DRAINAGE VULNERABILITY ANALYSIS FOR A COMBINED SEWERAGE SYSTEM USING SWMM

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ABSTRACT
Proper assessment of heavy rainfall impact on urban water logging has becoming important in growing urban areas in Bangladesh. Chittagong, the second largest city often experiences inundation due to excess runoff results from heavy rainfall and thus affected the adjacent lands of combined sewerage system. Apart from storm induced excess runoff, inadequacy of drainage system and backwater effect pose severe inundation throughout the city. Unfortunately except few scattered study, there is no such database which identify the vulnerable locations both in land surface and in drainage system. The aim of this study is to identify the vulnerable nodes in a selected drainage network and thus to assess capability of existing drainage system. The USEPA Storm Water Management Model (SWMMv5) is a dynamic rainfall-runoff simulation model engaged to simulate this feature. To incorporate relevant information in SWMM environment, Arc-GIS v9.3 was used to provide topographical and land use details. As the SWMM allows for continuous simulations using historical rainfall series, this was applied in the long-term rainfall event to convert the runoff to overland flow. Finally, the model outcomes were able to delineate the inundated node of conduit network, the duration of flood and surcharges and identified the vulnerable location .Thus, it is expected that SWMM model can provide valuable decision to locate drainage vulnerable location for proper drainage management.

Keywords: Heavy rainfall; drainage; SWMM; vulnerable; water logging

INTRODUCTION

The combined sewerage systems in the unplanned urban areas usually get inundated while carrying excess runoff and wastewater. Without proper identification of the vulnerable drain/channel it is difficult to maintain such sewerage system. Moreover this drainage system always faces problem due to solid waste accumulation, forming gullies from adjacent land, excess runoff generated from changing land use pattern of urban areas as well as tidal effect from the adjacent stream(Shoukat et al, 2014). Thus projects for maintenance of the drainage system often prioritized the field survey, subjective judgements and experience; that always results misleading and temporary solution (Rashid et al, 2011). For proper management of drainage system it is always preferable to aviod the preliminary field study cost envolvements, conducting a reasonable numerical modelling study to locate the vulnerable location in the sewerage system. For several decades a number of models developed those can simulate these issues in the drainage system. Rashid et al. (2011) suggested a dynamic programming prioritize sewerage projects under limited funding conditions on the basis of potential environmental, public health, and other benefits relative to the project costs. Wu (2008) worked with stochastic integer programming for liquid waste treatment process design.With the advancement of modeling-based evaluation of satellite precipitation data. Li et al. (2004) has used remote sensing technologies to develop a distributed multi scale model including annual water balance simulation, streamflow modeling, and near real-time flood monitoring. In addition to these a number of urban hydrological models engaged to assess the impact of urbanization on its runoff carrying system. Also, O'Loughlin et al. (1996) attempted to simulate the complete water system at the catchment scale. Hsu et al. (2000) suggested SWMM model for detailed physically based description of conduit for stormwater discharges as this model specially developed for urban hydolgy. Beside the SWMM model, others generally accepted software for stormwater drainage (and sewers) flow simulations viz. MUSIC (Dotto et al., 2011), InfoWORKS CS (Hurford et al., 2010), MOUSE (Thorndahl and Willems, 2008), and CANOE (Lhomme et al., 2004). In this paper, SWMM model has been used coupling with GIS to identify drain that are overflow during peak discharge of a selected rainfall time series i.e.June 2014 as this duration contained highest rainfall amount in the last 15 years. From the observation of runoff carried volume by drainage network, this can be decided the nodes and links are inundated.

METHODOLOGY

The Study Area

The study area (Figure 1) is located in the north-western part of Chittagong city comprise of a drainage area of 23.14 km^2. Based on the previous study by Shoukat et al. (2014) and also from the preliminary questionnaire survey, this area was selected covering several water logging prone wards i.e., Chadgaon, Panchlaish, West Halishohar and some parts of Bakalia. Based on subcatchment delineation that obtained from HEC-GeoHMS (Spatial tool of Arc-GIS) the boundary of Chittagong City Corporation area was divided into 77 subcatchments and for this study 11 subcatchments were intensively studied. Details on the physical properties of those subcatchments are tabulated on Table 1. It has 4 primary drains which collects runoff from secondary and tertiary drain finally 4 outfalls discharge the runoff to adjacent Karnafuli River (Table 1). The soil formation mainly sandy types however there are silty and clayey soil are also available.

