



Evaluating the Effectiveness of Water Sensitive Urban Design (WSUD) Measures in reducing Runoff at the Water Institute in Dar es Salaam, Tanzania

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Received Date: 02/08/2025 // Published Date: 21/11/2025

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Abstract

Rapid urbanization in cities like Dar es Salaam has led to increased stormwater runoff due to expanding impervious surfaces and insufficient drainage systems. The Water Institute, one of the region's fastest-growing institutions, is also experiencing these pressures. This study investigates the effectiveness of Water Sensitive Urban Design (WSUD) measures such as bioretention ponds, rain gardens, rain barrels, and infiltration trenches at the Water Institute (WI) using the Storm Water Management Model (SWMM). A Digital Elevation Model (DEM) and ArcGIS 10.4 were used for topographic and hydrological analysis, while soil infiltration capacity was measured in the field using a Guelph permeameter, which indicated rates ranging from 1.6 to 14.9 mm/hr. Simulations revealed that combining multiple WSUD measures could reduce stormwater inflows into the drainage system by up to 68.2%, indicating substantial reduction in surface runoff volumes generated from impervious campus areas. These findings underscore WSUD's value in managing urban runoff, promoting sustainability, and highlight the need for broader application across the Dar es Salaam and other rapidly urbanizing cities.

Keywords · Nature based solutions; Water harvesting interventions; Stormwater runoff; SWMM model; Urban drainage.

1. Introduction

Water Sensitive Urban Design (WSUD) is a holistic approach to urban planning and stormwater management that integrates the water cycle into the built environment, aiming to minimize the impact of urbanization on natural water systems (Brown et al., 2009; Fletcher et al., 2015). It promotes sustainable practices such as bioretention systems, permeable pavements, detention and retention basins, green roofs, and rainwater harvesting to manage stormwater at its source (Lloyd et al., 2002; Mwamila et al., 2016;

Sharma et al., 2016; Siphambe et al., 2024a&b). WSUD is crucial in addressing urban challenges like flooding, water pollution, reduced groundwater recharge, and water scarcity, particularly in fast-growing cities like Dar es Salaam. The U.S. Environmental Protection Agency's Storm Water Management Model (EPA-SWMM) is an effective hydrological and hydraulic tool for simulating rainfall-runoff processes, testing various WSUD scenarios, and evaluating their performance under different conditions (Rossman, 2015; Rossman, 2022). Existing

hydrological conditions were assessed using GIS and DEM.

The urban area around the Water Institute faces increasing stormwater challenges due to rapid urbanization, insufficient drainage infrastructure, and high imperviousness, causing localized flooding and reduced water quality (Kombe & Kreibich, 2006). Traditional stormwater systems prioritize fast runoff conveyance without retention, infiltration, or reuse (Lwasa, 2010). Nature-based, decentralized stormwater solutions are rarely applied in Tanzanian urban areas and institutions like the Water Institute. WSUD can bridge this gap by offering adaptable, cost-effective interventions that promote sustainable water management, reduce flood risk, and enhance environmental resilience (Chikozho, 2010; Mbanaso et al., 2016). Yet, practical implementation and performance assessment of WSUD measures in Tanzanian institutions remain limited, highlighting the need for simulation-based research.

This study used EPA-SWMM to evaluate potential WSUD measure scenarios for runoff control at the Water Institute. The outcomes provide valuable insights for integrating WSUD at both campus and city levels (Makaya et al., 2021). Despite growing interest in sustainable urban drainage, Tanzanian research lacks empirical and simulation-based assessments of WSUD performance in cities and institutional settings. This study fills that gap by providing evidence on how WSUD interventions can mitigate runoff and enhance urban water management in the local context.

2.0 Materials and Methods

2.1 Description of the Study Area.

The Water Institute (WI) in Dar es Salaam, Tanzania, has undergone significant transformation since its inception in 1974. Originally established as the Rwegarulila Water Resources Institute (RWRI) under the Ministry of Water, it began with a modest intake of 30 students. In 2008, it was restructured into an Executive Agency and renamed the Water Development and Management Institute (WDMI). By

2016, it adopted its current name, the Water Institute, reflecting its expanded mandate. As of 2025, the Institute has trained approximately 3,867 students across various programs. WI's capacity has grown to include three campuses: the main Ubungu campus in Dar es Salaam, Singida campus, and the Ngurdoto Research Center in Arusha. The Institute offers a diverse range of programs, including over twelve Ordinary Diploma courses, nine Bachelor's degree programs, and four Master's degree courses. Additionally, WI provides more than fifty short courses tailored to the water sector, covering areas such as water supply, resources planning, design, procurement, laws, and management. These offerings cater to both technicians and engineers, addressing the professional gap in Tanzania's water sector. Geographically, the Water Institute (WI) is located in Ubungu, Dar es Salaam, Tanzania, approximately at coordinates 6°48'S, 39°15'E. The Ubungu campus covers an area of 40.6 hectares, featuring a varied landscape that includes paved areas, plains, bare land, and the Sinza River. The campus land use is a mix of institutional buildings, residential facilities for students, open green spaces, and limited recreational areas. Institutional areas include classrooms, laboratories, and administrative buildings, while residential zones mainly comprise student hostels. Open spaces and landscaped areas serve both aesthetic and functional purposes, such as stormwater infiltration and recreational activities. The region is characterized by a tropical climate with average temperatures ranging between 23°C and 32°C, which contributes to high evaporation rates from both open water and surface runoff (Rossman, 2022).

