canal parameters were extracted from the attributes table for 17 sub-basins and for canal from ArcGIS 10.4 as prepared earlier and summarized in Table 6.3. Area, slope, percent (%) impervious are directly derived from ArcGIS 10.4. Hydraulic length, initial abstraction, lag time are derived using respective equation's mentioned in methodology chapter. Curve Number (CN) for each sub-basin was used from TR-55 Curve number Tables. The corrected curve number (CN*) found after optimization trials in HEC-HMS.

Table 3: Physical properties of Sub- basins used in model

Basin ID	Basin Area, A (ha)	Slope, H (%)	Hydraulic Length, L (m)	Curve Number, CN	Corrected Curve Number, CN*	Initial abstraction, Ia (mm)	Percent impervious (%)	Lag Time, (min)
S0	30.20	18.85	1523.36	84	79.06	13.45	37	16.38
S1	40.01	22.53	1675.36	80	76.83	15.32	4	17.29
S2	47.46	12.49	1114.83	87	83.56	10.00	63	13.57
S3	48.88	16.59	1134.61	82	78.75	13.71	43	13.92
S4	31.97	13.06	879.52	86	75.85	16.17	73	13.95
S5	32.03	13.74	880.46	87	76.73	15.40	68	13.27
S6	58.89	13.11	1268.81	86	82.59	10.71	56	15.16
S7	35.65	16.99	938.91	82	78.75	13.71	44	11.82
S8	48.87	16.75	1590.26	83	79.71	12.93	38	17.62
S9	19.02	18.11	1044.10	86	82.59	10.71	62	11.04
S10	44.53	16.51	1072.89	85	81.63	11.43	75	12.19
S11	37.32	16.13	965.10	85	81.63	11.43	45	11.33
S12	33.91	21.98	911.22	87	76.73	15.40	37	10.78
S13	40.93	14.30	1019.99	86	82.59	10.71	56	12.19
S14	68.07	13.82	1384.08	83	79.71	12.93	42	17.36
S15	44.13	17.22	1067.12	87	83.56	10.00	78	11.16
S16	74.71	17.78	1463.55	85	81.63	11.43	45	15.06

Reach parameters shown in Table 4 were found through field survey. Length, top width, depth, bottom width, side slope are determined direct measurement in the field. Bottom slopes have been determined using GPS instrument with respect to reduced level and finally validated and adjusted with the data extracted from DEM using 3D analyst in ArcGIS 10.4. Manning's n value used for the canal found from TR-55 Manning's n table and validated in optimization trials in HEC-HMS.

Table 4: Reach parameters used in the model

Reach Name	Length (m)[a]	Top width (m)[b]	Depth (m)[b]	Bottom width (m)[b]	Bottom Slope (m/m)[b]	Side slope (1:z)[b]	Manning's n[c]
R1	557.18	39.01	5.63	6.67	0.0011430	0.35	0.04000
R2	935.75	34.51	4.80	11.57	0.0021100	0.42	0.04500
R3	1196.06	39.22	3.51	10.57	0.0045000	0.24	0.04500
R4	1118.85	33.05	3.71	19.56	0.0051300	0.55	0.07750
R5	1601.93	17.27	3.34	8.06	0.0065400	0.73	0.10000
R6	896.04	10.82	2.87	7.20	0.0063700	1.59	0.07000

[a]DEM
[b]Field Survey
[c]Manning's n chart

Rainfall depths for different return periods have been shown in columns (2), (3), (4), (5), (6) of the Table 5 for the 2, 5, 10, 25, 50 and 100 year respectively. The storm depths are adopted from IDF curve. Others parameter includes total catchment area for the catchment, overland slope, total length of the canal and the time of concentration etc.

