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Original Article

Triple Bottom Line Benefits of Implementing Green Infrastructure for Runoff Management

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Abstract *- Urbanization and climate change are intensifying challenges in urban water management, including increased flood risks, reduced water quality, sewer overflows, and exacerbated urban heat island effects. Green Infrastructure (GI) provides a sustainable alternative to traditional gray infrastructure by managing stormwater on-site through natural processes, which mitigates surface runoff and improves environmental conditions. This study evaluates the effectiveness of GI in a 12.7-hectare cluster in Dubai Land, UAE, an area comprising residential zones, open spaces, and local roads. Two scenarios were modeled: a traditional gray infrastructure system with pipes, manholes, and gullies and a GI system integrating Green Roofs (GR), Rain Gardens (RG), Pervious Pavements (PP), and grassed side ditches. The study shows that GI reduces runoff by 79% with 50% GR coverage and pervious asphalt for roads and by 68% with 25% GR coverage compared to conventional concrete and asphalt surfaces. Specific metrics-including runoff volume reduction, cost efficiency, groundwater recharge, and urban cooling potential-were used to assess GI's performance. Economically, GI reduces the need for extensive gray infrastructure, with 60% GR coverage achieving costs similar to conventional systems but with improved runoff reduction. GI implementations covering 50% and 30% of roof areas yield 10% and 37% cost savings, respectively. Environmentally, GI lowers flood risks, enhances groundwater recharge, and improves water quality. Socially, GI fosters better air quality, recreational spaces, climate resilience, and public health.*

This study underscores the value of incorporating these triple bottom line (TBL) benefits into urban planning, illustrating GI's role in immediate stormwater management and the long-term sustainability of rapidly urbanizing regions.

Keywords *- Sustainable water system, Green roofs, Pervious pavement, Raingarden, Gray infrastructure.*

1. Introduction

The eyes of the world are now turning towards designing sustainable cities, and cities can adapt to climate change. Facing extreme weather events and rapid urban growth that have led to the overuse of natural resources and creating environmental degradation, cities are concerned with how to design the whole city in a more sustainable, efficient, adaptive, and resilient way. A significant research gap exists in identifying and implementing alternative urban design approaches that enhance resilience while supporting natural hydrological processes. Specifically, there is a need to examine how GI, which mimics natural processes to manage stormwater at the source, is a viable, sustainable solution. Unlike gray infrastructure, GI solutions such as GRs, PP, RGs, and vegetated swales work to absorb water where it falls, reducing surface runoff, improving water quality, and supporting biodiversity.

This study addresses this gap by evaluating the impact of GI on stormwater management in a 12.7-hectare cluster in Dubai Land, UAE. By comparing a traditional gray infrastructure model to a GI-based model, this research aims to assess how GI can reduce runoff, mitigate flooding risks, and deliver economic, environmental, and social benefits, thus offering a sustainable alternative to conventional urban water management practices.

Blue-Green City calls for the holistic planning and management of water, wastewater, and stormwater across the whole city to ensure that populations are resilient to climate change and extreme weather events while ensuring the health of the aquatic ecosystem [16].

In a Blue-Green City, Blue-Green Infrastructure involves the use of natural or man-made systems to enhance ecosystem service in the management of water resources and increase resilience to climate risks [12]. Traditionally, urban water managers have relied on gray infrastructural solutions to mitigate the flood risk with numerous environmental and economic consequences.