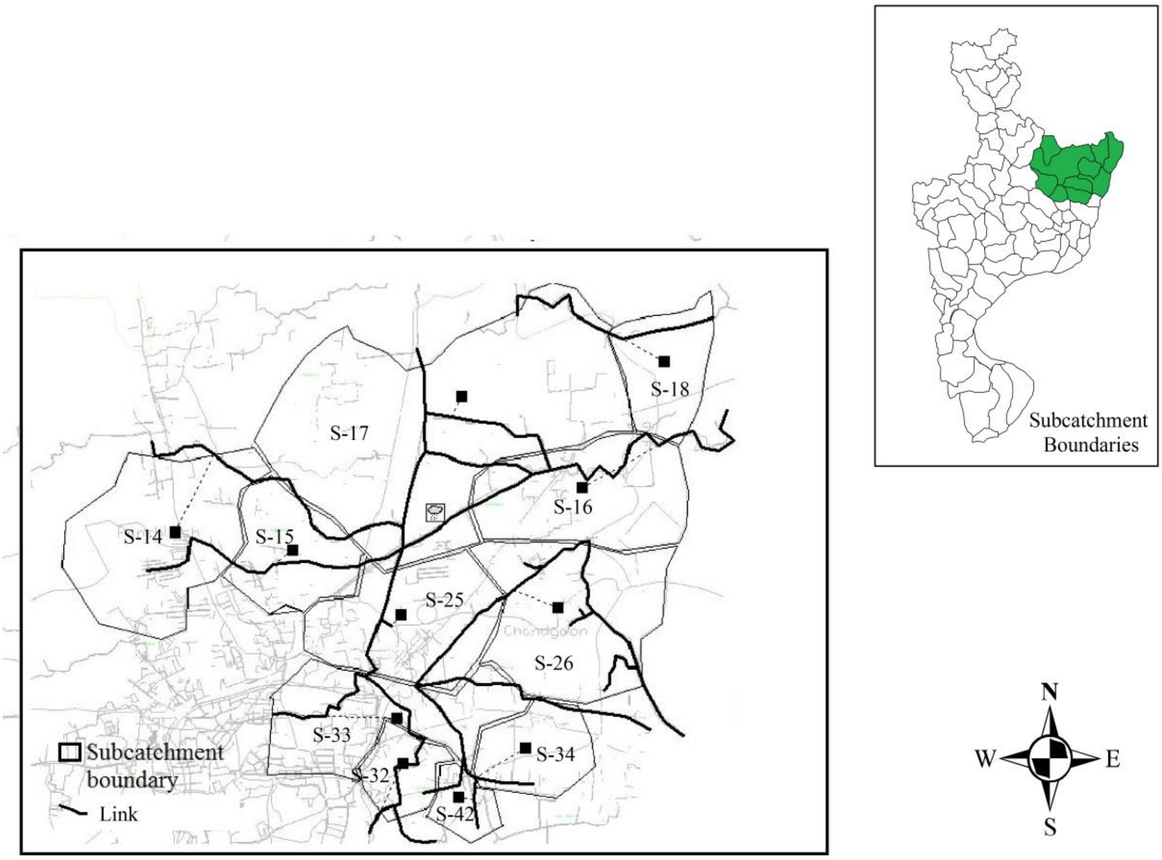

Fig. 1 Study Area

Table 1: Subcatchments Properties

Sub catchment ID	Area(hectare)	Width(m)	% imperviousness	% slope	SCS Curve Number
S-14	285.17	2485	6.84	3.17	46
S-17	667.67	3766	36.67	4.04	77
S-18	114.61	933	28.16	4.41	77
S-15	113.93	1253	16.98	2.98	65
S-16	224.24	1248	54	4.45	65
S-25	210.17	1340	39.64	3.17	66
S-26	273.95	1742	37.32	4.78	77
S-33	207.07	2637	27.44	2.44	65
S-32	62.9	1026	69.78	4.78	65
S-42	41.27	605	57.13	2.92	82
S-34	99.75	950	26.25	3.26	65

Data Collection and Preparation

The topography information was collected from SRTM 30m (http://gdex.cr.usgs.gov/gdex/) DEM data. In addition to these drainage and topography is created from CDA (2006) vector data. As most of channels are not maintained, weeds and brush uncut Manning's roughness coefficient n value ranges from 0.04 to 0.06 (Chow, 1958). Precipitation time series of year 2014 was obtained from Bangladesh Meteorological Department (BMD). Evapotranspiration was calculated using Penman-Monteith Method and Infiltration data was obtained using SCS Curve Number method.