2.2. Sub-catchment Characteristics

Determination of sub-catchment characteristics which included sub-catchment areas, widths, average slopes, land use/land cover maps, percentage imperviousness and Curve numbers (CN) started with the collection of spatial datasets, including a high-resolution Digital Elevation Model (DEM) sourced from <https://opentopography.org/> (entity ID:

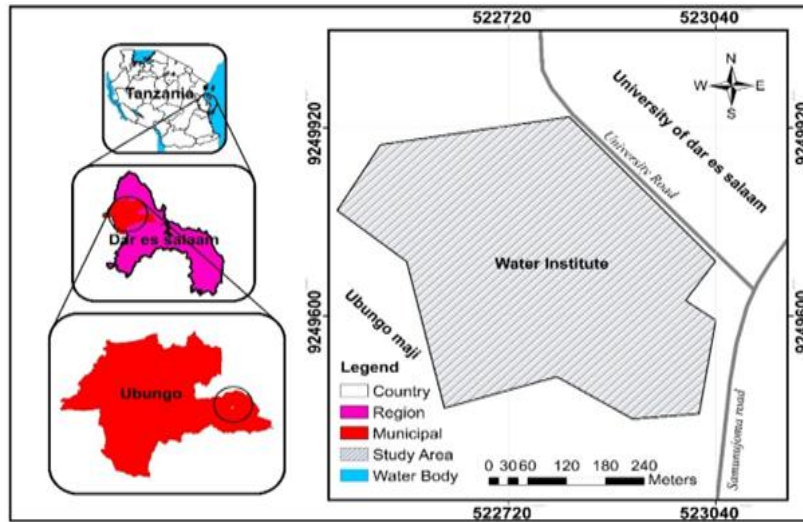


Figure 1: Study Area (Water Institute Dar es Salaam, Tanzania)

rt1676707346732, dataset: COP30) at a spatial resolution of 30×30 m. The ArcGIS tools was used to delineate sub-catchment areas, widths, average slopes, land use/land cover, percentage imperviousness as it shown in Table 1. The land use/land cover of the study area and USDA Hydrologic Soil Group (HSG) classified the soils within the Catchment into Hydrologic Soil Group B and C, and were used to assign the Curve Numbers (CN) for each sub-catchment using the USDA SCS-CN method. This step provides a spatially explicit understanding of runoff generation zones, aiding in accurate model parameterization (Zhan et al., 2014). DEM analysis helps determine natural flow paths and ponding areas, which are critical for siting WSUD interventions.

2.3 Determination of Infiltration Rate (Kf).

The Soil infiltration rate (Kf) is the property of water by which it moves through the soil particles, it's also known as hydraulic conductivity. This is essential parameter for evaluating sub-catchment topographic index values and in selecting a particular WSUD for implementation (Warganda & Sutjningsih, 2017). The field Kf was tested using a Guelph permeameter device (Model 2800K1) while the Hand auger Instrument was used for soil sampling during the wet season of the year 2025. This device was chosen because is easy to use, quickly and accurately measuring the in-situ hydraulic conductivity of soils (Swilla and Lingwanda, 2023). The basic formula for calculating the infiltration rate (Kf) using a Guelph Permeameter (Model 2800K1) is derived from saturated hydraulic conductivity and is based on steady-state flow from a cylindrical well bore as shown in equation 2.1:

$$K_f = \frac{Q}{C + \alpha H} \dots \dots \dots (2.1)$$

Where:

Kf = Saturated hydraulic conductivity or infiltration rate (cm/s or mm/hr.);

Q = Steady-state flow rate into the borehole (cm³/s or cm³/hr.);