For instance, traditional stormwater drainage systems, which are designed to prevent localized flooding, have created downstream flooding risks as well as stormwater overflows into waterways due to insufficient pipe systems to deal with severe events or successive events and cause other issues like changes in the local hydraulic cycle as the main purpose of the gray system is to collect rainwater as fast as possible and dispose of it through pipe system underground resulting in a decrease in the evaporation, evapotranspiration rate, and less groundwater recharge causing a change in local hydraulic cycle, also the traditional system can cause poor visual quality due to potential flooding in traditional systems and it becomes a problem in itself, also causes thermal pollution in the cause of moving this water to the nearest waterway due to the difference in waterway temperature and transmitted stormwater Which may harm some living aquatic organisms and also move pollutants to the nearest waterway, When stormwater, often heated by the sun as it flows over impervious urban surfaces like asphalt and concrete, is directed into nearby water bodies, it can raise the water temperature of those waterways. This sudden influx of warmer water disrupts the natural thermal balance of the ecosystem. Aquatic organisms, such as fish, insects, and plants, are adapted to specific temperature ranges; even small fluctuations can have harmful effects. Higher water temperatures can reduce dissolved oxygen levels, making it harder for aquatic species to breathe. Warmer waters also accelerate metabolic rates in organisms, leading to increased stress, reduced growth, and impaired reproduction. In extreme cases, thermal pollution can cause some species to die off if temperatures exceed their tolerance levels.

Moreover, elevated temperatures can encourage the growth of harmful algae blooms, which deplete oxygen in the water, further harming aquatic life. Therefore, the temperature difference between stormwater and natural waterways, when transferred through traditional systems, can create a hostile environment for many aquatic species, ultimately disrupting the health and balance of the ecosystem.

Over the last decades, rapid urban- and suburbanization has deteriorated natural landscapes that absorb excess water and significantly increased impervious surface area that causes stormwater runoff [12].

Due to urbanization and sprawling development, the issues of stormwater have increased with the increase of impervious surfaces, which in turn eliminates or reduces the ability of soil to percolate water, leading to the deterioration of the natural cycle of infiltration that leads to an increased volume of surface runoff.

On the other side, climate change has subjected communities worldwide to more frequent erratic and severe weather patterns that bring unprecedented stormwater surges [4, 15].

Most stormwater management focuses on water quantity. On the other hand, another issue has been ignored or has not received enough attention: water quality, which is the higher rate of pollutants that travel to the nearest waterway due to urbanization via stormwater runoff. So, a solution had to be found to mitigate the bad effect of stormwater runoff as gray infrastructure" Positive systems" are designed to avoid flooding by carrying stormwater away from cities; therefore, other alternatives had to be found, so attention was turned to GI.

GI incorporates nature to absorb water where it falls so it may be reused throughout the natural hydrologic cycle. GI mimics nature and restores nature to its original phase. It also can play its role in mitigation individually or combined with gray infrastructure to maximize the benefits of two systems.

GI is a promising alternative to current strategies as not only traditional stormwater management methods are structurally inefficient, but they also place an enormous economic burden on cities through costs of maintenance and extending infrastructure to sprawling areas as well as resulting flood damage and the case of these increment in stormwater are urbanization and climate change [10].

Low Impact Development (LID) is used in the US and Canada to describe an eco-friendly land planning and design approach to stormwater management. In the United Kingdom, this approach is called Sustainable Urban Drainage Systems (SUDS); in Australia, it is called Water-Sensitive Urban Design (WSUD).

GI integrates natural elements into architectural design and urban planning to create more sustainable and environmentally friendly urban spaces. GI can be categorized into the following elements:

- Green Buildings: This category includes GRs, blue roof downspouts, rain barrels, and bioretention cells.
- Green Streets: Components in this category include PP, gravel trenches, soak-aways, green park spaces, stormwater bump-outs, swales, and filter strips.
- Green Spaces: This category encompasses natural features such as wetlands and ponds.

These GI elements work together to enhance sustainability and improve the environmental quality of urban areas [17].

The four pillars of SUDs, Water Quantity, Water Quality, Amenities, and Biodiversity, can describe the benefits of GI. Water Quantity by using water runoff as a water resource, controlling the surface runoff where it falls, the adaptability and flexibility to cope with future change, the efficiency of site drainage, protecting the natural hydrological cycle and preserving it, and the delay of stormwater runoff.

Water quality can be improved by designing a resilience system that prevents the potential impacts on receiving waterways and decreases the potential pollution of groundwater.