Table 5: Parameters used for rainfall depth and watershed in the model

Rainfall depth (mm)[a]						
Present	**2 year**	**5 year**	**10 year**	**25 year**	**50 year**	**100 year**
74.13	91.06	122.62	143.57	169.99	189.58	209.06

Parameters for watershed		
Properties	Value	Unit
Catchment Area, A[b]	8.58	Km^2
Overland Slope, S[b]	16.37	%
Overland Slope, S[b]	163.70	m/Km
Length of the stream, L[b]	6.30	Km
Time of Concentration, Tc[c]	107.24	min

[a]IDF curve
[b]DEM
[c]Rational method

3.3 Validation of the model

Successful implementation of hydrological models mainly depends on how accurately the model is calibrated. Model calibration is done to match the values of runoff volume, peak discharge and time of hydrograph among observed and simulated values. The model calibration can be conducted both automatically and manually. In the present study, automatic calibration known as "Trial Optimization" was used to obtain the optimum parameter values that gives the more similar values among observed and simulated values as manual calibration could be erroneous. The assumed parameters undergoes an iterative adjustments under certain boundary conditions. The calibration was done between simulated and observed discharge. HEC-HMS model basically calibrated using event based simulation.

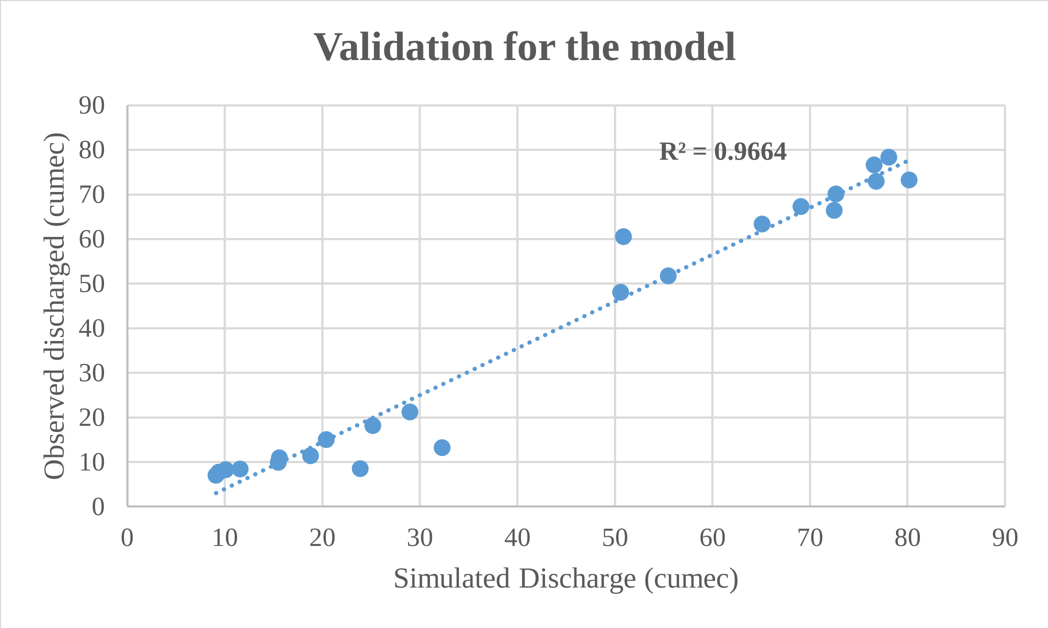

Figure 4: Observed and simulated discharge after calibration

A particular event (24 July, 2018) was selected for calibration of the HEC-HMS model parameters. The hydrograph generated from the model is compared with the observed direct runoff. Two important parameters Curve Number (CN) and manning's n were selected for calibration. Initial and corrected parameter values are show in Table 3. The corrected and calibrated values are considered for the further analysis and performance evaluation of the drainage system. The observed and simulated values were assessed using R^2 indicator and the R^2 value obtained after implementation of all calibrated values for this particular event is 0.9664 which indicates good accuracy of the calibration.

3.4 Performance evaluation based on present situation

For the simplicity, all the performance evaluation was conducted considering metrological effect only. Tidal effect, metrological effect, backwater effect and inflow were not considered. The reasons behind this approach are not availability of sufficient data set, no future master plan for the study area, limitations of the HEC-HMS model, uncertainties etc. The capacity of the canal has been considered subtracting the average peak tide discharge from actual capacity. Hence the capacity for the canal with respect to metrological consider for further performance evaluation. The cross section considered for determination of the actual capacity is the average cross section of the whole canal. The discharge due to tidal effect have considered the average peak discharge available of the canal throughout the year. The result found that the actual capacity of the canal is 103.85 m^3/sec whereas the average peak tidal height along with inflow has been found 3.75m and corresponding discharge due to tidal effect and inflow has been found 87.34 m^3/sec. Hence the capacity with respect to metrological effect is only 16.51 m^3/sec. Such kind of tidal effect cause frequent flooding in these area with limited rainfall.