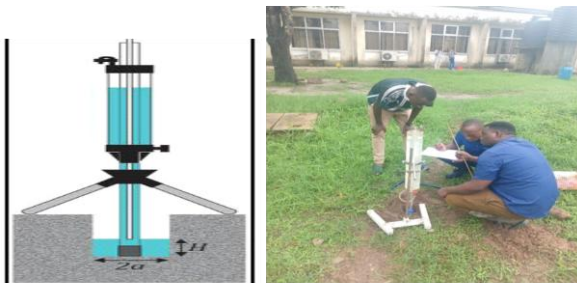


Figure 2: Field Guelph Permeameter Setup

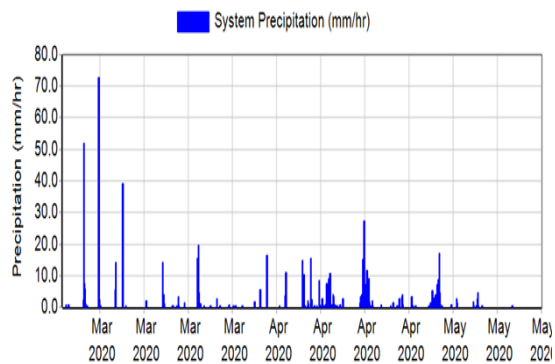


Figure 3: Time series for the Rainfall data events/system precipitation

H = Constant height of water maintained in the well above the borehole bottom (cm);

C = Shape factor, which depends on borehole radius and soil geometry (cm); and

α = Soil-specific factor related to sorptivity and capillarity (cm^{-1}).

In practice, measurements at two different heads (H_1 and H_2) are often taken, and corresponding flow rates (Q_1 and Q_2) are used to solve for both K_f and α using simultaneous equations. The method accounts for three-dimensional flow and is suitable for field determination of infiltration in unsaturated soils.

The average infiltration rate was determined for the sub-catchments. In figure 2 the Soil samples were collected from each borehole at a depth of 1.0 m and their particle size distributions analyzed (sieve analysis) were performed in the laboratory.

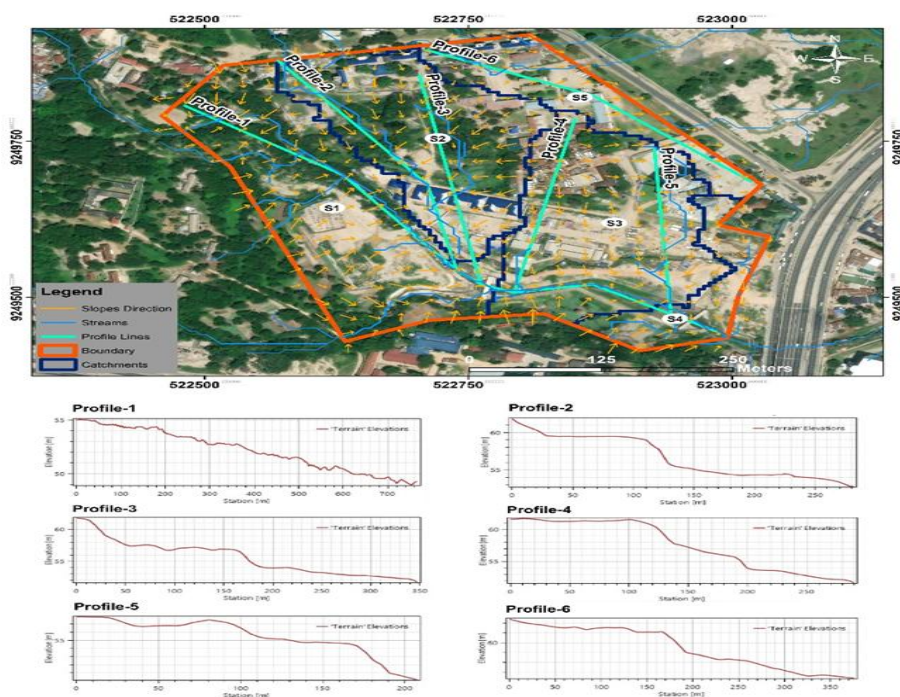


Figure 5: Sub catchment and Slope Profile Delineation

2.4 Rainfall Data

The historical recorded hourly rainfall data from 2009 to 2022 collected from the Wami/Ruvu Basin Water Board Office. The rainfall data were from a gauging station registered with ID TA00270, data logger ID 06-00708, latitude 516410 and longitude 9244500 located at Kinyerezi Primary School in Dar es Salaam City. The uploaded rainfall data were hourly precipitation patterns critical for simulating runoff in SWMM. It shows variable intensities, typical of tropical climates in Dar es Salaam especially the year with higher rainfall 2020 were used to the model because it likely represented typical or extreme hydrological conditions relevant for the study objectives. Using a single year simplifies model calibration and simulation, reducing computational complexity while still capturing realistic runoff patterns (Tan et al., 2008). The year 2020 recorded the highest average annual rainfall among the years 2009–2022. Although the overall mean rainfall for all years was lower than the maximum average recorded in 2020, this year was considered critical for assessing the maximum potential impacts of stormwater and Water-Sensitive Urban Design (WSUD) measures. Urban design (WSUD) measures. This variability is essential for assessing the performance of WSUD interventions under different rainfall conditions. The dataset provides the temporal distribution necessary for modeling peak flows and runoff volume. Figure 3

