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Inconsistent using FLOOD and Flooding Development of EPA SWMM for Assessing Flood Occurrences in Vulnerable Urban Watershed Considering Extreme Rainfall Events

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ABSTRACT Urban flood, commonly known as urban water congestion, is a type of water hazard that poses significant challenges for urban residents and water management experts. Chittagong, an essential economic hub in Bangladesh, renowned for its role as a port city, comprises a diverse range of land use, including residential, industrial, and commercial sectors. The Chaktai canal, an important element of Chittagong drainage system, is connected to the Karnaphuli river, playing a vital role in managing drainage by handling a substantial portion of the city water. Therefore, this research evaluated the operational efficiency of a specific drainage network under the influence of altered rainfall events using the Storm Water Management Model (SWMM). Using ArcGIS 10.4, the land use pattern of the area was researched, incorporating data from field surveys and secondary sources. SWMM 5.1 integrated watershed data, and further simulation was carried out to estimate runoff in various sub-catchments and drainage network limitations during heavy rain. During the intense monsoon period, the tool determined the average runoff depth, considering backwater effects and robust tidal surges, resulting in a depth of 3.3m compared to 2.6m in the dry season. This research evaluated the influence of impervious land use changes on urban drainage systems. While meteorological factors alone render drainage network sufficient in dry periods, the outfall shows vulnerability during the rainy season, with an allowance of only 0.7m, jeopardizing the catchment through flood. It contributed a schematic sub-catchment representation, emphasizing that flood events depend on volume runoff and peak flow in urban drainage system. SWMM model was used to illustrate the catchment surface runoff and interconnected node depths via conduits, as well as the current catchment scenario comprehensively.

KEYWORDS Urban Drainage; Extreme Rainfall; Flood; SWMM; Chittagong City

1 INTRODUCTION

Flood is one of the natural disasters that has been significantly experienced by numerous communities globally. Examples include Bangladesh, one of the most flood-prone areas, with increased vulnerability due to the risks associated with climate change (Ahmed, 2017). Therefore, the impact of heavy rainfall patterns is important in this area to determine the frequency of flood occurrences. According to preliminary studies, urban areas face worse challenges, particularly with high impermeability, thereby complicating the functionality of existing stormwater drainage infrastructure (Xiong et al., 2019). Climate change further intensifies this hazard, which triggers alterations in hydrological patterns (Patowary et al., 2018). Chittagong is one of the major cities in Bangladesh that is facing several complex issues due to flood (Islam and Das, 2014). According to recently acquired data, major canals in this city lost 42% and 87% of their carrying capacity due to siltation and dysfunctionality of existing silt traps (Chowdhury, 2017). This research explored the subject of flood in Chittagong City, with focus on how extreme rainfall affects urban drainage. It also investigated methods adopted to analyze and handle these hydrologic disasters using the Environmental Protection Agency Storm Water Management Model (EPA SWMM).

Most cities are becoming increasingly vulnerable to flood due to the combined effects of rapid urbanization, complicated infrastructure development, and changes in precipitation patterns attributed to human-induced climate change (Willems et al., 2012*b*). Chittagong, the second-largest city and commercial capital of Bangladesh,

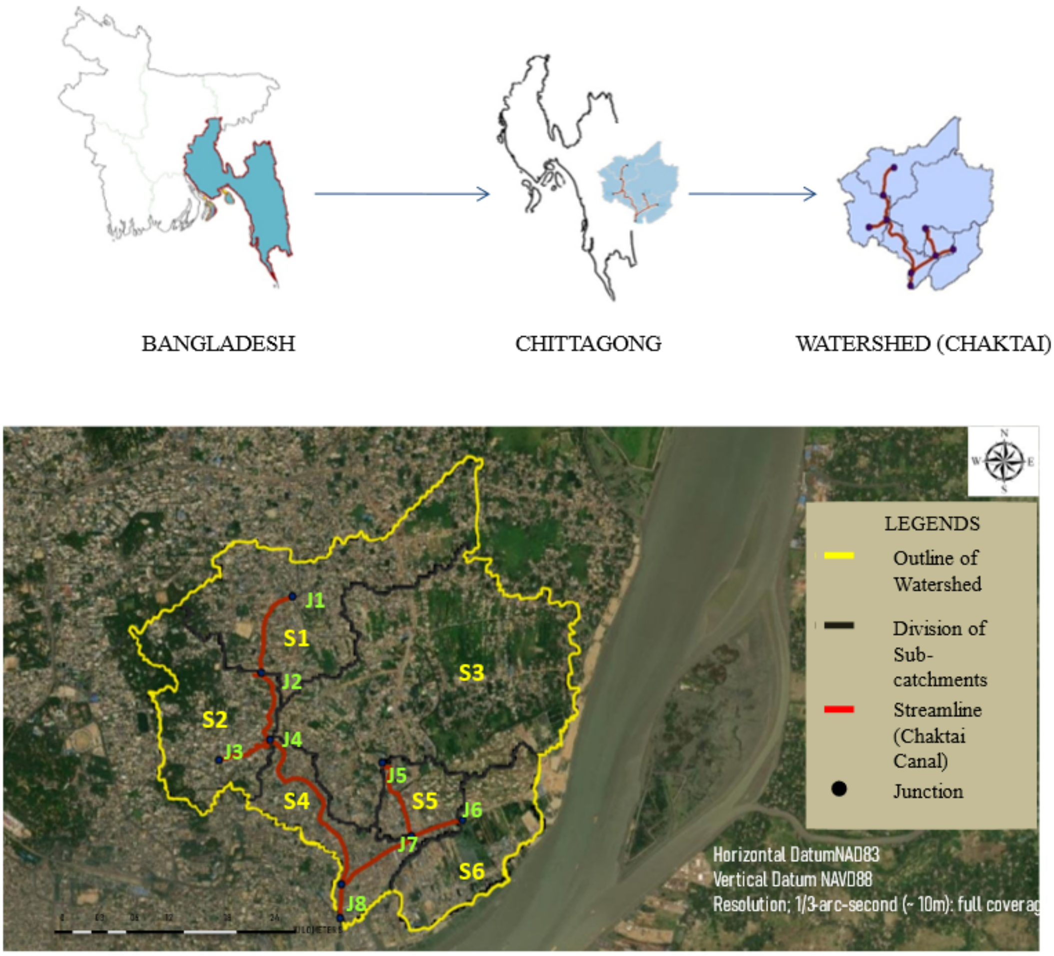
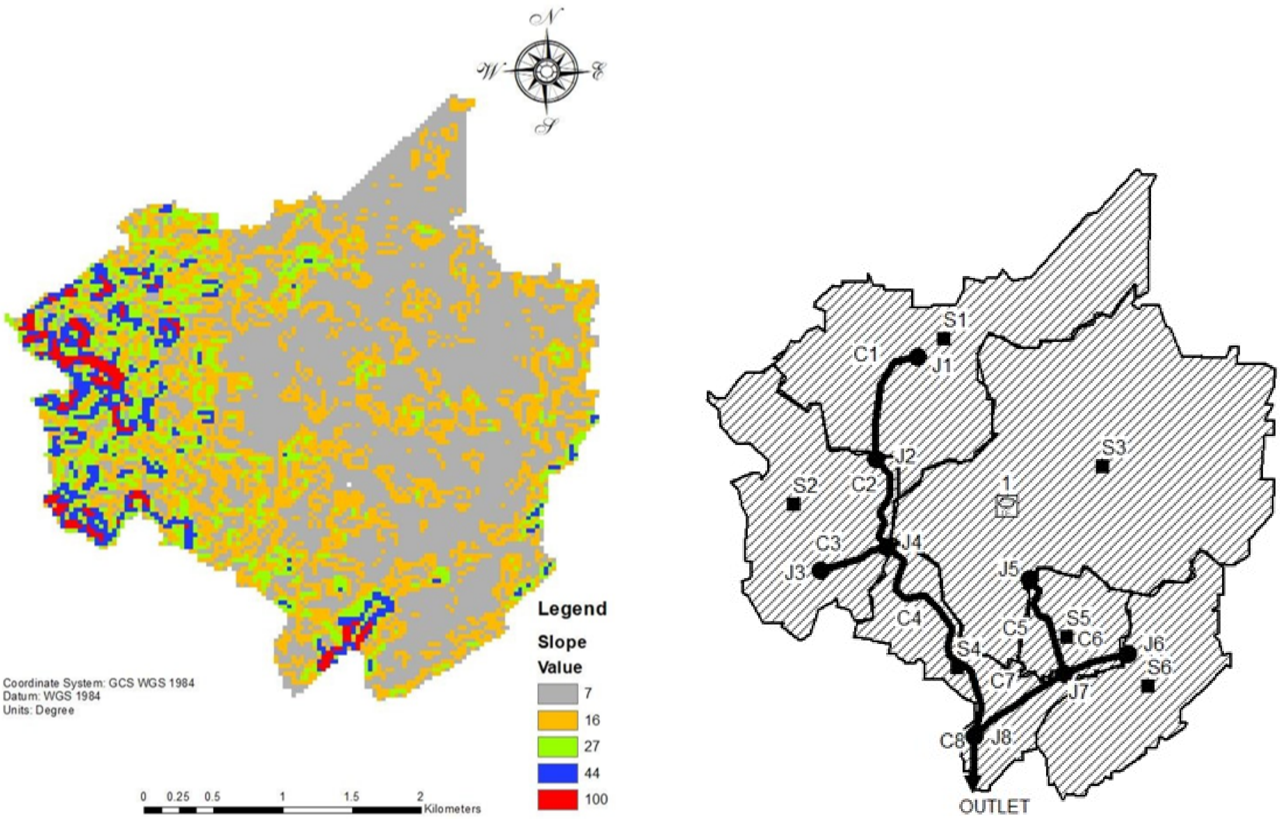


