# EXPLORING STORMWATER BEST MANAGEMENT PRACTICES IN KHULNA CITY CORPORATION USING PCSWMM

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## ABSTRACT

Khulna City Corporation (KCC), located in a low-lying area in southwestern Bangladesh, has been suffering from frequent water logging in the rainy season almost every year. This situation is intensified due to rapid urbanization and the impact of climate change, which have consequently created numerous problems in KCC related to stormwater management issues that require immediate consideration. Therefore, the current study aims to explore stormwater management problems in KCC and find possible countermeasures through different best management practices. Stormwater management must be incorporated into urban design and development, particularly in densely populated urban areas like KCC. In Ward No. 30 of KCC, controlling stormwater is a vital concern due to heavy rainfall, a lack of proper drainage infrastructure, unplanned growth, extensive land cover areas, etc. In the current study, the most widely used Personnel Computer Storm Water Management Model (PCSWMM) software was adopted to evaluate the city's current stormwater management practices and develop a long-term stormwater management strategy. A reconnaissance investigation of the existing states of the soil, drainage, and outlet infrastructures was conducted. The study area (KCC Ward No. 30) was then divided into many small catchments in the ArcGIS platform, and areas of each sub-catchment were identified. To determine the percentage of impervious area and the elevation of the study area, the land use and land cover (LULC) map and the digital elevation model (DEM) were generated using the ArcGIS software. All the aforementioned parameters were then entered into the PCSWMM software, and simulations were performed for various rainfall durations using different best management practices. The PCSWMM simulation provided the results of runoff, infiltration, peak runoff, floods, or surcharges at every drainage node or discharge point in the existing and altered drainage system of the study area due to the occurrence of extreme rainfall. The results indicate that various best management practices, increasing the slope, reducing the roughness of the drainage systems, reducing imperviousness, permitting more infiltrations, and promoting green infrastructure, are highly effective in controlling urban flooding or surcharges in the study area caused by the occurrence of extreme rainfall in the future. The findings of this study are expected to be supportive to policymakers, urban planners, and water managers in implementing and promoting sustainable and climate-resilient urban drainage infrastructures to tackle stormwater management problems in the KCC area.

***Keywords:*** *Stormwater Management, PCSWMM, Urban Flooding, Best Management Practices, ArcGIS.*

## 1.INTRODUCTION

Globally, extreme rainfall has been increasing due to the impact of climate change. In recent years, run-off caused by extreme rainfall has been a matter of concern to researchers and water managers, as it often causes urban flooding and imposes a serious burden on the drainage systems, particularly in urban areas. Stormwater management refers to the sustainable drainage of stormwater, which usually causes flooding and water logging. Water logging is caused by several reasons, including changes occurring in the hydrologic cycle, such as uneven precipitation distribution in time and space; land use changes, such as decreasing green areas and occupying water bodies for land development; and a lack of proper management, such as improper maintenance of storm water drainage systems and inadequate emergency response systems (Akter et al., 2017). Therefore, it is vital to develop appropriate management measures for the reduction of urban water logging and sustainable stormwater management in urban areas.

Waterlogging is a widespread issue, particularly in developing nations. The accumulation of water on the surface happens when the earth is saturated with water and can no longer absorb any more. High impervious surfaces in urban areas, poor drainage systems, and improper land-use planning are the main contributors to waterlogging (Islam et al., 2020). One of the largest cities in Bangladesh, Khulna, has a serious waterlogging issue during the rainy season. The city's infrastructure, residents' lives, and property all suffer substantial losses as a result of the waterlogging (Azad et al., 2022). Hence, it is crucial to comprehend the causes of the waterlogging and identify potential remedies to the issue. Natural drainage channels, canals, and man-made drainage facilities like culverts and pumps make up the majority of the drainage system in the city of Khulna. It is necessary to maintain drainage channels that are large enough for all the rainwater that collects in the area (Ermalizar and Junaidi, 2018). The surface runoff rate and volume are increased due to more impervious areas like rooftops, squares, and roads. Overland flow direction is also changed by man-made facilities such as drainage systems, roads, and buildings (Hsu et al., 2000). It has an impact on people's quality of life, particularly in places where agriculture is the main source of income (Jahan et al., 2018). Unfortunately, the drainage system has become unable to handle the extra water during the monsoon season as a result of growing urbanization and unplanned growth (Ahmed et al., 2017).