2.5 Water Sensitive Urban Design (WSUD) Measure Types.

Water Sensitive Urban Design (WSUD) measures manage stormwater by mimicking natural hydrological processes. Bioretention ponds, rain gardens, infiltration trenches, and detention basins collect and temporarily store runoff, enhancing pollutant removal and attenuating peak flows, and can perform effectively even on low-infiltration soils (7–20 mm/hr), typically found in HSG B and C soils (Davis, 2007; Hatt et al., 2009). Rain barrels harvest roof runoff for reuse and runoff control. Vegetated swales convey and treat runoff along channels, performing well on

moderate soils (HSG B–C). Permeable pavements allow water to infiltrate underlying layers, favoring higher infiltration soils (HSG A–B). Green roofs retain rainfall on rooftops for evapotranspiration,

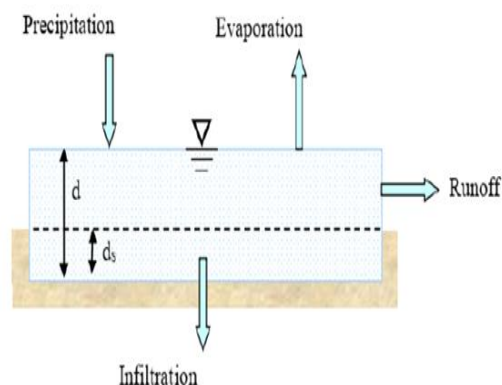


Figure 4: Nonlinear reservoir model of a sub-catchment (Rossman, 2022)

independent of ground soil but requiring engineered media. These WSUD measures collectively enhance runoff management, groundwater recharge, and urban flood mitigation (Fletcher et al., 2015).

2.6 EPA-SWMM Model

The Storm Water Management Model (SWMM) was first developed by the United States Environmental Protection Agency (US EPA) in 1971 for simulating stormwater runoff in urban areas. The current version of EPA SWMM 5.2, is considered as one of the best models for simulating urban rainfall-runoff quantities (Rossman, 2022).

The EPA SWMM 5.2 routing component transports runoff through either pipes, channels, storage units or pumps with regulators. During simulations, the model tracks the runoff quantity in each sub-catchments, pipes and channels (Rossman, 2022). The EPA SWMM 5.2 model conceptualizes the catchment to be a rectangular surface with a uniform slope (S) and width (W) that drains into a single outlet channel and considers the sub-catchment as a nonlinear reservoir, as shown in Figure 4. The excess runoff above the depression storage (ds) becomes runoff outflow when the sub-catchment (d) and the depression storage

(ds) is considered as the surface ponding, vegetation, interception by flat roofs, and surface wetting (Rossman and Simon 2022). The model uses the Manning equation 2.2 in quantifying the runoff flow rate.

infiltration data. The outputs of the model simulations include total flows and flow volumes, infiltration runoff, evaporations and water depths (Rossman, 2022).

3.0 Results and Discussion

Table 1: Characteristics of the WI sub-catchments

Sub-Catchment	Area (ha)	Width (m)	Average slope (%)	% Imperviousness	CN (curve number)
S1	7.9	59	4.88	45.18	80
S2	5.4	25	3.11	10.4	80
S3	4	31	4.55	10.9	80
S4	1.97	39	2.74	28.71	80
S5	1.6	24	3.51	8.42	80

$$q = \frac{1.49WS^{1/2} \times (d-d_s)^{5/3}}{An} \quad \dots\dots\dots (2.2)$$

Where: W = width of the sub-catchment, S = sub-catchment slope, A = area of the sub-catchment, n = Manning's surface roughness coefficient, ds = depression storage and d = ponded depth

The inputs of the SWMM includes the sub-catchment characteristics (catchment areas, sub-catchment width, percentage impervious, average slope gradient and main outlets), rainfall data and soil

3.1 Digital Elevation Model (DEM) Analysis.

The sub-catchments were named S1 to S5, whereas the sub-catchment areas range from 1.60 ha to 7.92 ha with S1 being the largest sub-catchment while the S5 being the smallest with average catchment width ranging from 23.72 m to 58.61 m (Figure 5). GIS-based analysis of the Digital Elevation Model (DEM) revealed that the study area consists of low to moderately sloping terrain, with slopes: flat (0–1%), gentle (1–5%), undulating (5–10%), rolling (10–15%),

Table 2: Soil Properties and Infiltration Rates at sampling locations within the Water Institute Catchment.