Figure 1 Schematic Illustration and Satellite image of the catchment area

stands out in this regard due to its vulnerable location along the south-east coast and close proximity to the Bay of Bengal (Mia et al., 2015). The city faces frequent flood, particularly during the monsoon season, characterized by excessive water logging (Kleidorfer et al., 2014). The heavy monsoons in the region engulf existing drainage systems, which lead to flood in urban areas. Based on historical data, Chittagong experiences an annual precipitation ranging from 2100 to 3800 mm, with monsoon season precipitation averaging approximately 2400 mm (BMD, 2017). During the monsoon, precipitation reached 1750 mm, constituting 72% of the yearly average (Terwisscha van Scheltinga, 2015). The minimum and maximum temperatures in Chittagong ranges from 9.5 degrees Celsius, to 39.5 degrees Celsius respectively, with the highest recorded 24-hour rainfall reaching 438 millimeters (Tashmin et al., 2018). The intense monsoons and tidal effects produce an average runoff depth of 3.3 m, usually reduced to 2.6 m without tides. This persistent flood posed significant challenges to infrastructure, socio-economic stability, and public health. The consequences include frequent evictions, property damages and disruptions to critical services. The main causes of these urban flood include heavy rainfall, inadequate drainage systems, daily tides in the river Karnaphuli, unplanned urban expansion, encroachment and congestion of channels and structural development on nearby water retention bodies (Mahmood and Matin, 2018).

The Fourth Assessment Report (AR4), published by the Intergovernmental Panel on Climate Change (IPCC, 2007), stated that there was a global rise in the frequency of excessive rainstorm events since the late 20th century due to global warming (Willems et al., 2012*a*). Effective urban drainage is essential for controlling water overflow during these intense rainfall occurrences (Arnbjerg-Nielsen et al., 2013). Recent urban flood has been significantly influenced by the increasing severity and unpredictability of rainfall



(a) (b)

Figure 2 Map of the geographic pattern of the research area with DEM generated in ArcGis (a) and drainage network map of Chaktai canal in SWMM (b) (Alam, 2022)

patterns (Zhang et al., 2021). While sewage systems designed to handle standard conditions have generally reduced city vulnerability, surpassing design criteria can increase sensitivity to excessive rainfall events, thereby leading to critical challenges (Willems et al., 2012*b*). The main objective of urban drainage management system is to safely channel municipal runoff resulting from extreme rainfall to a commendable discharge point (Wernstedt and Carlet, 2014). Extreme rainfall events heighten the risk of flash flood occurrences (Lu and Qin, 2020). Recognizing the importance of understanding extreme rainfall events and hydrological phenomena in cities has driven advancements in this field (Willems et al., 2012). The challenge intensifies when dealing with intense runoff episodes, given their distinct characteristics compared to ordinary precipitation (Willems et al., 2012*b*). However, the unplanned development in Chittagong and rapid urbanization have negatively affected the entire drainage network. The proliferation of impervious surfaces such as concrete roads and buildings has reduced the quantity of rainwater that naturally seeps through the ground, causing increased surface runoff and placing a strain on the stormwater management system as it becomes inundated with excessive water intake. Traditional drainage systems ill-equipped to handle substantial water volumes during heavy rainfall, frequently result in flood, particularly in low-lying areas, thereby increasing its risks (Kleidorfer et al., 2014).