Khulna, being the third-largest city, is located in the southwest region of Bangladesh. A flat alluvial plain with an average height of 1-2 meters above sea level best describes this area. The Ganges-Brahmaputra Delta, the biggest delta in the world and one of the most densely inhabited regions on earth, dominates the area. The network of rivers and tributaries that pass through the Khulna area, including the Ganges, Brahmaputra, and Meghna rivers and countless smaller rivers and canals, has influenced its landscape. These rivers have produced an intricate network of linked streams, channels, and estuaries that provide a critical habitat for a wide variety of plants and wildlife. Drainage difficulties are one of the main concerns brought on by urbanization in Khulna city. As a consequence, flooding has been a common occurrence in the city, particularly during the monsoon season. (Islam et al., 2017). The upshot is that the city's streets, residences, and businesses regularly flood, resulting in substantial economic and social losses. The city has a monsoon-influenced tropical climate, with a dry season from November to March and a wet season from May to October. The annual average rainfall in Khulna is 1802 mm and the temperature in Khulna varies from 21.3°C to 31.1°C with a mean value of 26.2°C (Rana and Adhikary, 2023).

Personnel Computer Storm Water Management Model (PCSWMM) is a widely adopted stormwater management simulation software that was employed to assess the effectiveness of a low-impact development strategy for stormwater management in a residential area (Lee et al., 2015). They discovered that the method was successful in lowering peak flow rates and stormwater discharge. In another study, PCSWMM was used to plan and assess a stormwater management system for the campus of a Chinese institution (Wang et al., 2016). They discovered that the technique was successful in lowering the danger of floods and raising the quality of the water. A complete examination of the current stormwater infrastructure is required to conduct the stormwater management project in Khulna Ward-30. The efficacy of current stormwater infrastructure may be assessed, and new stormwater management systems can be designed, utilizing PCSWMM for this study. The use of PCSWMM will also make it possible to locate probable flood zones and create effective stormwater management plans. So, the goal of this study is to study the existing drainage properties, soil condition, land use condition, and land elevation of the area and to develop a model using PCSWMM to calculate runoff, infiltration, peak runoff, etc. It will enable us to check whether any flooding occurs in the study area; if not, then some preventive measures would be proposed to reduce runoff and increase infiltration in the area. The objective of this study is to explore the potentiality of using best management practices in urban stormwater management in Khulna City Corporation of Bangladesh.

## 2.METHODOLOGY

### 2.1. Study Area and Data Collection

In this study, Ward No. 30 in Khulna City Corporation (KCC) is selected as the study area. Its location is approximately at latitude 22.80 degrees and longitude is 89.6 degree. The total study area is approximately 1233271 $m^2$ (approximately 1.23 $km^2$). The total study area was divided into 26 smaller areas named sub-catchments. Figure 1 represents the study area divided into several sub-catchments that flow water into a common junction/node. The study area was visited to calculate the drainage dimensions, outlet dimensions & types of the soil present in the study area. The existing drainage map of ward-30 is collected from KCC. The areas of sub-catchment, percent imperviousness of land use, and percent slope have been found by using ArcGIS. The width is found by dividing the area of each sub-catchment by the longest flow path using Equation (1).

$$Width\ of\ a\ sub\ catchment = \frac{Area\ of\ a\ sub\ catchment}{Longest\ flow\ path} \quad (1)$$

Figure 1: Ward No. 30 of KCC (the study area) with its delineated sub-catchments

### 2.2 Model Development

The existing drainage model is developed in PCSWMM after collecting all the data. After that, a simulation was done for a particular Ten-Year Rainfall Data from 2011 to 2020 which was taken from a website of NASA called Data Access Viewer. Horton's Infiltration parameters have been used for necessary calculations. Figure 2 shows the PCSWMM model for the existing condition of the study area with nodes, outfalls, sub-catchments, and conduits.

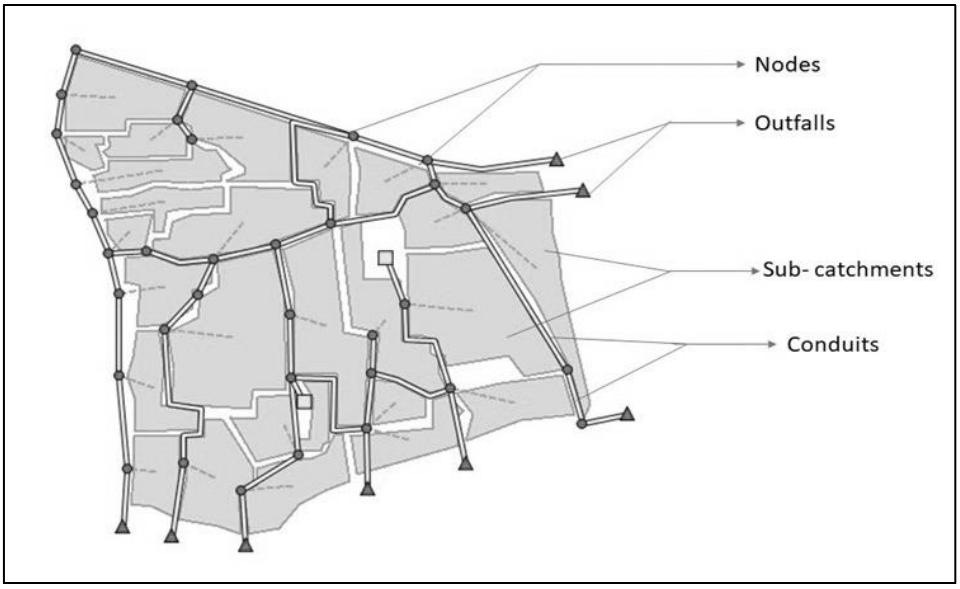

Figure 2: The Model Developed in PCSWMM for the study area with their designations