B/H	Depth(m)	Clay/silt (%)	Sand (%)	Gravel (%)	Water Table(m)	Infiltration Rate(mm/h)
BH 1	0.7-1.0	20.88	79.04	0	No	14.9
BH2	0.7-1.0	19.95	80.05	0	No	14.9
BH3	0.7-1.0	26.67	73.33	0	No	12.7
BH4	0.7-1.0	28.58	71.3	0.13	0.8	5.91
BH5	0.7-1.0	20.87	78.14	1	0.8	4.96
BH6	0.7-1.0	17.13	82.88	0	0.63	4.86
BH7	0.7-1.0	20.57	61.73	17.7	No	1.6
BH8	0.7-1.0	23.36	68.66	7.99	No	2.98
Average infiltration rate (by arithmetic mean (average) method) =						7.9

and steep ($>15\%$), averaging from 0.5% to 4.88% as it seen on slope profile 1 to profile 6 and table 1. Imperviousness was estimated at approximately 45%, primarily due to built-up areas (roofs, roads, pavements), and is expected to increase in the future.

The Water Institute (WI) catchment was assigned a composite Curve Number (CN) of 80 to represent its overall runoff potential. This value reflected the mixed characteristics of the campus, which included approximately 45% impervious surfaces (buildings, pavements, and roads) and areas of vegetated and bare

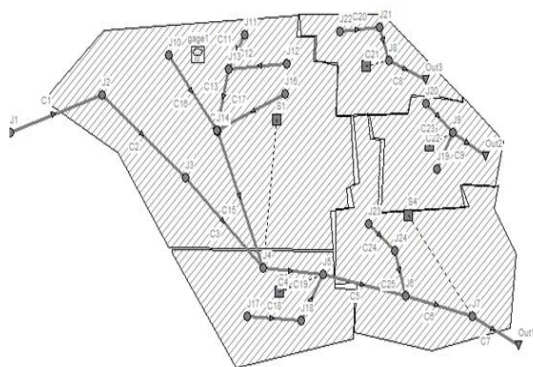


Figure 6: Rainfall runoff prediction model for the water institute (Figure by author based on EPA-SWMM).

soil under Hydrologic Soil Groups B, C, and D, as determined from field infiltration tests (1.6–14.9 mm/hr using a Guelph permeameter). According to the USDA SCS-CN method, impervious areas typically had CN values near 98, grassed areas on HSG B soils ranged from 61–74, grassed areas on HSG C soils ranged from 73–86, and soils on HSG D (very low infiltration, clay) ranged from 78–98 (USDA, 1986; Chow et al., 1988). An area-weighted average of these CN values across the 40.6-hectare campus resulted in a composite CN of approximately 80, which accurately represented the catchment's moderate runoff potential under typical hydrologic conditions (Table 1).

3.2 Soil Infiltration Rate Capacity Values and Soil Properties.

The infiltration rates measured across the eight locations at the Water Institute catchment varied from 1.6 mm/h to 14.9 mm/h, reflecting the diversity of soil textures and subsurface conditions. Higher rates (12.5–14.9 mm/h) were observed in sandy soils with low clay content (BH1–BH3), indicating moderate percolation capacity (HSG B), while lower rates (1.6–2.76 mm/h) corresponded to soils with higher clay or silt fractions and shallow water tables (BH4–BH8), which were classified as very low infiltration soils (HSG D) table 2. These results were consistent with previous studies: Hawley (2003) reported infiltration rates of 1.5–15 mm/h for sandy loam and clay loam soils, while Wu et al. (2007) measured urban soil infiltration rates of 2–14 mm/h under variable clay content. The results demonstrated that infiltration capacity was strongly influenced by both soil texture and groundwater proximity, which had to be considered when designing WSUD measures for runoff management.

3.3 EPA SWMM Model Simulation

The catchment characteristics (area, slope, imperviousness), rainfall events data, and soil infiltration parameters in form of Curve Number were used to set a rainfall runoff simulation model (Figure 6).

The EPA-SWMM simulation revealed that Outfall 1, which drains sub-catchments S1 to S3, recorded the highest peak flow of 1.946 m³/s and a total volume of 92.859 million liters per whole rainfall season in a year, indicating the inadequacy of the existing drainage infrastructure to handle intense, short-duration storms. The rapid runoff response suggests a lack of sufficient on-site retention or detention capacity, limiting opportunities for infiltration and increasing flood risk. Compared to Outfall 2 (0.274 m³/s) and Outfall 3 (0.265 m³/s) (figure 6). The Outfall 1 is significantly higher discharge highlights the impact of impervious surfaces and insufficient stormwater controls. These findings align with previous studies that found urban

areas with greater impervious cover and limited retention features produce higher peak flows and require targeted Water Sensitive Urban Design (WSUD) retrofits to improve hydrological