The Amenity by enhancing visual characteristics, recreation, and leisure, the safe delivery of surface water, resiliency to climate change, and healthier air quality. Biodiversity is achieved by supporting natural habitats and creating resilience and self-sustaining ecosystems [3, 13].

2. Case Study

The city of Dubai has recently experienced numerous climatic changes and rainstorms. These phenomena are unusual for the region, as Dubai is known for its desert climate. These climatic changes may result from global climate change and increased weather volatility. Among the most notable changes are the heavy rainstorms that have led to flooding in some areas, causing traffic disruptions and impacts on infrastructure.

Local authorities address these challenges by improving drainage systems and enhancing emergency preparedness. The case study focuses on a cluster located in Dubai Land, Dubai, United Arab Emirates. Dubai Land is a burgeoning area with commercial and residential properties and leisure and entertainment facilities. This particular cluster spans a total area of 12.7 ha. The developed portion of the cluster includes residential areas covering 7.1 ha, constituting approximately 56% of the total cluster area. Additionally, there are open spaces totaling 1.7 ha, making up about 13% of the area, and right of way areas occupying 3.9 ha, representing around 31% of the cluster, as shown in Figure 1.

The study aims to generate insights that apply to other rapidly urbanizing, arid environments by focusing on this specific cluster. The findings could inform strategies for similar urban developments in Dubai and other regions experiencing growth alongside climate-induced weather changes, contributing to broader urban resilience planning in comparable contexts.

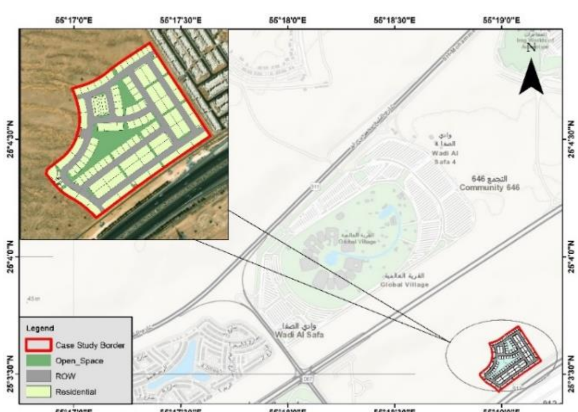

Fig. 1 Layout for case study location

The design storms defined in the DM's drainage design manual are used for this case study.

The proposed system for the case study is a positive system that consists of pipes, manholes, and gullies. This study examines four key elements of GI, focusing on their impact on reducing runoff volume and flow. The primary element under consideration is extensive GRs, which are characterized by their simplicity, featuring a low substrate depth that minimizes the structural load on buildings. These roofs typically support simple, low-maintenance vegetation and require minimal upkeep once established.

While this study centers on extensive GRs, two other types of GRs-blue roofs and intensive GRs-are acknowledged but not the focus of this research. Blue roofs are engineered specifically for water management and designed to store water and release it in a controlled manner. This stored water can be utilized for various purposes, such as irrigation for adjacent GRs, non-potable water uses within the building, or recreational opportunities. Blue roofs can incorporate water storage beneath or within a porous medium. Intensive GRs, in contrast, are more complex systems with deeper substrates that support a diverse range of plants and often include fully accessible park-like spaces. These roofs demand greater structural support and more intensive maintenance [17, 14, 2].

In addition to GRs, this study also explores RGs, PP, and grassed swales. PP is a critical component of SUDS because it controls runoff by allowing water to infiltrate the pavement surface. This pavement can be constructed from pervious asphalt, pervious concrete, permeable interlock systems, or JW Eco-Pavement technology, which utilizes a horizontal and vertical grid of hollow cylinders that function as drainage channels [8, 9].

Grassed swales, or side ditches, are also examined for their role in collecting and channeling excess runoff water. The study focuses on understanding how these GI elements collectively reduce runoff volume and flow.