### 2.3 Scenario Analysis for Different Best Management Practices

A reconnaissance investigation of the existing states of the soil, drainage, and outlet infrastructures was conducted. The study area (KCC Ward No. 30) was then divided into many small catchments in the ArcGIS platform, and areas of each sub-catchment were identified. In order to calculate the percentage of impervious area and the elevation of the study area, the land use and land cover (LULC) map and the digital elevation model (DEM) were generated using the ArcGIS software. All the aforementioned parameters were then entered into the PCSWMM software, and simulations were performed for various rainfall durations using different best management practices. The PCSWMM simulation provided the results of runoff, infiltration, peak runoff, floods, or surcharges at every drainage node or discharge point in the existing and altered drainage system of the study area due to the occurrence of extreme rainfall.

## 3.RESULTS AND DISCUSSION

Table 1 represents the sub-catchment runoff and infiltration for 10-year rainfall with existing imperviousness which shows total precipitation, total infiltration, impervious runoff, pervious runoff, total runoff, peak runoff, and runoff of every catchment.

Table 2 shows Outfall discharges for 10 years of rain with existing imperviousness of the area where there are a total of 8 outlets, 2 directly fall at Rupsha River, and the other 6 falls at Khal par area which indirectly connects at Rupsha River. Here, from the table, the percent flow frequency, average flow, maximum flow, and total volume of discharge have been found. The total discharge volume for the existing condition is 15570.216×106 L.

Table 1: Sub-catchment runoff and infiltration for 10-year rainfall with existing imperviousness

| **Sub-catchment** | **Total precipitation (mm)** | **Total infiltration (mm)** | **Impervious runoff (mm)** | **Previous runoff (mm)** | **Total runoff (mm)** | **Total runoff (×106 liters)** | **Peak runoff (m3/s)** | **Runoff coefficient** |
|---|---|---|---|---|---|---|---|---|
| S4 | 21158.75 | 4922.98 | 14812.25 | 1424.92 | 16237.1 | 396.19 | 0.19 | 0.767 |
| S5 | | 4965.46 | 14811.87 | 1382.35 | 16194.2 | 510.12 | 0.24 | 0.765 |
| S8 | | 4913.96 | 14812.38 | 1433.97 | 16246.3 | 495.52 | 0.24 | 0.768 |
| S9 | | 4960.66 | 14811.9 | 1387.15 | 16199.0 | 349.9 | 0.17 | 0.766 |
| S10 | | 4957.47 | 14811.92 | 1390.35 | 16202.2 | 275.44 | 0.13 | 0.766 |
| S11 | | 4918.62 | 14812.31 | 1429.3 | 16241.6 | 495.37 | 0.24 | 0.768 |
| S12 | | 4957.8 | 14811.92 | 1390.01 | 16201.9 | 430.97 | 0.21 | 0.766 |
| S13 | | 4947.17 | 14812 | 1400.67 | 16212.6 | 405.32 | 0.19 | 0.766 |
| S22 | | 12353.96 | 5290.53 | 3515.66 | 8806.19 | 440.31 | 0.38 | 0.416 |
| S24 | | 4958.68 | 14811.92 | 1389.13 | 16201.0 | 1344.6 | 0.64 | 0.766 |
| S23 | | 4920.81 | 14812.28 | 1427.1 | 16239.3 | 446.59 | 0.21 | 0.768 |
| S25 | | 4932.67 | 14812.13 | 1415.2 | 16227.3 | 308.32 | 0.15 | 0.767 |
| S19 | | 4985.16 | 14811.78 | 1362.62 | 16174.4 | 769.91 | 0.37 | 0.764 |
| S26 | | 4969.46 | 14811.85 | 1378.35 | 16190.2 | 971.42 | 0.47 | 0.765 |
| S1 | | 4946.82 | 14812 | 1401.01 | 16213.0 | 1085.7 | 0.52 | 0.766 |
| S2 | | 4952.88 | 14811.96 | 1394.94 | 16206.9 | 836.28 | 0.4 | 0.766 |
| S3 | | 4915.46 | 14812.36 | 1432.46 | 16244.8 | 175.77 | 0.08 | 0.768 |
| S7 | | 4945.11 | 14812.02 | 1402.73 | 16214.7 | 405.37 | 0.19 | 0.766 |
| S6 | | 4880.64 | 14813.35 | 1467.57 | 16280.9 | 182.35 | 0.09 | 0.769 |
| S16 | | 4943.91 | 14812.03 | 1403.93 | 16215.9 | 489.72 | 0.23 | 0.766 |
| S17 | | 4918.19 | 14812.31 | 1429.72 | 16242.0 | 438.54 | 0.21 | 0.768 |
| S15 | | 4989.81 | 14811.76 | 1357.97 | 16169.7 | 1109.2 | 0.53 | 0.764 |
| S14 | | 4969.02 | 14811.85 | 1378.78 | 16190.6 | 1586.6 | 0.76 | 0.765 |
| S18 | | 4962.82 | 14811.89 | 1384.99 | 16196.8 | 1023.65 | 0.49 | 0.765 |
| S20 | | 4939.79 | 14812.06 | 1408.06 | 16220.1 | 220.59 | 0.11 | 0.767 |
| S21 | | 4949.06 | 14811.98 | 1398.77 | 16210.76 | 376.09 | 0.18 | 0.766 |