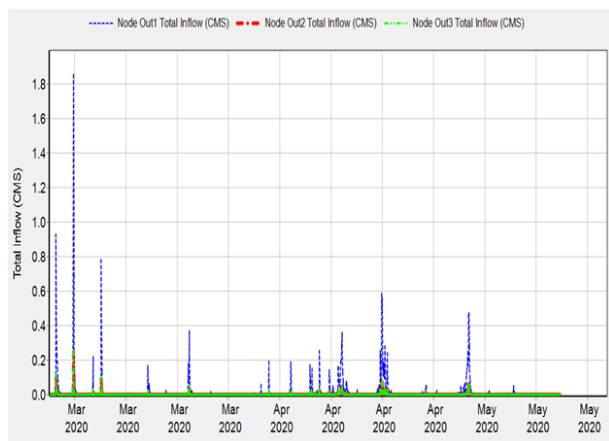


Figure 7: Simulation Model Total inflow at the three outfall nodes without WSUD interventions performance and reduce flooding (Walsh et al., 2005; Dietz, 2007; Roy et al., 2008; Lee et al., 2012; Fletcher et al., 2013).

3.3.1 EPA SWMM Model Time Series Simulation Without Measure Types

Total inflow at the three outfall nodes (Out1, Out2, and Out3) between March and May 2020 revealed significant variations in runoff behavior across the study area, with Figure 7 illustrating these patterns during the peak rainfall period. Node Out1 recorded the highest and most frequent inflow peaks, reaching up to 1.946 m³/s (168,038.4 m³/day) in early March, indicating intense and rapid runoff likely due to the absence of Water Sensitive Urban Design (WSUD) interventions. Similar peak flows were observed in urban catchments without WSUD measures, such as 2.1 m³/s (181,440 m³/day) reported by Brabec et al. (2002) and 1.9 m³/s (164,160 m³/day) noted by Rosa et al. (2015). In contrast, Node Out2 showed significantly lower and less frequent inflow peaks, not exceeding 0.27 m³/s (23,328 m³/day), suggesting improved infiltration and reduced imperviousness. These trends are consistent with observations by Barbosa et al.

(2012) and Walsh et al. (2005), who reported runoff between 0.25–0.4 m³/s (21,600–34,560 m³/day) in less urbanized or treated sub-catchments. Node Out3 displayed moderate inflow peaks, with a maximum of 0.26 m³/s (22,464 m³/day), pointing to partial impervious coverage and lack of stormwater control. These findings align with values reported by Shuster et al. (2005) and Emerson et al. (2005), who documented peak flows of 0.28–0.3 m³/s (24,192–25,920 m³/day) in suburban environments without green infrastructure.

3.3.2 WSUD interventions Parameters to the SWMM model

Parameters for WSUD systems adhering to standard design practices. Soil layers in bioretention ponds, rain gardens, and infiltration trenches had high porosity (0.5) and conductivity (60 mm/h), promoting infiltration, as changes in porosity and conductivity strongly influence infiltration and storage performance. Lower values lead to reduced runoff reduction, while higher values enhance the effectiveness of bioretention ponds and rain gardens. (Hatt et al., 2009). Underdrains with 0.5 flow coefficient and 300 mm offsets enhanced drainage control (Davis et al., 2009). Rain barrels featured a 3250 mm storage height and 6-hour drain delay to mimic delayed discharge (table 3). These configurations support optimal stormwater retention and runoff reduction.

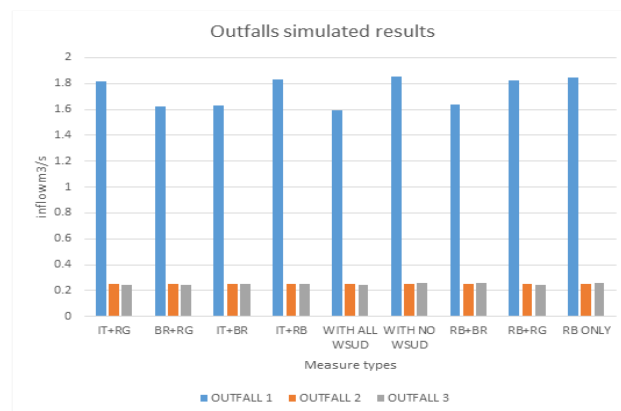


Figure 8: WSUD interventions simulated Results

Table 3: Parameters for bioretention ponds, rain gardens, infiltration trenches, and rain barrels

Layers	Parameters	Bioretention pond	Rain garden	Rain barrel	Infiltration trenches
Surface	Berm height/depth of water (mm)	300	300	-	300
	Vegetative fraction (volume)	0.1	0.1	-	0.1
	Surface roughness (Manning n)	0	0	-	0.1
	Surface slope (%)	0	0	-	-
Soil	Thickness (mm)	600	600	-	-
	Porosity (volume fraction)	0.5	0.5	-	-
	Field capacity (volume fraction)	0.2	0.2	-	-
	Wilting point (volume fraction)	0.1	0.1	-	-
	Conductivity (mm/h)	60	60	-	-
	Conductivity slope	10	10	-	-
	Suction head (mm)	25	5	-	-
	Thickness (mm)	300	-	-	600
Storage	Void ratio (voids/solids)	0.6	-	-	0.6
	Clogging factor	0	-	-	0
	Seepage rate (mm/h)	7.9	7.9	-	7.9
	Flow coefficient	0.5	-	0.5	0.5
Underdrain	Flow exponent	0.5	-	0.5	0.5
	Offset height (mm)	300	-	300	300
Drainage	Barrel height (mm)	-	-	3250	-
	Drain delay (hours)	-	-	6	-