3. Modeling

GI can indeed be effectively modeled using software solutions like Bentley Sewer GEMS. Sewer GEMS is a comprehensive tool that supports dynamic modeling for sanitary and combined sewer systems, allowing for the integration of GI components into more extensive drainage networks. The Stormwater Management Modeling (SWMM) algorithm is widely used for modeling rainfall-runoff processes, especially suited for urban environments. It provides a detailed, dynamic simulation of stormwater runoff's quantity and quality. The key components and functionalities of SWMM are represented as follows:

- The runoff component of SWMM calculates the runoff generated from rainfall on various land surfaces (subcatchment) and assesses the pollutants carried with it.

Subcatchment Areas: Each area is defined by slope, surface roughness, and imperviousness, impacting how much and quickly runoff is generated.

- Routing Component: The routing portion handles runoff transport through drainage networks. SWMM simulates flow through pipes, channels, and other conveyance structures, considering backflow, surcharge, and pressurized flow conditions. Components like ponds, detention basins, and wetlands can be modeled to simulate the temporary storage and treatment of runoff before it moves downstream. Devices like pumps and regulators are modeled to manage flow rates, which can be particularly useful in designing and optimizing combined sewer systems.

SWMM monitors several factors over time, including:

Runoff Volumes and Flow Rates: This allows for assessing peak flows and overall runoff generated during different rainfall events.

Pollutant Concentrations: SWMM tracks pollutant loads and concentrations throughout the system, supporting water quality analysis for contaminants like sediment, nutrients, and heavy metals.

- Dynamic Simulation: The SWMM model dynamically calculates flow and pollutant transport in small steps, providing a real-time response to changing rainfall and runoff conditions. This feature is crucial for understanding storm events' immediate and cumulative effects, enabling accurate prediction of flood risk and water quality impacts.

SWMM is a powerful tool that provides an in-depth simulation of stormwater systems by modeling the hydrology of runoff generation and the hydraulics of runoff routing through urban drainage systems. Its ability to handle complex urban environments makes it ideal for designing effective stormwater management systems, including GI components, to manage stormwater quantity and quality [5].

The EPA-SWMM Runoff module models both the quantity and quality of stormwater runoff.

It employs a unique non-linear reservoir method, which treats each subcatchment as a shallow reservoir. In this method, precipitation generates inflow, while outflows are represented by infiltration, evaporation, surface runoff, and losses like depression storage.

Depression storage, an initial rainfall abstraction, includes water held by surfaces such as flat roofs and vegetation. Only when water depth exceeds the depression storage ds threshold does it contribute to runoff outflow, as illustrated in Figure 2.

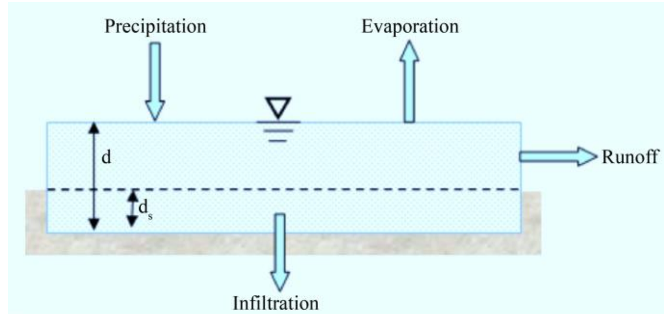

Fig. 2 Conceptual view of surface runoff

The nonlinear reservoir runoff method can be mathematically described by mass conservation.

$$\frac{\partial d}{\partial t} = i - e - f - q \qquad (1)$$

Where:
I=rainfall rate + snowmelt (m/s)
E=evaporation rate(m/s)
F=infiltration rate(m/s)
Q=runoff rate(m/s)
Note that I, E, F, and Q are expressed as flows per unit area (CMS/m2).

Assuming that flow across the subcatchment surface behaves as if it were uniform flow within a rectangular channel of width W (m), height (d–ds), and slope S, as shown in Figure 3.