3.4.1 Performance evaluation for different Curve Number (CN)

Figure 5 illustrates the change of discharge with different CN number varying from 30 to 98 in different return periods. Basically Curve Number (CN) value is a hydrological parameter that used to predict the direct surface runoff. Considering water present in canal for tidal effect, the peak discharge would be within the capacity in present condition and also in 2 years return period for CN values up to 30, 40, 50 respectively but for further increased values of CN, it has found to exceed the carrying capacity limit of the canal. As with the increase of CN values, more direct surfaces runoff occurs and hence the discharge has been found higher for higher values of CN.

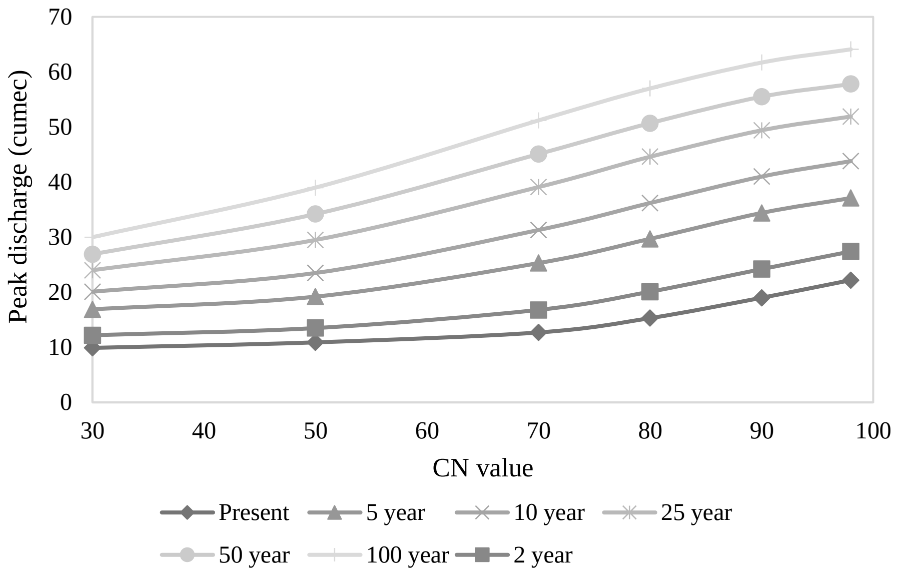

Figure 5: Variation of discharge with CN value in different return periods

The deviation changes at a constant rate in different return periods for a particular CN value. The average values found for 2 and 100 year return periods are 26 m^3/sec and 50.5 m^3/sec respectively with respect to different CN value. The result also shows that the deviation changes more rapidly up to CN value 70 and for further increase of CN value the deviation is almost same. The average discharge value found for CN value 30 and 90 are 20 26 m^3/sec and 43.47 26 m^3/sec respectively.

3.4.2 Performance evaluation for different Percentage impervious

The following graph illustrates the change of discharge with different % impervious land varying from 30% to 98% in different return periods. Percent (%) impervious indicates the area which will contribute 100% surface runoff without any loss (i.e. infiltration, percolation etc.). The discharge increase linearly with the increase of the % impervious as shown in Figure 6. The more impervious areas increases, there will be more surface runoff and hence the discharge would be higher that's why the value increases with the increase of % impervious.