The application of modern hydrological and hydraulic tools has become crucial to address flood-related issues and create effective management measures. However, due to significant changes in urban surface, conventional models have been proven inadequate in replicating the complex urban hydrological cycle. SWMM, urban hydrological-hydraulic model, is frequently used for planning drainage infrastructure, simulating rainfall-runoff in cities, and research the effects of climate change on urban regions (Yan, 2014; Kim et al., 2016; Luan et al., 2017; Abbasizadeh et al., 2018; Xiong et al., 2019). In this context, the EPA SWMM is a state-of-the-art tool for modelling urban drainage systems and assessing the potential for flood in complex metropolitan watershed (Wang and Altunkaynak, 2012). The

Table 1. Parameters of respective reach

Reach	Manning's n[d]	Length (m)[a]	Initial Depth (m)[c]	Max Depth (m)[b]
R-1	0.05	863.85	0.15	0.84
R-2	0.07	729.79	1.03	2.61
R-3	0.06	609.10	0.4	1.89
R-4	0.05	1799.89	1.11	2.96
R-5	0.04	820.46	0.41	2.31
R-6	0.05	480.16	0.72	2.65
R-7	0.017	791.09	0.25	1.65
R-8	0.06	309.78	1.31	3.89

[a]Digital Elevation Model (DEM)
[b,c]Data from Field Survey
[d]Manning's n Chart

Table 2. Properties related to sub-catchments

Sub-Catchments	Area, A (a)	Area, A (sq m)[a]	Width (m)[e]	Curve Number, CN[c]	Slope, H (%)[b]	(%) Impervious[d]	Downstream of Sub-catchment to Canal Reach
S-1	230	2295603	2768.6	88.98	19.89	46.85	R-2
S-2	150	1489285	2398.6	89.68	12.1	38.13	R-4
S-3	406	4026305	4102.2	91.93	35.5	40.46	R-5
S-4	91	896737	1709.6	89.86	6.6	51.31	R-8
S-5	49	506785	10982	88.98	4.3	49.86	R-7
S-6	109	1021726	1789.1	91.08	9.5	27.5	R-6

[a,b]Digital Elevation Model (DEM)-(From ASTER radar data in USGS website)
[c]CN Grid
[d]Derived from ArcGIS 10.4.
[e]Hydraulic length of watershed = $110A^{06}$ (Schwab et al., 1982)

Table 3. Co-relation co-efficient chart for Various Return Periods

Return Period (Year)	Correlation Coefficient, R	Equation
5	.985	Y = 1551X −0.667
10	.987	Y= 1816X −0.667
25	.987	Y= 2150.1X −0.667
50	.987	Y= 2644.3X −0.667

EPA SWMM enables preliminary research and engineers to understand flood patterns, identify susceptible regions, and provide solutions to enhance the resilience of urban drainage systems (Alam, 2022). This can be realized through a comprehensive analysis of the relationship between precipitation, runoff, and drainage systems.

The aim of this research is to develop and apply the EPA SWMM within urban watershed of Chittagong City, Bangladesh. The core focus is on understanding how the city drainage system responds to heavy downpours with the intention to advance the knowledge of urban planners, decision-makers, and disaster management authorities concerning local flood dynamics, while providing these individuals with crucial data. Furthermore, this information is instrumental for devising more informed flood mitigation plans and strengthening the overall resilience of the city to hydrologic disasters. The present research specifically investigated the effects of extreme rainfall events on urban drainage as well as the difficulties caused by flood in Chittagong City, using the EPA SWMM model. The main objective is to examine the complexities of the hydrologic behaviour of the city and provide data-driven solutions to reduce the disastrous effects of flood in this thriving Bangladeshi metropolitan centre.

2 METHODS

2.1 Description of Research Area

The structured workflow used to simulate rainfall-runoff on SWMM includes generalizing drainage network, using a GIS tool to set up the research area, producing attribute data, and incorporating parameters (Xiong et al., 2019). This research aims to assess the draining efficiency of the canal during heavy monsoon rains with the area comprising economically significant neighbourhoods, such as Chawkbazar, Bakalia, Sholoshohor, Chaktai, and Bahaddarhat. Some of the main drainage canals, such as Chaktai in the city were discharged into the river Karnaphuli. The canal with a 14.8% slope and watershed area of 11.31 square kilometres (1131 hectares) was selected to understand the city drainage issues comprehensively, which consists of six catchments, most of which were used for commercial and residential purposes. Geographically, the research area is located between latitudes 22°19'36.9948 N and 22°22'3.3312 N and longitudes 91°50'48.6816 E and 91°50'35.4768 E, as shown in Figure 1.

2.2 Methodology

Watershed geometry of SWMM model was created using a digital elevation model (DEM), with a 10m x 10m resolution generated from ASTER radar data available on USGS websites. To analyze the existing cross-sectional profile, a total of eight sites were selected along the transverse direction. The breadth of the Chaktai canal was divided into various strips using a rope and weight system fastened at the bottom, while its longitudinal distance was determined with the ArcGIS 10.4 field calculator. The average bottom slopes were computed from field measurements and modified for specific reference points and locations. After physically examining the canal bed material, the Manning roughness coefficient (n) was selected using established tables. Field data on land cover and land use

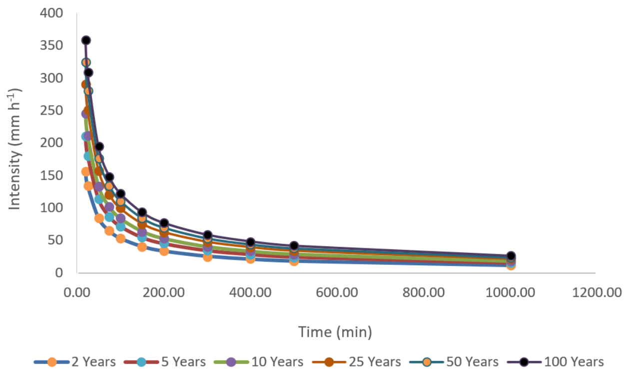


Figure 3 IDF curve for Chittagong (Rasel and Chowdhury, 2015)

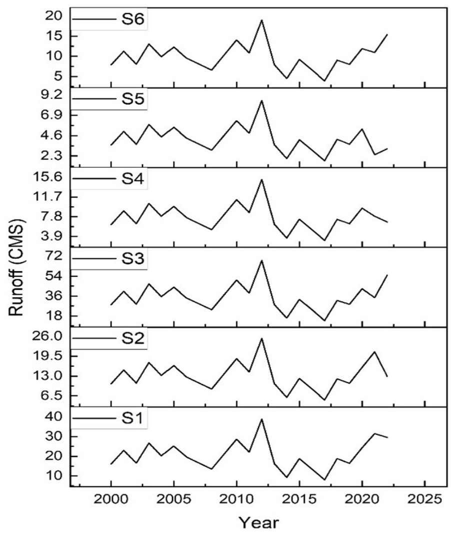


Figure 4 Sub-catchment Runoff for 3-hr Interval in different years (2000-2022)

at several places were captured, as well as other relevant information to ascertain the accuracy of the land use map produced with ArcGIS 10.4 from the DEM. In addition, reach parameters were analyzed and documented through field surveys, as shown in Table 1. The length, depth and width of the canal were directly obtained from field survey measurements. Manning n values were also generated using Technical Release 55 (TR-55) Manning n table, which is a simplified process for determining the volume of surface runoff, hydrographs and peak discharge rate.