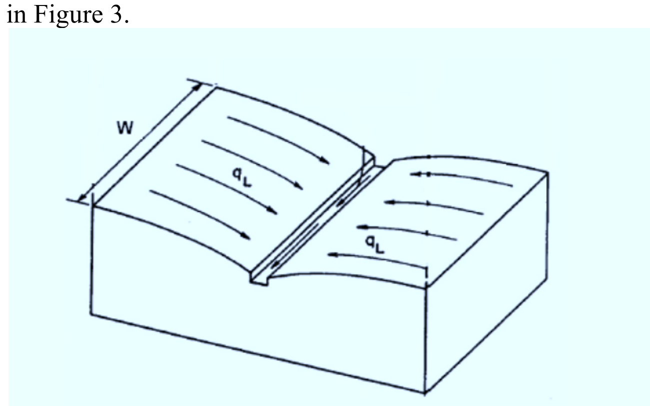

Fig. 3 Subcatchment representation

The Manning equation can be used to express the runoff's volumetric flow rate Q (CMS) as:

$$Q = \frac{1}{n} R_x^{2/3} S^{1/2} A_x \qquad (2)$$

Where n is a roughness coefficient, Rx is the hydraulic radius(m), Ax is the area across the subcatchment width through which the runoff flows(m2), Ax=W(d-ds), Rx is the hydraulic radius associated with this area (m), and S is the apparent average slope of subcatchment (m/m).

$$A_x = W(d-d_s), \qquad R_x = (d-d_s) \qquad (3)$$

$$Q = \frac{1}{n} W S^{1/2} (d-d_s)^{5/3} \qquad (4)$$

To obtain the runoff rate per unit surface area, q divides equation (4) by the surface area of subcatchment A.

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

By substituting equation (5) into the mass balance relation in equation (1) results

$$\frac{\partial d}{\partial t} = i - e - f - \propto (d - ds) \quad (6)$$

Where:
$\propto = W s^{1/2}/An$ [6, 7]

This equation was developed based on a rectangular subcatchment area with uniform characteristics. However, subcatchment typically consists of mixed land surface types, broadly classified into two main categories: pervious surfaces (such as fields and lawns) and impervious surfaces (like roads, parking lots, and roofs).

To better represent these variations, SWMM allows impervious surfaces within a subcatchment to be divided into two types: those with depression storage and those without. Impervious surfaces begin generating runoff only once their depression storage is filled. Therefore, SWMM models this behavior by categorizing impervious areas accordingly, resulting in each subcatchment containing three surface types, as illustrated in Figure 4.

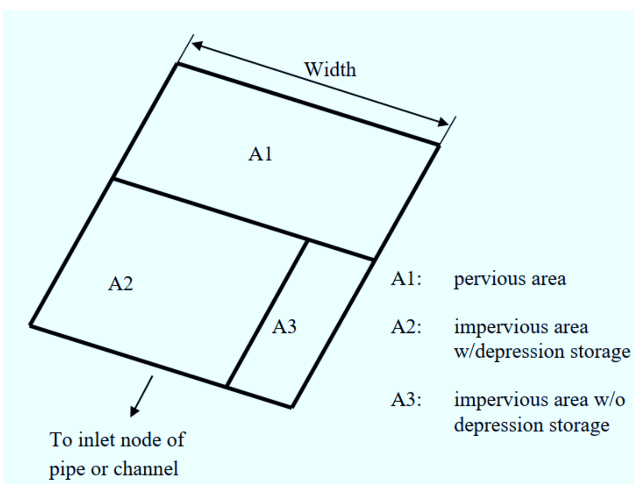

Fig. 4 Types of subcatchment

The symbols A1, A2, and A3 represent the pervious subarea and the two types of impervious subareas, those with and without depression storage, respectively. The input parameter "% impervious area with no depression storage" specifies the portion of the impervious subcatchment that lacks depression storage.

3.1. Modeling GI

LID controls are designed to capture and manage surface runoff through detention, evapotranspiration, and infiltration. When precipitation occurs, water flows into various outflow paths, including evaporation, infiltration, and surface runoff. Once surface runoff is generated, the LID controls begin functioning, providing detention, promoting infiltration, and enabling evapotranspiration.