Table 2 shows Outfall discharges for 10 years of rain with existing imperviousness of the area where there are a total of 8 outlets, 2 directly fall at Rupsha River, and the other 6 falls at Khal par area which indirectly connects at Rupsha River. Here, from the table, the percent flow frequency, average flow, maximum flow, and total volume of discharge have been found. The total discharge volume for the existing condition is $15570.216\times10^6$ L.

Table 2: Outfall discharges for 10 Year rain with existing imperviousness of the area

| **Outfall Node** | **Flow frequency (%)** | **Average flow (m3/s)** | **Maximum flow (m3/s)** | **Total volume (×106 L)** |
|---|---|---|---|---|
| O6 | 59.71 | 0.01 | 0.997 | 1952.434 |
| O3 | 55.46 | 0.008 | 0.734 | 1303.506 |
| O1 | 60.14 | 0.022 | 1.521 | 4188.151 |
| O2 | 58.27 | 0.013 | 1.135 | 2457.93 |
| O4 | 58.63 | 0.013 | 1.143 | 2467.178 |
| O5 | 54.19 | 0.008 | 0.79 | 1328.613 |
| O8 | 54.36 | 0.004 | 0.4 | 646.014 |
| O7 | 53.15 | 0.007 | 0.9 | 1226.39 |
| | | | Total = | 15570.216 |

Table 3 shows the node depth for existing imperviousness and drainage. From this maximum reported depth is less than the drainage depth so that for the existing condition of my study area, no node or junction is flooded. From these, it is clear that there is no flooding in my model simulation.

Table 3: Node depth for existing imperviousness and drainage

| **Node** | **Type** | **Average depth (m)** | **Maximum depth (m)** | **Maximum HGL (m)** | **Day of maximum depth** | **Hour of maximum Depth** | **Maximum depth (m)** |
|---|---|---|---|---|---|---|---|
| J1 | JUNCTION | 0.02 | 0.48 | 8.83 | 2485 | 12:00 | 0.48 |
| J2 | | 0.01 | 0.39 | 8.69 | 2485 | | 0.39 |
| J3 | | 0.01 | 0.87 | 8.67 | 2485 | | 0.87 |
| J6 | | 0.03 | 1.01 | 8.56 | 2485 | | 1.01 |
| J7 | | 0.03 | 0.93 | 8.43 | 2485 | | 0.93 |
| J8 | | 0.03 | 0.65 | 8.1 | 2485 | | 0.65 |
| J12 | | 0.02 | 0.6 | 8.55 | 2485 | | 0.6 |
| J4 | | 0.02 | 0.95 | 8.65 | 2485 | | 0.95 |
| J13 | | 0.01 | 0.42 | 8.32 | 2485 | | 0.42 |
| J41 | | 0.01 | 0.39 | 8.24 | 2485 | | 0.39 |
| J40 | | 0.01 | 0.41 | 8.33 | 2485 | | 0.41 |
| J37 | | 0.01 | 0.54 | 8.52 | 2485 | | 0.54 |
| J23 | | 0 | 0.53 | 8.53 | 2485 | | 0.53 |
| J16 | | 0.01 | 0.8 | 8.6 | 2485 | | 0.8 |
| J5 | | 0.03 | 1 | 8.6 | 2485 | | 1 |
| J15 | | 0.01 | 0.65 | 8.6 | 2485 | | 0.65 |
| J18 | | 0.02 | 0.71 | 8.59 | 2485 | | 0.71 |
| J22 | | 0.02 | 0.51 | 8.11 | 2485 | | 0.51 |
| J17 | | 0.01 | 0.7 | 8.6 | 2485 | | 0.7 |
| J45 | | 0.01 | 0.4 | 7.9 | 2485 | | 0.4 |
| J46 | | 0.01 | 0.24 | 7.72 | 2485 | | 0.24 |
| J24 | | 0.01 | 0.62 | 8.52 | 2485 | | 0.62 |
| J26 | | 0.01 | 0.46 | 8.21 | 2485 | | 0.46 |
| J27 | | 0.01 | 0.36 | 8.01 | 2485 | | 0.36 |
| J32 | | 0.01 | 0.49 | 8.24 | 2485 | | 0.49 |
| J31 | | 0.02 | 0.48 | 8.18 | 2485 | | 0.48 |
| J30 | | 0.01 | 0.46 | 8.11 | 2485 | | 0.46 |
| J25 | | 0.01 | 0.46 | 8.26 | 2485 | | 0.46 |
| J33 | | 0.02 | 0.56 | 8.46 | 2485 | | 0.56 |
| J35 | | 0.01 | 0.43 | 8.18 | 2485 | | 0.43 |
| J10 | | 0.02 | 0.61 | 8.89 | 2485 | | 0.61 |
| J11 | | 0.01 | 0.58 | 8.83 | 2485 | | 0.58 |
| J9 | | 0.01 | 0.6 | 8.9 | 2485 | | 0.6 |
| INLET | | 0 | 0.33 | 8.83 | 2485 | | 0.33 |
| O6 | OUTFALL | 0.01 | 0.38 | 7.73 | 2485 | | 0.38 |
| O3 | | 0.01 | 0.31 | 7.81 | 2485 | | 0.31 |
| O1 | | 0.01 | 0.5 | 7.9 | 2485 | | 0.5 |
| O2 | | 0.01 | 0.41 | 7.86 | 2485 | | 0.41 |
| O4 | | 0.01 | 0.41 | 7.86 | 2485 | | 0.41 |
| O5 | | 0.01 | 0.38 | 7.83 | 2485 | | 0.38 |
| O8 | | 0 | 0.21 | 7.56 | 2485 | | 0.21 |
| O7 | | 0.01 | 0.35 | 7.75 | 2485 | | 0.35 |