Additionally, in S1, a total of 4 rain barrels (33.2 m² each), 6 raingardens (70 m² each), 3 infiltration trenches (30 m² each), and 1 large bio-retention pond (2,800 m²) were Simulated. S2 included 3 rain barrels, 5 raingardens, and 2 infiltration trenches covering 18 m². S3 featured 3 rain barrels, 3 raingardens, and 1 infiltration trench (24 m²). In S4 and S5, each had 1 rain barrel, 1 raingarden, and 1 infiltration trench of 30 m² and 24 m² respectively (figure 5). Likewise, Huang

et al. (2020) reported surface runoff reduction over 2200 m² using permeable pavements and infiltration trenches in commercial zones.

3.3.3 WSUD Interventions Simulation Analysis.

The simulation of WSUD measures Rain Garden (RG), Bioretention Pond (BR), Rain Barrels (RB) and Infiltration trenches (IT) using EPA-SWMM in Figure 8 revealed significant runoff reduction impacts across

various outfalls. Outfall 1 showed the greatest improvement under combined interventions, reducing peak flow from 1.8572 m³/s to 1.59 m³/s, while Rain Barrels alone had minimal impact (1.8474 m³/s). At Outfall 2, runoff remained unchanged (0.25 m³/s), indicating effective natural infiltration and limited impervious surfaces. Outfall 3 demonstrated notable reductions, with combined WSUD reducing flow from 0.2586 m³/s to 0.2407 m³/s. Combinations such as IT+RG and BR+RG were more effective than RB alone, highlighting the importance of integrated systems. Site-specific characteristics like soil composition and surface cover influenced the performance outcomes. Literature supports these findings: Dietz (2007) showed runoff reductions of 0.28 to 0.05 m³/s using LID practices. Similarly, Liu et al. (2014) reported a decrease from 0.31 to 0.12 m³/s with bio-retention. Fletcher et al. (2015) emphasized design integration. Additionally, Burns et al. (2012) observed a flow drop from 0.45 to 0.18 m³/s using permeable pavements. Jeong et al. (2018) recorded

3.4 Outfall and Sub catchment Loading (without and with WSUD Interventions).

Runoff was significantly reduced after the implementation of WSUD interventions. At Outfall 1, the maximum flow decreased from 1.946 m³/s to 0.661 m³/s, a reduction of approximately 66%, while the total runoff volume dropped from 92.859 to 68.849 million liters, representing a 25.9% decrease (table 4). In Sub-catchment S1, total runoff reduced from 648.44 mm to 521.49 mm, a reduction of about 19.6%, and peak runoff decreased from 1.17 to 0.42 m³/s, a 64.1% drop. Across all sub-catchments, similar patterns were observed with runoff coefficients also falling, confirming that WSUD interventions effectively reduced both the volume and intensity of runoff by 20% to 68%, depending on the parameter measured (table 5). Similar results have been reported in previous studies, where WSUD or Low Impact Development (LID) strategies, such as bioretention, rain gardens, and infiltration systems, led to runoff volume reductions of

Table 4: Outfall loadings

Outfall simulation with no WSUD measures				
Outfall Node	Flow Frequency %	Average flow, (m ³ /s)	Maximum Flow (m ³ /s)	Total volume (10 ⁶ ltr)
Out1	92.15	0.016	1.946	92.859
Out2	51.14	0.003	0.258	10.749
Out3	53.7	0.003	0.265	11.609
Outfall simulation with all WSUD measures				
Out1	68.34	0.01	0.661	68.849
Out2	41.02	0.001	0.156	6.68
Out3	42.02	0.001	0.146	6.832

reductions from 0.35 to 0.21 m³/s using green roofs and swales. When tested individually Rain Gardens (RG) were the most effective in reducing runoff through infiltration. These results were consistent with previous findings on WSUD effectiveness (Hatt et al., 2009; Davis et al., 2009).

20–70% and peak flow reductions of 30–80% (Dietz, 2007; Liu et al., 2014; Fletcher et al., 2015; Chui et al., 2016; Eckart et al., 2017).