The hydrological processes involved in modeling LID are illustrated in Figure 5.

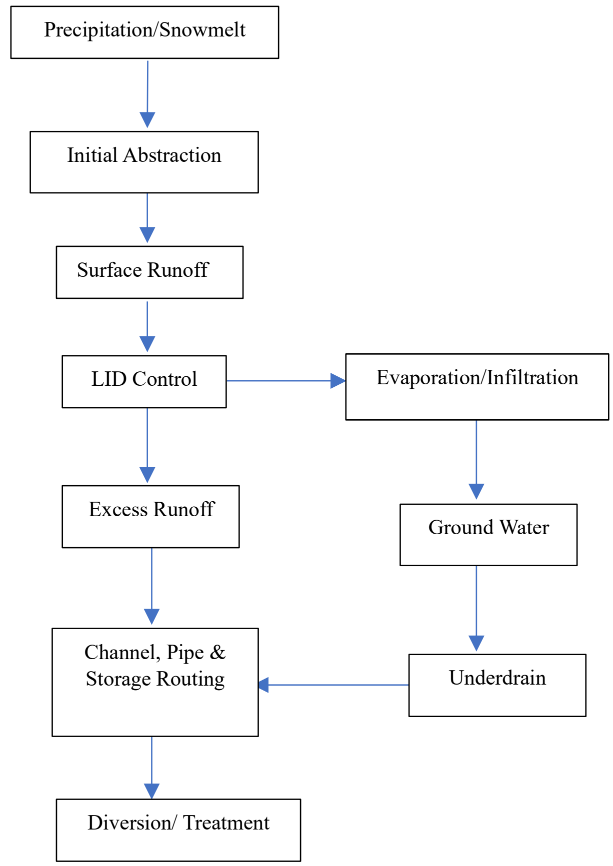

Fig. 5 Hydrological process of modeling the LID

SWMM models the runoff mass load reduction by considering the decrease in runoff flow volume.

There are two primary approaches for placing LID controls within a subcatchment:

Option One involves creating a new subcatchment dedicated to a single LID practice. Here, a separate subcatchment is defined for each LID control in the network, known as the "Parent Catchment," which represents only the area occupied by that specific LID control. This approach has several advantages: it allows multiple LIDs to be placed in series and enables the redirection of upstream pervious areas toward the LID control. In contrast, only non-LID impervious areas within the parent catchment can be directed to the LID. Option Two places multiple LID controls within an existing subcatchment, displacing an equivalent amount of non-LID area. In this approach, the parent catchment includes the total area occupied by the LID control(s) and the adjacent non-LID area. This method permits multiple LID controls to be associated with a single subcatchment. If multiple LIDs are present, they act in parallel to treat runoff generated from the non-LID portion of the catchment area. Additionally, the percentage of impervious area and width must be adjusted to reflect the non-LID portion of the catchment area accurately [6].

3.2. LID Representation

LID controls are composed of vertical layers, with each layer's properties specified per unit area basis.

This setup allows SWMM to simulate LIDs with the same design but varying coverage areas. During simulation, SWMM performs a moisture balance to track the movement and storage of water within each LID layer.

The layers within an LID control include the following:

- *Surface Layer:* This layer receives direct rainfall and runoff from the upstream catchment. It stores water in surface depressions, loses it through infiltration into the soil layer below, and produces surface outflow when capacity is exceeded, which either flows into a downstream catchment or enters the drainage system.
- *Soil Layer*: Typically a blend of engineered soil or sand, this layer supports vegetation or acts as bedding under pavement. It filters and retains water received from the surface layer and allows percolation down into the storage layer.
- *Storage Layer*: Composed of crushed stone or gravel, this layer stores percolated water from the soil layer, gradually releasing it into the natural soil below or through an underdrain system if one is installed.
- *Underdrain System*: This component conveys excess water from the storage layer to an outlet pipe or drainage chamber.
- *Drainage Mat Layer*: Positioned between the soil layer and a roof or other structure, this mat assists with water distribution and drainage.
- *Pavement Layer*: This layer is used in permeable pavement systems. It consists of porous asphalt, concrete, or permeable pavers designed to filter water and allow it to infiltrate the layers below.