The initial stage in preparing watershed model is the Fill DEM preparation, a critical step where drainage network is designed to adhere to the flow pattern of each cell before extending beyond the grid. This is realized by selecting the fill tool, the Hydrology toolbar, the raw DEM as the faster input surface, and the output surface raster from the search window bar. After the acquired data had been analyzed, the fill DEM was constructed and prepared for usage. The flow direction was established by identifying landscape drains and selecting the Flow Direction menu option. Every cell in the surface grid was positioned towards the direction of the steepest downward fall, using the ArcGIS grid processor to identify the final flow channel. The attribute tables and slope area were used to generate efficient canal parameters for each of the six sub-catchments. The percentage imperviousness extracted directly from ArcGIS 10.4 is shown in Table 2. Furthermore, the CN grid system determined the curve number (CN) for each respective area.

The first step in the model development process is to establish settings for each model element. Subsequently, SWMM channel routing was used to model the quantity of surface runoff flows overland within the build-up region using total precipitation data and considering time series parameters and control specifications. Probability distributions for mean rainfall intensities were evaluated at relevant time scales, while rainfall extreme was of utmost significance for applications related to urban drainage (Coles, 2001). The SCS method, also known as the USDA Natural Resources Conservation Service (NRCS) method, was used to determine stormwater volumes, hydrographs, and runoff rates. The core component of the NRCS method is its Curve Number (CN), which measures surface covering, hydrologic phenomena, and soil permeability. The empirical formulas used to determine the percentage of rainfall were formulated regarding infiltration and runoff.

$$\mathrm{CN} = \frac{\Sigma \mathrm{AXCNi}}{\Sigma \mathrm{A}} \tag{1}$$

$$\mathrm{S} = \frac{25400}{CN} - 254 \tag{2}$$

$$Ia = 0.2\mathrm{S} \tag{3}$$

$$\mathrm{Q} = \frac{(\mathrm{P\text{-}Ia})}{(P - Ia) + \mathrm{S}} \tag{4}$$

Where Q is denoted as Surface Runoff (m^3 sec^{-1}), P as Precipitation (mm), S as Maximum Retention, Ia as primary Abstraction and CN as the Curve Number. The rational method determines the peak surface runoff during a specific uniform precipitation time. Thompson (2018) proposed the formula for calculating time of concentration:

$$t_c = \frac{FL}{A0.1xS0.2} \quad (5)$$

Where, t_c is the time of Concentration in minutes, the Length of the stream L in a kilometer, Area of the sub-basin A in square kilometers, Slope of land as S in meter per kilometer and F is taken as 58.5 when A is measured in square kilometer). The initial assumption of the relevant parameters, including the CN, was determined after examining the data limit obtained from both ArcGIS and the field survey.

The representation of the research area in SWMM is shown in Figure 2. The research area contains a single rain gauge station, six sub catchments connected by eight conduits and nodes, including an outlet. The runoff produced by each sub-catchment contributes to a number of nodes that are interconnected by the conduits.

Rainfall Intensity Duration Frequency (IDF) shown in Figure 3, developed by Rasel and Chowdhury (2015), was evaluated in respect to the depth, intensity of the storm, surface runoff events for a known duration and return periods of various magnitudes at specified locations. The preparation of the IDF curve includes considering 24-hour rainfall data from 1974 to 2014, sourced from the Bangladesh Meteorological Department (BMD). In addition, Gumbel distributional method was used to analyze IDF. The surface runoff volume for return periods of 5, 10, 25 and 50 years, were calculated using the following empirical equations and a correlation coefficient chart for Chittagong city (Rasel and Chowdhury, 2015).

2.3 Run-off Model Validation

The surface run-off process can be divided into two main sections, namely transforming the precipitation data into surface run-off volume and associating it with relevant parameters, as well as converting this data into hydrographic shapes. The sequential steps include collecting authentic data, selecting initial estimates for the parameters, simulating SWMM 5.1 model for the boundary conditions of the impervious land for the surface run-off volume, comparing the hydrograph shapes to the executed ones, calibrating the pervious surface area, checking the fit, conducting optimization trials, and finally incorporating the satisfactory parameters into the model suitable for routing computation. In this scheme, the validation of the model output was obtained using distinct real-world data in the calibration process. After the completion of the model-building process, it is set up for simulation, and the results obtained are compared to field data for validation.

Table 4. Surface run-off variation in different sub-catchments for particularly severe cases with time series from 2000 to 2022

Year	Date	Time	Peak Runoff (CMS)					
			S-1	S-2	S-3	S-4	S-5	S-6
2000	29/08 - 30/08	1:30 - 22:30	15.89	11.01	29.1	5.88	2.52	8.16
2001	16/07 - 17/07	1:30 - 22:30	21	15.02	41.1	9.01	4.98	11.21
2002	10/06 - 11/06	1:30 - 22:30	15.78	9.68	29.01	6.03	4.1	7.93
2003	11/08 - 12/08	1:30 - 22:30	27.89	17.01	46.9	11.08	6.21	12.99
2004	07/08 - 08/08	1:30 - 22:30	21.01	12.95	36.1	8	4.01	10.2
2005	10/07- 11/07	1:30 - 22:30	24.98	17.1	45.12	10.03	5.78	11.98
2006	29/07 -30/07	1:30 - 22:30	20.02	13.05	34.01	8.12	5.21	10.11
2008	28/06 -29/06	1:30 - 22:30	12.99	9.1	24.56	5.13	3.01	7.1
2010	13/07 -14/07	1:30 - 22:30	28.34	17.88	51.8	11.20	7.23	13.87
2011	18/08 -19/08	1:30 - 22:30	21.88	13.86	39.01	9.61	5.23	10.78
2012	11/06 - 12/06	1:30 - 22:30	39.01	24.9	68.86	14.88	7.55	18.91
2013	19/07 - 20/07	1:30 - 22:30	15.91	11.2	27.97	7.01	4.01	8.01
2014	25/07 - 26/07	1:30 - 22:30	10.01	6.1	15.01	4	1.99	4.55
2015	03/08 - 04/08	1:30 - 22:30	17.89	11.90	32.97	6.91	3.88	9.12
2016	23/08 - 24/08	1:30 - 22:30	13.87	9.1	24.02	5.12	3.03	6.87
2017	21/08 - 22/08	1:30 - 22:30	8.01	4.96	14	3.2	2.4	4.01
2018	10/06 - 11/06	1:30- 22:30	19.03	11.83	31.88	8.1	3.90	8.88
2019	03/07 - 04/07	1:30 - 22:30	15.89	10.92	29.6	4.4	3.81	7.98
2020	13/07 - 14/07	1:30 - 22:30	23.97	16.11	43.23	9.56	5.45	12
2021	09/08 - 10/08	1:30- 22:30	32.01	21.01	35.3	8.01	3.33	11.01
2022	24/08 - 25/08	1:30 - 22:30	28.88	13.12	55.6	7.01	3.01	15.51

3 RESULTS

It was observed that SWMM simulation of runoff for extreme rainfall events was conducted in a reasonable manner. Efforts were made to ascertain the maximum runoff for each sub-catchment by considering specific dates of extreme rainfall events in the respective years. The runoff produced by the main sub-catchments for rainfall events from 2000 to 2022 is shown in Table 3. With regard to numerous extreme rainfall events over the course of 22 years, these graphs help in understanding the relationship between rainfall and runoff in the sub-catchments. Figure 4 shows that rainfall events with higher intensities corresponded to the largest runoff peaks.