Table 4 represents the sub-catchment runoff and infiltration for 10-year rainfall with 60% improved imperviousness and a 1.5% slope increase. It can be seen that the total runoff decreases from $396.19\times10^6$ L to $356.05\times10^6$ L (sub-catchment 4) and the runoff coefficient decreases from 0.76 to 0.69.

Table 4: Sub-catchment Runoff and Infiltration for 10-year Rainfall with 60% improved imperviousness and 1.5% slope increases

| **Sub catchment** | **Total precipitation (mm)** | **Total infiltration (mm)** | **Impervious runoff (mm)** | **Pervious runoff (mm)** | **Total runoff (mm)** | **Total runoff (×106 L)** | **Peak runoff (m3/s)** | **Runoff coefficient** |
|---|---|---|---|---|---|---|---|---|
| S4 | 21158.75 | 6568.07 | 12696.42 | 1895.78 | 14592.2 | 356.05 | 0.19 | 0.69 |
| S5 | | 6616.71 | 12696.08 | 1847.04 | 14543.12 | 458.11 | 0.24 | 0.687 |
| S8 | | 6559.53 | 12696.51 | 1904.35 | 14600.86 | 445.33 | 0.24 | 0.69 |
| S9 | | 6610.45 | 12696.12 | 1853.31 | 14549.42 | 314.27 | 0.17 | 0.688 |
| S10 | | 6578.65 | 12696.33 | 1885.17 | 14581.5 | 247.89 | 0.13 | 0.689 |
| S11 | | 6566.29 | 12696.44 | 1897.56 | 14594 | 445.12 | 0.24 | 0.69 |
| S12 | | 6596.33 | 12696.2 | 1867.45 | 14563.65 | 387.4 | 0.21 | 0.688 |
| S13 | | 6601.57 | 12696.17 | 1862.2 | 14558.37 | 363.96 | 0.19 | 0.688 |
| S22 | | 12342.86 | 5290.55 | 3526.78 | 8817.33 | 440.87 | 0.38 | 0.417 |
| S24 | | 6614.02 | 12696.1 | 1849.73 | 14545.83 | 1207.31 | 0.64 | 0.687 |
| S23 | | 4915.3 | 14812.36 | 1432.63 | 16244.99 | 446.74 | 0.21 | 0.768 |
| S25 | | 6581.95 | 12696.3 | 1881.86 | 14578.16 | 276.99 | 0.15 | 0.689 |
| S19 | | 6647.71 | 12695.95 | 1816 | 14511.95 | 690.77 | 0.37 | 0.686 |
| S26 | | 6637.8 | 12695.99 | 1825.92 | 14521.91 | 871.32 | 0.46 | 0.686 |
| S1 | | 6599.95 | 12696.18 | 1863.82 | 14560 | 975.09 | 0.52 | 0.688 |
| S2 | | 6605.36 | 12696.14 | 1858.41 | 14554.55 | 751.02 | 0.4 | 0.688 |
| S3 | | 6545.25 | 12696.69 | 1918.69 | 14615.38 | 158.14 | 0.08 | 0.691 |
| S7 | | 6598.18 | 12696.19 | 1865.6 | 14561.78 | 364.05 | 0.19 | 0.688 |
| S6 | | 6499.1 | 12697.67 | 1965.36 | 14663.03 | 164.23 | 0.09 | 0.693 |
| S16 | | 6594.02 | 12696.21 | 1869.77 | 14565.98 | 439.9 | 0.23 | 0.688 |
| S17 | | 6562.15 | 12696.48 | 1901.72 | 14598.2 | 394.15 | 0.21 | 0.69 |
| S15 | | 6648.48 | 12695.95 | 1815.23 | 14511.18 | 995.47 | 0.53 | 0.686 |
| S14 | | 6626.11 | 12696.04 | 1837.63 | 14533.67 | 1424.31 | 0.76 | 0.687 |
| S18 | | 6629.96 | 12696.02 | 1833.77 | 14529.79 | 918.29 | 0.49 | 0.687 |
| S20 | | 6559.98 | 12696.5 | 1903.9 | 14600.4 | 198.57 | 0.11 | 0.69 |
| S21 | | 6600.98 | 12696.17 | 1862.79 | 14558.96 | 337.77 | 0.18 | 0.688 |