Comparison the Pre and Post WSUD

57.11% inflow cut and 42.89% outflow, in contrast to

Table 5: Sub catchment loadings

Sub Catchment simulation with no WSUD measures										
Sub catchment ltr)	Total Precip(mm)			Total Runon(mm)			Total Evap(mm)			Total infil (mm)
	Imperv	Runoff(mm)	Peak Runoff((m3/s)	Perv	Runoff(mm)	Runoff coefficient	Total Runoff(mm)		Total Runoff(10^6	
S1	849.8	0	0	218.74	362.19	286.25	648.44	51.23	1.17	0.763
S2	849.8	0	0	280.79	215.16	368.16	583.31	11.49	0.27	0.686
S3	849.8	0	0	332.47	92.98	439.68	532.67	10.65	0.26	0.627
S4	849.8	0	0	280.96	216.95	363.93	580.88	31.37	0.63	0.684
S5	849.8	0	0	278.57	214.21	372.63	586.85	9.39	0.24	0.691
Sub Catchment simulation with WSUD measures										
S1	849.8	0	0	472.51	246.99	274.5	521.49	28.41	0.42	0.614
S2	849.8	0	0	415.55	110.52	360.5	471.02	8.72	0.16	0.554
S3	849.8	0	0	384.16	42.72	438.45	481.17	8.59	0.15	0.566
S4	849.8	0	0	390.24	116.4	363.84	480.24	10.73	0.22	0.565
S5	849.8	0	0	394.8	112.5	369.72	482.22	5.08	0.12	0.567

3.5 Evaluation of the Effectiveness of WSUD Measures Using EPA-SWMM

The evaluation of the effectiveness of WSUD measures justified by comparison the pre- and post-WSUD interventions at all three outfalls demonstrates significant improvements in managing stormwater (figure 9). At Outfall 1, WSUD measures reduced inflow by 68.17%, lowering outflow to 31.83%, compared to only 24.24% inflow reduction and 75.76% outflow without WSUD, aligning with Brabec et al. (2002), who reported over 60% flow control using LID. Outfall 2 showed inflow of 59.89% and outflow at 40.11% with WSUD, while without WSUD, the reduction was just 40.50% with a higher outflow of 59.50%, comparable to findings by Fletcher et al. (2015), who recorded 55–65% reduction using integrated green systems. At Outfall 3, WSUD led to a

39.20% inflow and 60.80% outflow pre-intervention values similar to those reported by Liu et al. (2014), where bioretention reduced runoff by up to 58%.

Overall, the combined inflow reduction across all outfalls improved from 34.65% without WSUD to 61.06% with WSUD, and outflow decreased from 65.35% to 38.94%, confirming that WSUD strategies substantially enhance hydrological response. These findings are consistent with Dietz (2007), who observed runoff volume reductions ranging from 20% to 70% and peak flow reductions of 30% to 80% with LID practices, and Chui et al. (2016), who reported integrated WSUD interventions reducing runoff volume and peak discharge by 55% to 65% in urban sub-catchments.

4.0 Conclusion and Recommendations

This study evaluated the effectiveness of Water Sensitive Urban Design (WSUD) measures in reducing runoff at the Water Institute in Dar es Salaam, Tanzania using the SWMM model. The assessment and simulation results demonstrated that the Water Institute campus is highly susceptible to stormwater runoff due to its 45% impervious area and moderate infiltration capacity ranging between 1.6 mm/hr and 14.9 mm/hr. Baseline modeling confirmed rapid, high-volume runoff during storm events, highlighting the inadequacy of existing drainage infrastructure. Integration of WSUD measures, particularly when combined, achieved the highest inflow reduction of 68.17%, lowering inflow to 31.83%. Additionally, combined inflow reduction across all outfalls improved from 34.65% without WSUD to 61.06% with WSUD, and outflow decreased from 65.35% to 38.94%, confirming the effectiveness of WSUD in improving hydrological responses, mitigating flood risks, and enhancing water sustainability. Therefore, adopting a mix of bioretention systems, infiltration trenches, rain gardens, and rain barrels presents a viable and context-appropriate solution for managing stormwater at the Water Institute. Further studies at city-wide scale are necessary to strengthen urban-level applicability. Finally, for successful long-term implementation, it is critical to address knowledge gaps on resilience under extreme rainfall and social acceptance. The Water Institute and local urban authorities should support research to evaluate lifecycle costs, integrate WSUD with grey infrastructure, and develop context-specific design guidelines.

Acknowledgements

The author acknowledges the partial financial support to accomplish this task obtained from the Masheku Sadima family and RUWASA Mara Region Office.

Conflict of interest

The authors declare there is no conflict.

Data availability

All relevant data are included in the paper or its Supplementary Information.

Author Contributions:

MMS: Content outlining, Conceptualization, Analysis, Writing - original draft, Writing – review and editing; T.B.M: Conceptualization, Writing – review and editing, Visualization, Supervision; and W.D: Writing – review and editing, Visualization, Supervision. All authors have read and agreed to the published version of the manuscript.

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