The runoff patterns across different sub-catchments illustrate significant temporal variability, as shown in Figure 4. However, sub-catchments 3 and 5 consistently faced the highest and least runoff generation every year due to its larger paved area as well as open

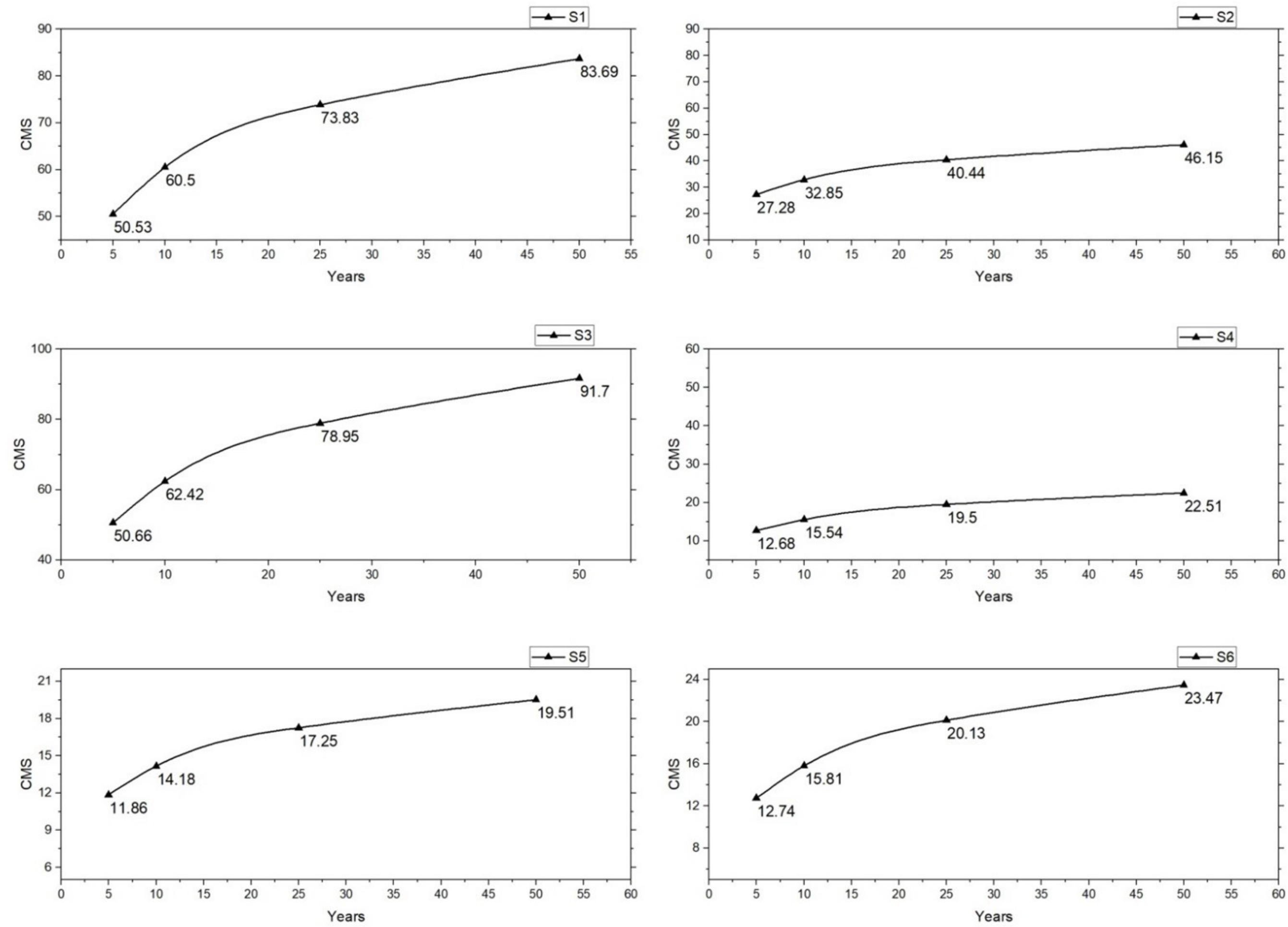


Figure 5 Variation of surface runoff (CMS) on the Sub-catchments for Different Return Periods (Years) with meteorological effect

terrain and lower water body, respectively. The results showed that drainage networks were under tremendous pressure to drain a sizable amount of runoff produced from the areas, mostly during the monsoon season, experienced in the months of July to August. The generation of runoff varied as anticipated with rainfall and land use trends. In 2012, there was a significant spike in rainfall intensity, relatively 138.42 mm in 24 hours, exceeding the levels observed in previous years. Consequently, the surface runoff significantly increased in that particular year, rendering the sub-catchments more vulnerable to water-related challenges.

In 2012, sub-catchment 3 experienced an increase in surface runoff by 72 cms, due to extreme rainfall, which led to flood. The results of this research could also be used to predict future surface runoff for various return periods (5, 10, 25, 50 years), in addition to the meteorological effect shown in Figure 5. This prediction is similar to the current scenario, presenting the anticipated runoff levels for various return periods while considering the influence of weather conditions.