Table 5 shows outfall discharges for 10-year rainfall with improved 60% Imperviousness and a 1.5% increase in slope. The total discharge volume for the existing condition is 14073.144×$10^6$ L.

Table 5: Outfall discharges for 10-year rainfall with improved 60% imperviousness and 1.5% increase in slope

| **Outfall Node** | **Flow frequency (%)** | **Average flow (m3/s)** | **Maximum flow (m3/s)** | **Total volume (×106 L)** |
|---|---|---|---|---|
| O6 | 59.1 | 0.01 | 0.992 | 1762.201 |
| O3 | 54.41 | 0.007 | 0.73 | 1170.523 |
| O1 | 59.11 | 0.02 | 1.515 | 3759.056 |
| O2 | 56.86 | 0.012 | 1.129 | 2206.052 |
| O4 | 57.46 | 0.012 | 1.138 | 2228.34 |
| O5 | 53.13 | 0.007 | 0.787 | 1225.225 |
| O8 | 53.63 | 0.004 | 0.398 | 594.821 |
| O7 | 52.25 | 0.007 | 0.896 | 1126.926 |
| | | | Total = | 14073.144 |

Here table 6 shows the Sub-catchment Runoff and Infiltration for 10-year rainfall with improved 50% imperviousness and 2.5% increase in slope where it is seen that the total runoff decreases from

$396.19\times10^6$ L to $315.76\times10^6$ L (sub-catchment 4) and the runoff coefficient decreases from 0.76 to 0.612.

Table 6: Sub-catchment Runoff and Infiltration for 10-year rainfall with improved 50% imperviousness and 2.5% increase in slope

| **Sub catchment** | **Total rainfall (mm)** | **Total infiltration (mm)** | **Impervious runoff (mm)** | **Pervious runoff (mm)** | **Total runoff (mm)** | **Total runoff (×106 L)** | **Peak runoff (m3/s)** | **Runoff coefficient** |
|---|---|---|---|---|---|---|---|---|
| S4 | 21158.75 | 8219.48 | 10580.5 | 2360.3 | 12940.81 | 315.76 | 0.19 | 0.612 |
| S5 | | 8280.44 | 10580.2 | 2299.23 | 12879.43 | ` | 0.24 | 0.609 |
| S8 | | 8210.17 | 10580.57 | 2369.64 | 12950.21 | 394.98 | 0.23 | 0.612 |
| S9 | | 8272.28 | 10580.23 | 2307.4 | 12887.63 | 278.37 | 0.17 | 0.609 |
| S10 | | 8225.07 | 10580.47 | 2354.7 | 12935.17 | 219.9 | 0.13 | 0.611 |
| S11 | | 8219.37 | 10580.51 | 2360.42 | 12940.92 | 394.7 | 0.23 | 0.612 |
| S12 | | 8250.9 | 10580.33 | 2328.82 | 12909.14 | 343.39 | 0.2 | 0.61 |
| S13 | | 8264.23 | 10580.26 | 2315.47 | 12895.73 | 322.4 | 0.19 | 0.609 |
| S22 | | 12317.37 | 5290.61 | 3552.33 | 8842.94 | 442.15 | 0.38 | 0.418 |
| S24 | | 8279.26 | 10580.2 | 2300.41 | 12880.61 | 1069.1 | 0.64 | 0.609 |
| S23 | | 8225.98 | 10580.46 | 2353.79 | 12934.25 | 355.69 | 0.21 | 0.611 |
| S25 | | 8238.27 | 10580.39 | 2341.47 | 12921.86 | 245.52 | 0.15 | 0.611 |
| S19 | | 8322.8 | 10580.07 | 2256.82 | 12836.89 | 611.04 | 0.37 | 0.607 |
| S26 | | 8315.03 | 10580.09 | 2264.6 | 12844.69 | 770.69 | 0.46 | 0.607 |
| S1 | | 8261.56 | 10580.28 | 2318.14 | 12898.42 | 863.81 | 0.51 | 0.61 |
| S2 | | 8267.53 | 10580.25 | 2312.16 | 12892.41 | 665.25 | 0.4 | 0.609 |
| S3 | | 8184.94 | 10580.78 | 2394.96 | 12975.75 | 140.4 | 0.08 | 0.613 |
| S7 | | 8259.46 | 10580.29 | 2320.24 | 12900.53 | 322.52 | 0.19 | 0.61 |
| S6 | | 8124.34 | 10581.5 | 2456.22 | 13037.72 | 146.02 | 0.09 | 0.616 |
| S16 | | 8252.83 | 10580.32 | 2326.88 | 12907.2 | 389.8 | 0.23 | 0.61 |
| S17 | | 8211.92 | 10580.56 | 2367.89 | 12948.45 | 349.61 | 0.21 | 0.612 |
| S15 | | 8321.85 | 10580.07 | 2257.77 | 12837.84 | 880.68 | 0.53 | 0.607 |
| S14 | | 8294.48 | 10580.15 | 2285.17 | 12865.32 | 1260.81 | 0.75 | 0.608 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| S18 | 8305.47 | 10580.12 | 2274.17 | 12854.29 | 812.4 | 0.49 | 0.608 |
| S20 | 8201.45 | 10580.64 | 2378.39 | 12959.03 | 176.24 | 0.1 | 0.612 |
| S21 | 8262.06 | 10580.27 | 2317.64 | 12897.91 | 299.23 | 0.18 | 0.61 |