Model Setup

Initially raw SRTM 30m data was used for terrain processing with HEC-GeoHMS terrain pre-processing tool which was used for subcatchment delineation following several steps viz. flow direction grid initialization, flow accumulation grid processing and stream link grid generation. With input stream link and flow direction catchment grid was obtained that converts to catchment vector. The catchment polygon was used further with channel topography to prepare a runoff model environment using Arc-GIS. HEC-GeoRAS channel topography was used for extraction of stream centreline, bank

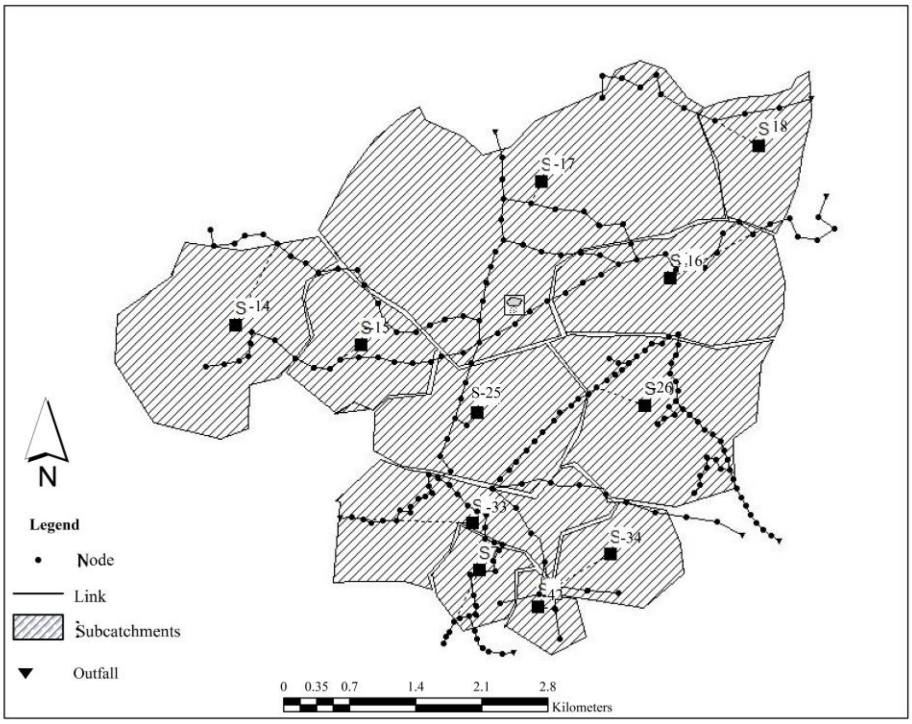

Fig. 2: Model set up

lines and channel cross section. Finally, model geometry was exported to SWMM as metadata which further regenerate in SWMM model environment. The % slope of subcatchments was obtained using spatial analysis of Arc-GIS. Cross sections containing elevation data were positioned and assigned as transects and nodes were placed on each cross sections. SWMM model simulated the runoff response of the catchment area to the given amount and distribution of precipitation over a defined period of time i.e. from 1st May, 2014 to 30th September 2014. The dynamic wave routing method with a time steps of 30s is used for flow routing. A small time step of less than 1 minute is recommended for this method (Rossman 2008). Potenga rain gauge station was used for derivation of rainfall and evaporation time series.

MODEL OUTCOMES

The simulation conducted from 1st May up to 30th September 2014. Considering heavy rainfall amount water logging for 5 days from 19th June to 24th June was simulated in SWMM. Table 2 shows variation of different hydrologic parameter during Month June 2014. Figure 3 shows due to flow direction in runoff discharge was accumulating more in the red zone marked as red (Fig. 3), indicating most vulnerable zone of water logging if links have not enough capacity to drain out the runoff within the capacity of drainage. From simulation results the peak discharge of subcatchment runoff hydrograph observed at 22nd June 2014. The runoff volume exceeding the link capacity (Figure 4 link capacity more than 1 or full) can be marked as inundated. Those drains are identified as most vulnerable majority of those located in Bahadderhat, Muradpur, Sholashahar and Bakalia.