The persistent intensity of rainfall over time is expected to result in a definite rise in surface runoff volume, posing a potential threat of flood occurrences in the future. This is because the analysis conducted in SWMM showed that the nodes with increased depths, particularly within the discharge point at Karnaphuli, consistently exceeded the threshold (3.3m) in terms of both meteorological and tidal effects. The sub-catchment areas have already become flood-prone in recent years,meaning that when the scenario persists in the future without precautionary measures, the rising runoff volume will pose a long-lasting threat to urban inhabitants. In SWMM, transects alongside overbank and channel projections for each catchment were separately developed using field-surveyed elevations as input parameters for the simulation. This graphical analysis was introduced to help understand the relative behavior of every variable in a set of information. The elevation of the tran-

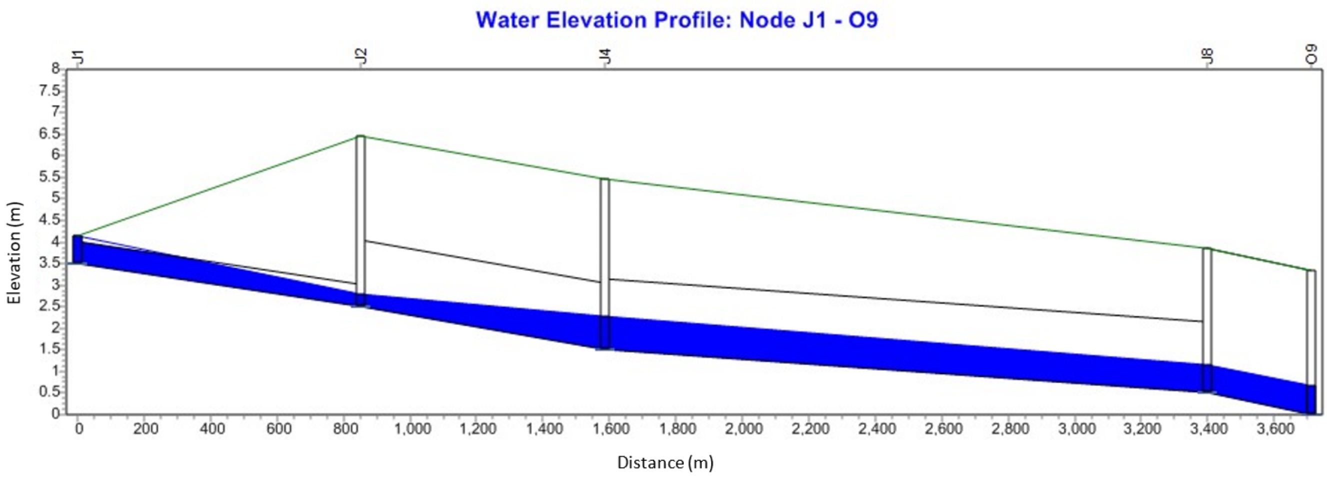


Figure 6 Water Elevation profile for the Nodes

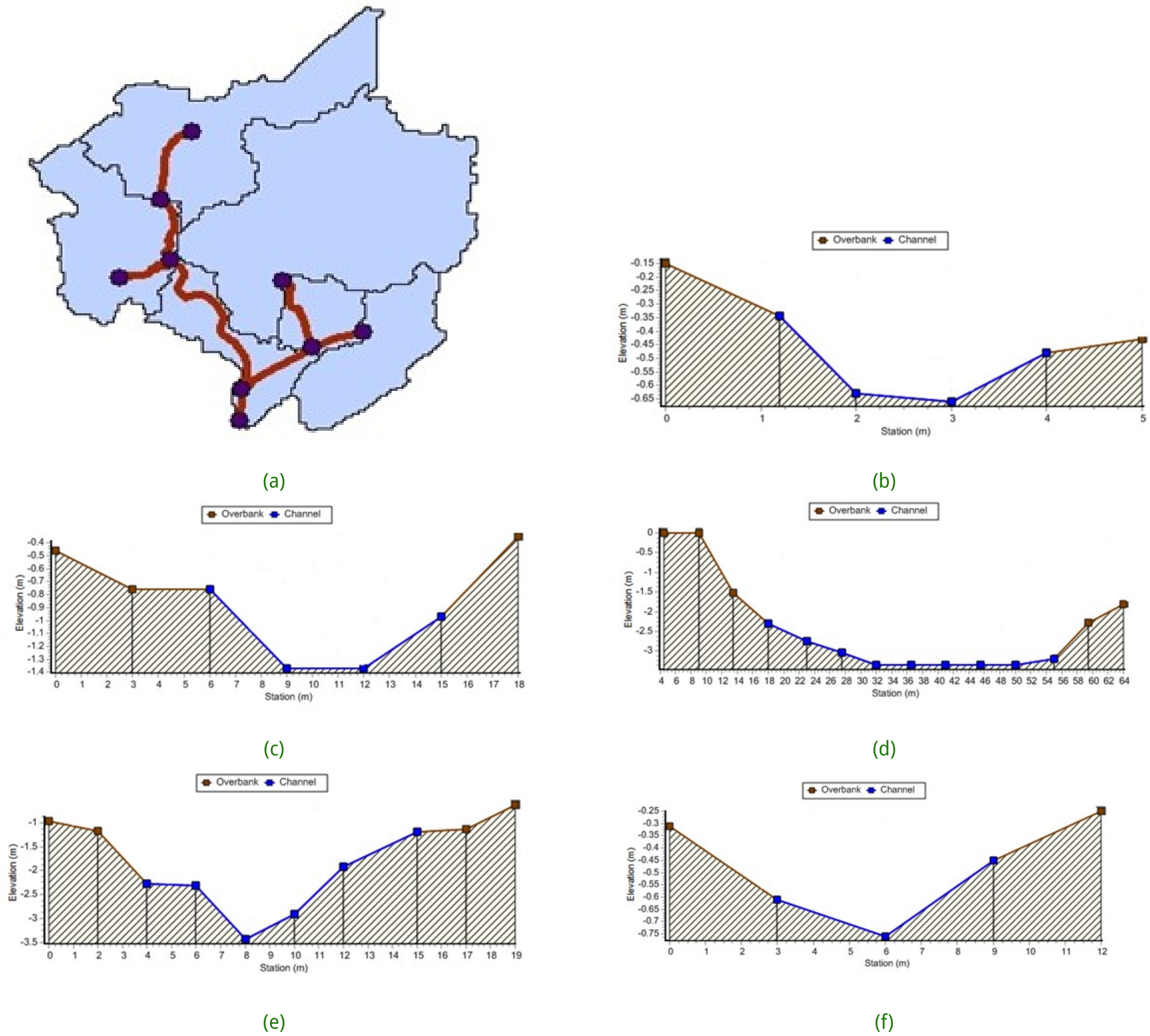


Figure 7 Transect projection of overbank (brown) and channel (blue) for sub-catchments