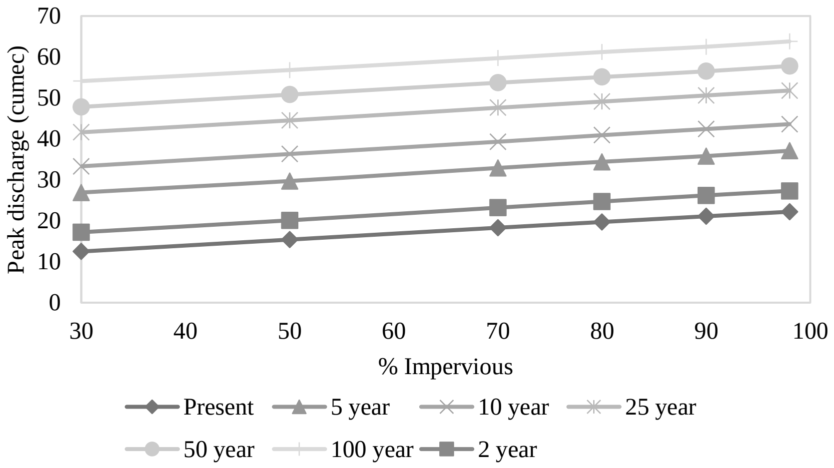

Figure 6: Variation of discharge with % impervious in different return periods

The study also found that average value of discharge for 2 year and 100 year return period have been found 18.2m^3/sec and 59.68m^3/sec respectively. The standard deviation found almost same for all return periods and the value is about 3.78. On the other hand, the average value changes from 33.34 to 43.37 m^3/sec for the % impervious value of 30 and 98. The standard deviation value found almost same for different % impervious value and the value is about 15.48. The carrying capacity of the canal exceeds almost every values of % impervious for any return periods considering back flow from river.

3.4.3 Performance evaluation in different return periods

The change of discharge with time has been found in the figure 7 for different return periods. For a day period, the maximum discharge has been found from 9am to 2pm. In present situation the maximum discharge value is about 15cumec which increase with the increase of return period and become 55cumec in 100years return period.

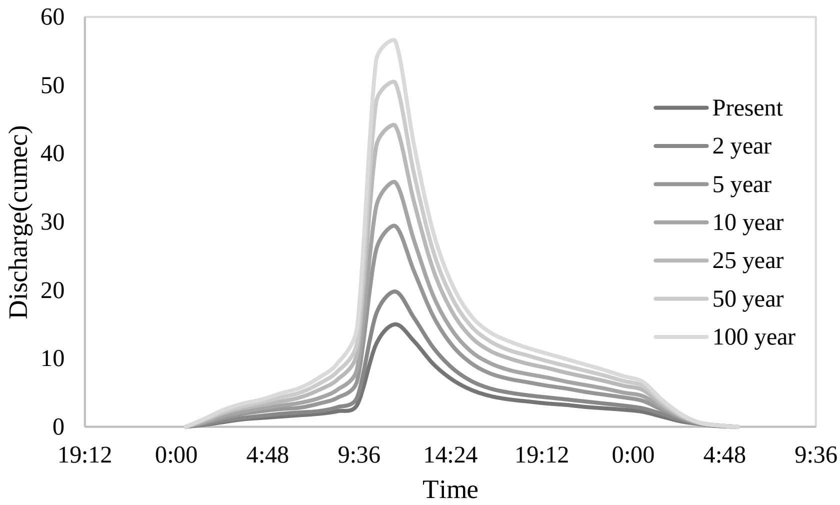

Figure 7: Variation of discharge in return periods.

4. CONCLUSIONS

Rapid growth of urbanization and dense population has great effect on every sector of environment including increased percent impervious areas, surface runoff, decreased vegetation, open space, water quality, and also in physical, chemical and biological disturbance of the watershed of a drainage system. The major findings of this study are given below :

1. The build-up area has increased about 28.49% from the year 1988 to 2018 and lost its 28.12% of the vegetation and open areas. Therefore it can be easily predicted that the build-up areas will increase and reach to above 90% of the total area within short time span if no measures are taken and checked back to ensure sustainable urban planning.
2. Maximum discharge has been found from 9am to 2pm. In present situation the maximum discharge value is about 15cumec which increase with the increase of return period and become 55cumec in 100years return period.
3. The peak discharge found within the capacity in present condition and also in 2 years return period for CN values up to 30, 40, 50 respectively but for further increased values of CN, it has found to exceed the carrying capacity limit of the canal considering water present in canal for tidal effect.
4. The discharge increases linearly with the increase of the % impervious and the carrying capacity of the canal exceeds almost every values of % impervious for any return periods considering back flow from river.
5. Thus, few more improvement required of the next phase of this study incorporating quality of the discharged water and susceptibility of sustainable urban drainage system in Chattogram drainage basin.

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