4. Results and Discussion

The impact of using the GI element in the generated runoff volume and generated flow for 1 in 5 yr. As a critical scenario, a storm duration of 720 minutes is described below.

For GR: The table and graph below describe the effect of the implementation of a GR on the generated volume and runoff flow of one of the subcatchment areas in the case study. Table 1 below shows residential unit characteristics and the percent of used GRs from its total roof area, and Table 2 Shows the effect of using this percent of GR on the generated runoff volume and flow, and the generated runoff volume and flow in case of using the concrete roof for this unit. Also, Figures 6 and 7 illustrate this comparison.

Table 1. Subcatchment characteristics

Area(m2)	%impervious	%Green Roof	CN
446	50	50	61

Table 2. Effect of using green roof on generated volume and runoff flow

Flow with G.R(L/s)	Volume with G.R(m3)
0.48	4.7
Flow without G.R(L/s)	**Volume without G.R(m3)**
0.99	9.4
%Flow reduction	**%Volume reduction**
52%	50%

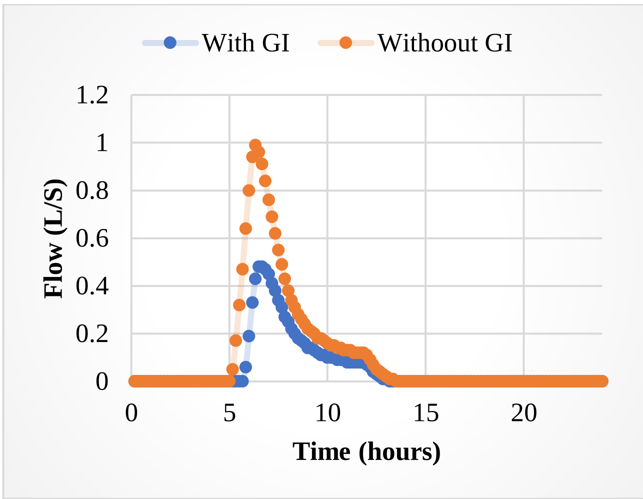

Fig. 6 Effect of using G.R. on generated runoff

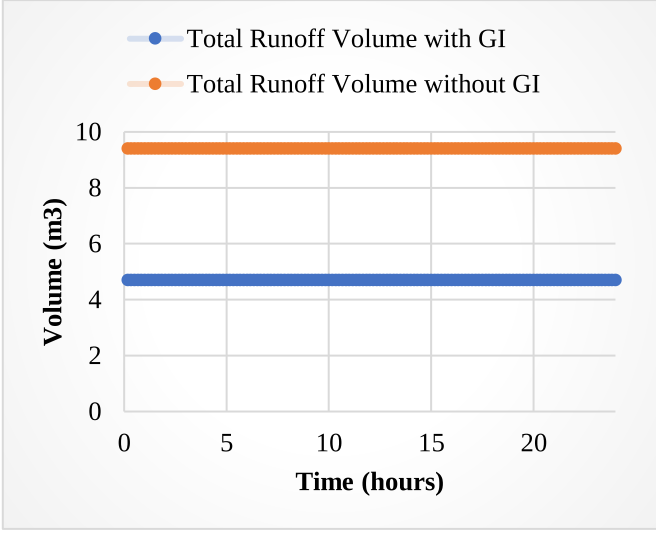

Fig. 7 Effect of using G.R. on generated volume

For RG: The table and graph below describe the effect of the implementation of RG on the generated volume and runoff flow of one of the sub-catchment areas in the case study. Table 3 below shows residential unit characteristics and the percent of used RGs from its total area, and Table 4 shows the effect of using this percent of RG on the generated runoff volume and flow, and the generated runoff volume and flow in case of not using it for this unit. Figures 8 and 9 illustrate this comparison [1, 11].