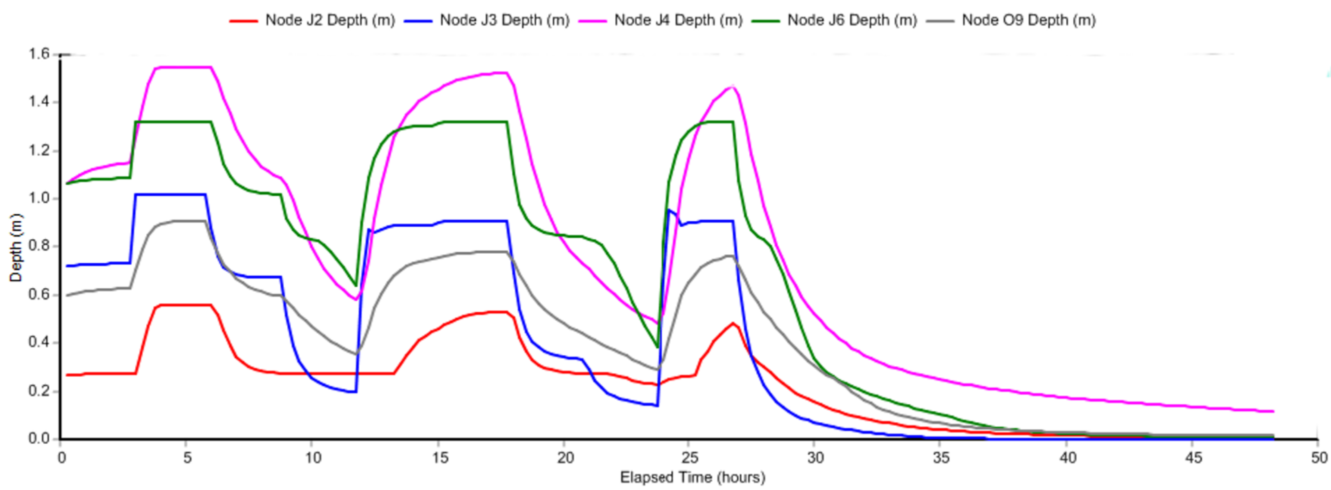
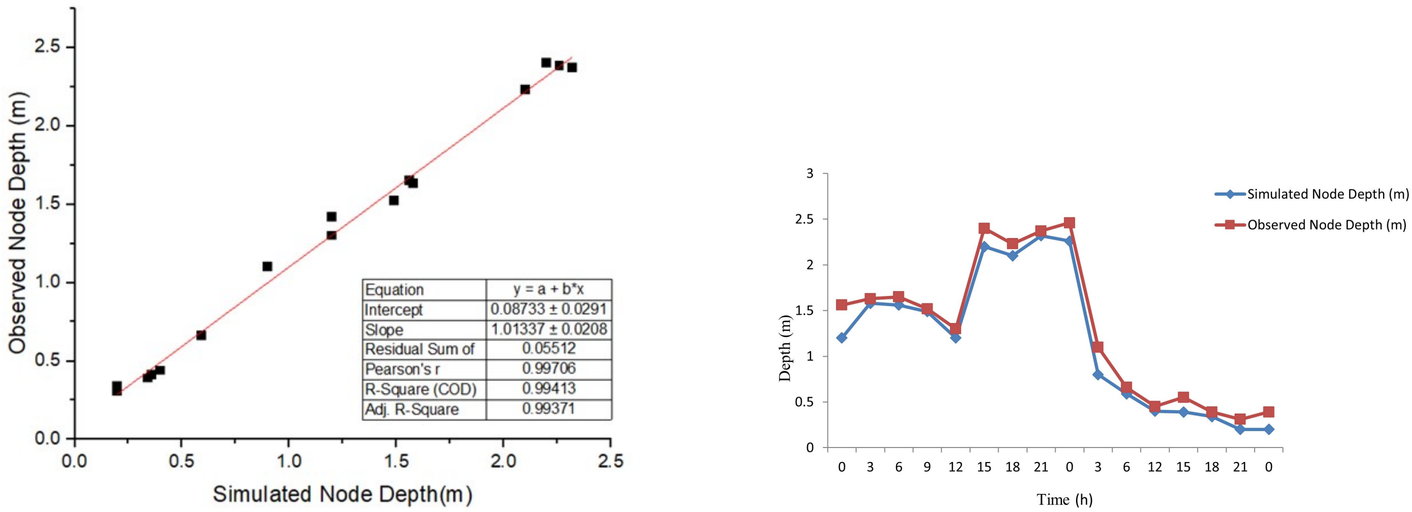


Figure 8 Junction depth generated in SWMM with time series (Year 2008)



(a) (b)

Figure 9 Model Validation for Outfall Node depth

sect generated from SWMM has shown that the soil erosion and alluvium layer resulted from frequent flash flood. This information is crucial for assessing the capacity of nodes to hold water at respective depths and in understanding extreme cases of rainfall patterns is profile plots, a graphical summary of the acquired data. Table 4 shows a data profile for water elevation from Nodes J1 to J8, generated based on extreme cases of rainfall patterns.

The results of the simulation offer a clear perspective, stating that the node near the starting point of the canal has a shallower depth compared to the one at the mouth of discharge point, at Karnaphuli denoted as J8. Meanwhile, over the years, the maximum depths of nodes in specific areas consistently remained below the threshold level, showing that these areas are not prone to flood. Figure 8 shows the pattern of outfall depth concerning extreme rainfall patterns.

Table 4 shows the initial and maximum depth a node can carry, which was simulated and is similar to the values in Figure 8. It was showed that node J-4 exceeded the maximum depth limit of 1.42 m, leading to water overflow in 2008. From the analysis, the other nodes could not exceed the maximum limit during that period. Therefore, it was reported that those have not been overflown. The nodes would have been at risk of approaching the threshold, showing potential water congestion. The results from SWMM analysis also clearly showed that sub-catchment 3 generated higher run-off due to its substantial paved surface area of 406 ha and a significantly steeper

Table 5. Variation of Node depth in different sub-catchments for extreme cases with time