Table 7 shows outfall discharge volumes for 10-year rainfall with improved imperviousness of 50% and an increase in slope is 2.5%. The total discharge volume for the existing condition is 12476.199×$10^6$ liter.

Table 7: Outfall discharges for 10-year rainfall with improved 50% imperviousness and 1.5% increase in slope

| Outfall Node | Flow frequency (%) | Average flow (m3/s) | Maximum flow (m3/s) | Total volume (×106 L) |
|---|---|---|---|---|
| O6 | 58.57 | 0.009 | 0.986 | 1568.39 |
| O3 | 53.57 | 0.006 | 0.725 | 1036.79 |
| O1 | 58.31 | 0.018 | 1.508 | 3328.407 |
| O2 | 55.86 | 0.011 | 1.123 | 1951.975 |
| O4 | 56.51 | 0.011 | 1.131 | 1961.983 |
| O5 | 52.11 | 0.007 | 0.782 | 1056.147 |
| O8 | 52.96 | 0.003 | 0.396 | 543.963 |
| O7 | 51.49 | 0.006 | 0.892 | 1028.544 |
| | | | Total = | 12476.199 |

Figure 3 shows the graph of outlet volume discharge reduced with improving measures. For 70% imperviousness with a normal slope, the outlet discharge is less than 1600 (106 L). The outlet discharge reduces to about 14000 (106 L) for 60% imperviousness with a 1.5% increased slope. At last, it becomes almost 12500 (106 L) for 50% imperviousness with a 2.5 % increased slope. Therefore this study also shows the outfall discharge volumes also decrease with decreasing imperviousness and increasing slopes. it is seen that the outfall discharge volume is reduced when the imperviousness is reduced and the slope is increased.

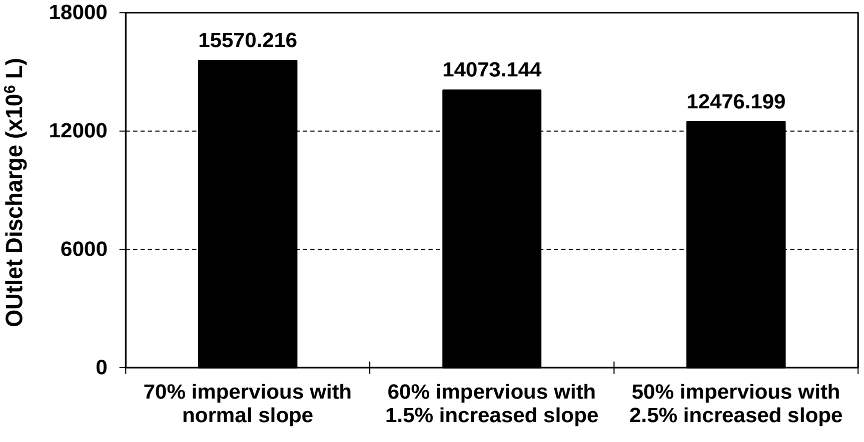

Figure 3: Reduction in the outlet discharges after applying the best management practices

Figure 4 shows the variation in runoff and infiltration for 10-year rainfall with three different scenarios of imperviousness and slopes. The infiltration loss and surface runoff are about 539 hectare-m in volume, 5400 mm in depth, and almost 1600 hectare-m, in volume and 15800 mm in depth respectively. For 60 % imperviousness and a 1.5% increase in slope, it reduces a little. Finally, for 50% imperviousness and a 2.5 % increase in slope, infiltration loss became about 833 hectare-m in volume and less than 8500 mm in depth. On the other hand, surface runoff became a little less than 1250 hectare-m in volume and almost 12600 mm in depth. As can be seen from the figure, the infiltration losses increase with the decrease of imperviousness and increase of slopes. At the same time, the surface runoff decreases with the reduction in imperviousness and increase of slopes. This implies that the implementation of the best management practices or nature-based solutions are highly effective to reduce water logging and helps in the effective stormwater management in the urban areas.