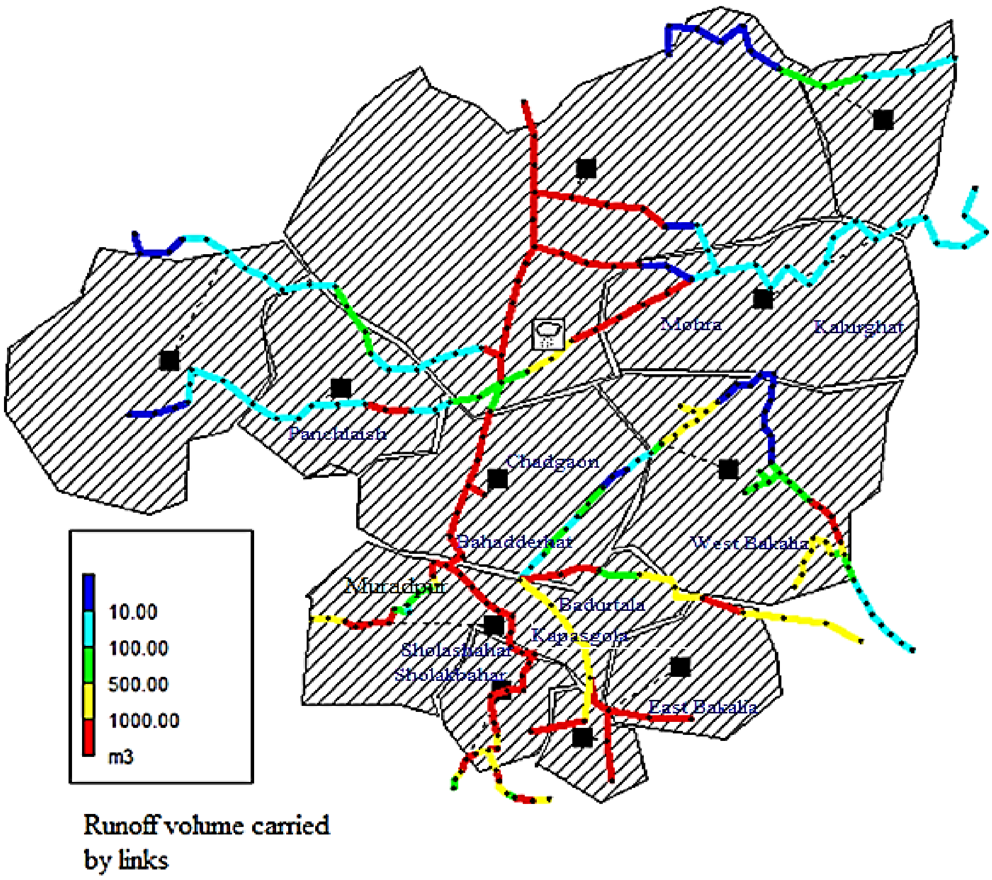

Fig. 3: Runoff volume carried by link network during month June 2014

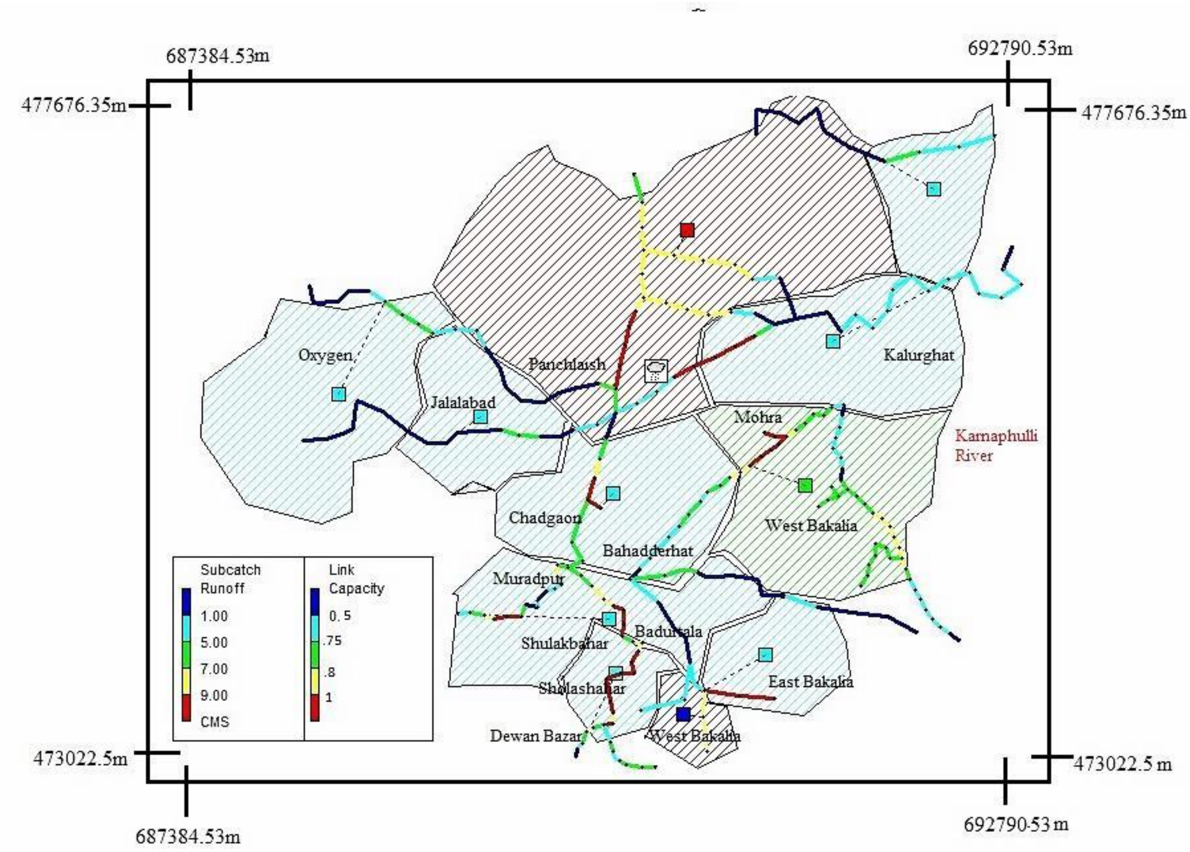

Fig. 4: Vulnerable drain and their location analyzed for water logging 22nd June,2014 (Coordinate system UTM)

Table 2: Sub catchments runoff

Subcatchment ID	Total precipitation (mm)	Total Evaporation (mm)	Infiltration (mm)	Total Runoff (mm)	Total Runoff Volume (Million liter)
S-14	1469.12	101.04	330.91	1035.88	2959.93
S-17	1469.12	104.69	80.09	1284.61	8577.00
S-18	1469.12	102.14	93.31	1275.01	1461.30
S-15	1469.12	102.07	167.96	1198.62	1605.32
S-16	1469.12	102.62	92.94	1274.83	2858.69
S-25	1469.12	103.52	122.12	1243.83	2614.18
S-26	1469.12	103.42	81.41	1285.74	3522.30
S-33	1469.12	99.70	150.04	1221.03	2528.41
S-32	1469.12	93.43	62.43	1315.13	827.22
S-42	1469.12	98.28	43.23	1329.51	548.69
S-34	1469.12	101.01	149.00	1219.24	1216.20

CONCLUSIONS

The continuity error (%) found from model analysis was -0.252%. It is recommended that less than 1% continuity error with a time steps less than one minute has a good acceptance in a terrain. The model consistently indicates that there is little to no direct runoff from pervious areas in the watershed. This was as expected due to the rapid infiltration rates encountered throughout the watershed. These findings demonstrate the importance of the correct handling of storm water runoff from developed areas. New impervious or paved areas cause almost complete runoff of precipitation if uncontrolled and conveyed directly to adjacent streams or water bodies. This results more increased amount may indicate urbanization impact on water logging problem. Special land use features of urban areas in SWMM thus can promote most reliable prediction of flood.

RECOMMENDATIONS

This Paper has outlined a model to predict runoff and base flow for the watershed. In order to fully assess the condition of the watershed regular monitoring should be needed to assess all those parameters like flow at different nodes, depth continuous rainfall recording. Further recommendation enlisted below:

- Required numbers of gages should be placed at necessary places to conduct elaborate study on water logging.
- If USGS High resolution customary 3m DEM is available, this model would provide more accurate outcomes.
- Due to tidal effect at downstream the backwater effect is remarkable, this can be simulated using tidal curves.
- The vulnerable drainage network shown in Figure 4 can be regarded for improvement of drainage facility in Chittagong city areas.

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