Year	Node Depth (meter)															
	J-1		J-2		J-3		J-4		J-5		J-6		J-7		J-8	
	Int.	Max.	Int.	Max.	Int.	Max.	Int.	Max.	Int.	Max.	Int.	Max.	Int.	Max .	Int.	Max
2000	0.15	0.66	1.41	2.96	0.35	1.37	1.03	2.96	0.41	1.19	0.82	2.13	0.25	0.76	1.82	3.35
2001	0.15	0.51	0.03	1.55	0.04	1.2	1.13	2.51	0.05	0.78	1.32	1.5	0.31	0.51	1.91	3.45
2003	0.34	0.89	1.76	2.43	0.56	2.01	1.23	2.32	0.72	2.31	1.56	2.41	0.55	0.75	2.03	3.01
2004	0.23	0.71	1.31	2.17	0.44	0.49	1.16	2.01	0.86	1.47	1.39	2.04	0.69	0.88	2.14	3.17
2006	0.18	0.84	1.22	2.45	0.43	1.89	0.82	1.98	0.75	1.31	1.41	2.52	0.73	1.08	1.31	2.83
2008	0.21	0.55	0.89	1.02	0.54	1.26	0.97	1.42	0.59	1.03	2.04	2.65	1.03	1.55	1.59	3.02
2010	0.23	0.71	1.79	2.62	0.59	1.58	1.11	1.89	0.61	1.09	1.87	2.12	0.83	1.23	2.02	3.77
2011	0.19	0.77	1.67	2.24	0.95	1.59	1.08	2.56	0.66	1.21	0.77	2.59	0.35	0.88	1.66	3.03
2012	0.37	0.72	1.62	2.19	0.29	1.08	1.08	2.24	0.44	1.58	0.93	2.02	0.54	0.85	2.21	3.82
2013	0.24	0.57	1.73	2.61	0.86	1.08	2.09	3.11	0.33	1.09	0.82	2.11	0.31	0.87	1.82	3.67
2014	0.31	0.84	1.21	2.16	0.55	1.02	2.21	2.42	0.72	1.52	0.91	2.28	0.65	0.91	1.67	3.41
2015	0.27	0.51	1.26	2.31	0.57	0.95	1.88	2.75	0.69	1.83	1.01	2.05	0.84	1.63	1.85	3.88
2016	0.52	0.86	1.18	2.59	0.62	1.25	1.96	2.12	0.51	1.67	0.72	1.82	0.53	1.02	1.95	3.62
2017	0.77	0.94	1.03	2.32	0.73	1.12	1.64	2.82	0.67	1.82	1.11	2.01	0.7	1.3	1.86	3.78
2018	0.56	0.84	1.15	2.29	0.68	1.65	0.31	2.15	0.53	1.62	1.06	1.89	0.69	1.29	2.01	3.91
2019	0.57	0.75	1.78	2.11	0.76	1.86	1.86	2.94	0.48	1.35	0.82	1.47	0.72	1.33	1.85	3.77
2020	0.78	0.87	0.11	2.27	0.77	1.03	1.02	2.21	0.72	1.84	0.79	1.81	0.82	1.48	1.92	3.81
2021	0.43	0.64	0.55	2.41	0.63	0.98	1.03	2.35	0.66	1.73	1.02	1.94	0.71	1.31	1.81	3.74
2022	0.63	0.82	0.61	2.48	0.75	1.69	1.32	2.47	0.59	1.69	0.96	2.48	0.88	1.65	1.95	3.89

slope. The steeper slopes limit water infiltration, resulting in rapid runoff and rendering the entire sub-catchment region susceptible to flood. Table 5 shows that J1 connected to sub-catchment S1 has shallower depths than other nodes. While this sub-catchment generates a huge volume of runoff, the J1 node becomes vulnerable due to its shallow depths, intensified by meteorological effect. Figure 6 shows the entire watershed path from the starting node (J1) to the outlet (O9), with its runoff capability under meteorological conditions. However, J1 experienced an overflow situation, suggesting flood in this area as its conduit was fully saturated. The projection of transverse sections for most catchments, separately created in SWMM by using the elevation data from respective sub-catchments are shown in Figure 7.

For calibration and validation purposes in the hydrologic-hydraulic model, it is essential to compare observed stormwater runoff values with those initially simulated. Furthermore, the results of these processes tend to be satisfied assuming the coefficient of determination (R^2) is greater than 0.6 (Engel et al., 2007). Figure 9 shows the validation and calibration of the EPA SWMM model were obtained by comparing simulated data from SWMM analysis at outfall with real observed data.

4 DISCUSSION

Preliminary research focused on a deeper understanding of how human activities impact water accumulation in selected catchment areas. Therefore, this research showed the effectiveness of SWMM in managing urban flood conditions using user-friendly features such as scattered plots and time series with diverse data interpretation methods.Although the impact was measured by changes in imperviousness as a result of altering land use, the drainage network was considered sufficient under meteorological factors with rise in vulnerabilities during monsoons. The outfalls, with a height of 3.3m, became susceptible to flood, leading to an overflow of watershed. ArcGIS results showed that S1 and S3 sub-catchments with greater slope regions experience stronger runoff flow from the steeper northeast to the shallower south. These regions are totally covered with concrete and paved surfaces, which is in contrast with the limited vegetative area shown in the western and southern parts of the S2 and S6 sub-catchments, respectively. Therefore, S2 and S6 generate lower volume of surface runoff compared to S1 and S3, due to higher infiltration rates, despite having impervious surfaces. S-5, which is the smallest region among the six sub-catchments, with 49 ha produced the least surface run-off, despite having a higher imperviousness rate than S2 and S6. The node depths ranged between 0.03m to 3.91m during extreme rainfall events, with lower depth in J1 connected to S1 sub-catchment. During the monsoon season J1 is susceptible to flood because of its lower depths and is connected to S1 which generates more runoff. The allowed depth of J1 has consistently been exceeded, particularly at the outfall, the final discharge point of the canal, during tidal waves and meteorological influences, leading to flood that threaten the entire drainage system. This research stated that S1 and S3 sub-catchmensts have the highest imperviousness, resulting in predicted runoff values of 83.69 and 91.7, respectively, thereby exceeding those of other areas. The J8 node serve as the final discharge point in some cases and exceeded the threshold depth, during high-intensity precipitation episodes. This research provided valuable insights for selecting sub-catchments in specific locations, through conceptual illustrations with limitations due to flow representation and model composition.

EPA SWMM 5.1 is appropriate for numerical analysis but is unsuitable in case of comprehensive water distribution system design. However, this process lacks the capability to model crucial factors like inlet losses and manhole properties, which are integral to hydraulic design and show slight instability as a hydraulic engine compared to other models. To address the unavailability of precise data on node depths from Chittagong Port Authority (CPA), the validation process focused on the outfall depth, yielding an adjusted R^2 value of 0.993. The graphical interpretation for future events in terms of different return periods suggested an increasing trend in the surface run-off volume. This shows a likelihood of higher future precipitation values, potentially altering the characteristics of surface runoff and the sensitivity of the soil landscape.

5 CONCLUSION

In conclusion, watershed under consideration was characterized by predominantly impermeable land, with few water bodies and limited vegetation. This obstructed the easy percolation of excessive rainfall into the soil, leading to the accumulation of significant surface runoff in sub-catchment areas S1 and S3, severely affecting the depth of the canal. The research showed the potential of event-based and simulation modelling at Chittagong Chaktai Canal, an important water transport route. Storm water management and land development strategies aimed at reducing pre-disturbance hydrologic process by minimizing impervious surface. The process was considered crucial due to the anticipated urbanization of the region, with increased industrial development in watershed. Additionally, the model guaranteed that SWMM model generated was acceptable and suitable in creating actual hydrologic conditions. The program served as a valuable tool, simplifying the creation of input data for SWMM model when users had GIS files. The input data could be quickly created and applied in the model by using soil data, DEM, sub-catchments, land use and sewage network distribution maps. The incorporation of a graphical user interface further enhanced user convenience and it is strongly recommended for future drainage system planning and management in urban watershed, with a focus on volume and peak flow runoffs as the main factors influencing flood occurrences in urban drainage management. The LID method need to be optimized for multiple Non-point Source Pollution (NPS) contamination and stormwater runoff. Therefore, the most vulnerable landscape entities should be given special consideration when designing strategies to combat, cope with and alleviate the effects of severe rainfall events.

DISCLAIMER

The authors declare no conflict of interest.

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