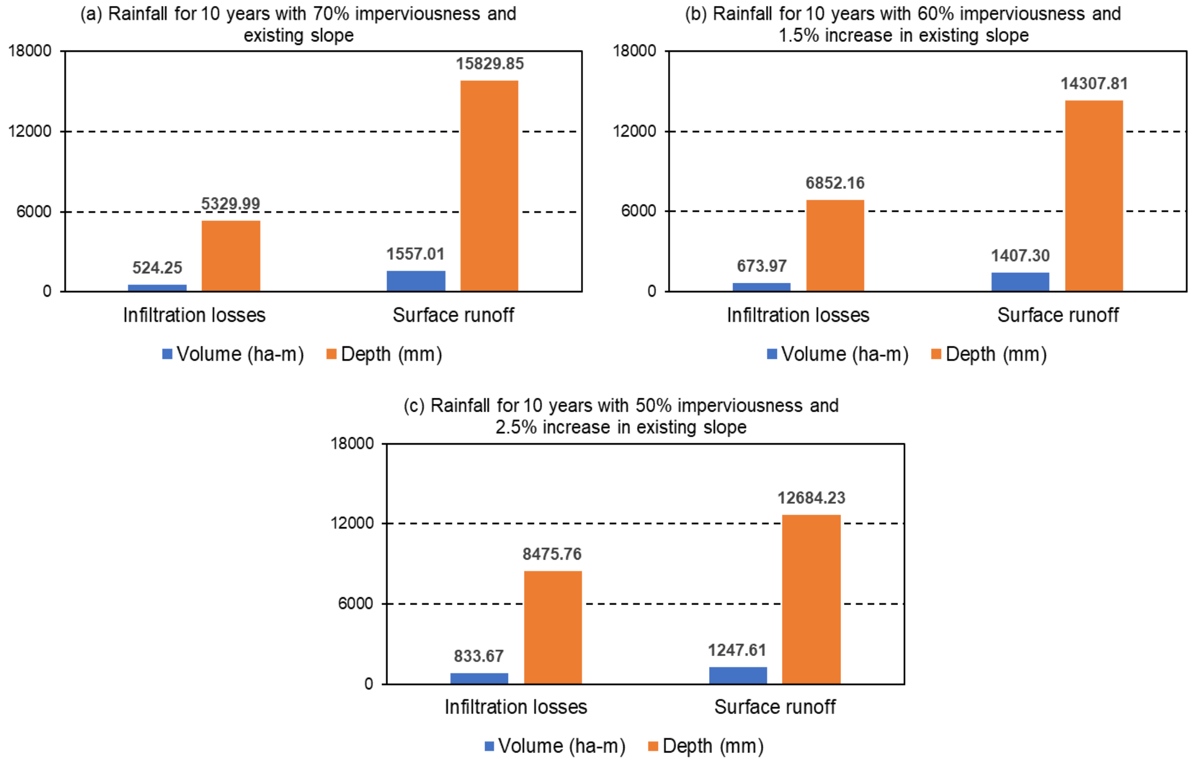

Figure 4: Variation in runoff and infiltration for 10-year rainfall with three different scenarios of imperviousness and slopes

## 4. CONCLUSIONS

Based on the findings of the current study, the following conclusions can be drawn:

- It is found that with a reduction in imperviousness of 60% and an increase in slope of 1.5%, the outlet discharge is reduced by almost 1.497*106 m3. It is also obtained in this study that with a decreased imperviousness of 50% and an increased slope of 2.5%, the outlet discharge volume is decreased by almost 3.094*106 m3. This happened as a result of the increased infiltration in the study area. This reveals that the best management practices, such as increasing infiltration and reducing imperviousness, are highly effective as a nature-based solution to minimize water logging in urban areas and sustainable stormwater management.
- The average infiltration loss for the existing condition is found to be 5329.993 mm, whereas for the proposed reduction of imperviousness, this loss is found to be 6852.159 mm. Hence, as imperviousness is decreased by 10%, the average infiltration is increased by about 1522.166 mm (in depth) and 1.872*106 m3 (in volume), and the runoff is decreased with the same values as infiltration.
- The study conclusively demonstrates the usefulness of various best management practices, including increasing slopes, reducing the roughness of the drainage systems, reducing imperviousness, and permitting more infiltrations, which are highly effective in controlling urban flooding or surcharges in urban areas caused by the occurrence of extreme rainfall.

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