Table 3. Subcatchment characteristics

Area(m2)	%impervious	%Rain Garden	LID area (m2)
446	50	28	60

Table 4. Effect of using Rain Garden on generated volume and runoff flow

Flow with R.G(L/s)	Volume with R.G(m3)
0.87	8.20
Flow without R.G(L/s)	**Volume without R.G(m3)**
0.99	9.40
%Flow reduction	**%Volume reduction**
12%	13%

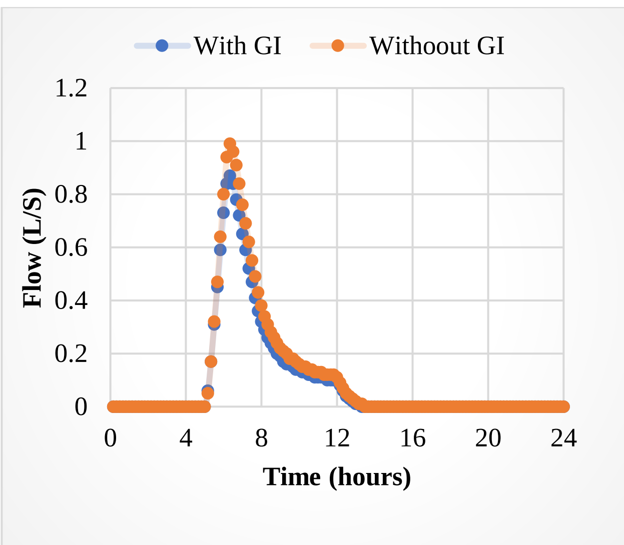

Fig. 8 Effect of using RG on generated runoff

The integration of these two systems leads to a greater reduction in runoff volume and flow compared to using each element individually, as illustrated in the table and figures below. The GR initially captures and holds a portion of the rainfall, reducing the overall runoff that reaches the surface. The remaining runoff is then collected by the RG, which further absorbs and infiltrates the water, significantly reducing runoff volume and flow.

This integration enhances the efficiency of stormwater management by leveraging the strengths of both systems, resulting in a greater reduction in stormwater impact than if either system were used alone.

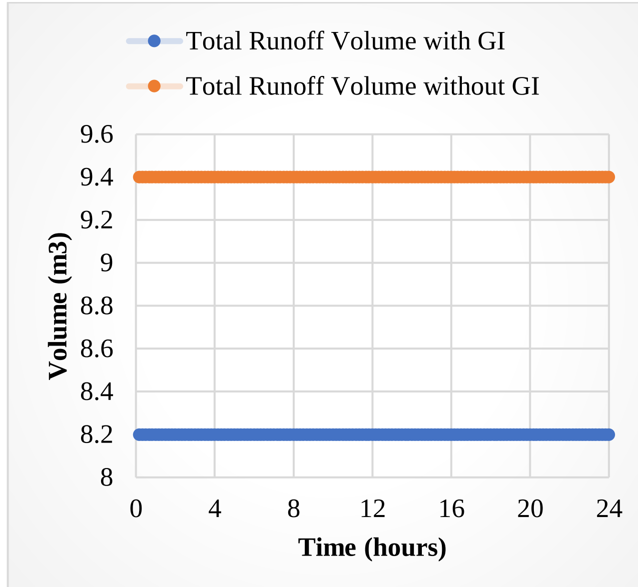

Fig. 9 Effect of using RG on generated Volume

Table 5. Effect of integrating G.R and RG on generated volume and runoff flow

Flow with G.R& G.R(L/s)	Volume with G.R& G.R(m3)
0.41	3.9
Flow without G.R& G.R(L/s)	**Volume without G.R& G.R(m3)**
0.99	9.4
%Flow reduction	**%Volume reduction**
59%	59%

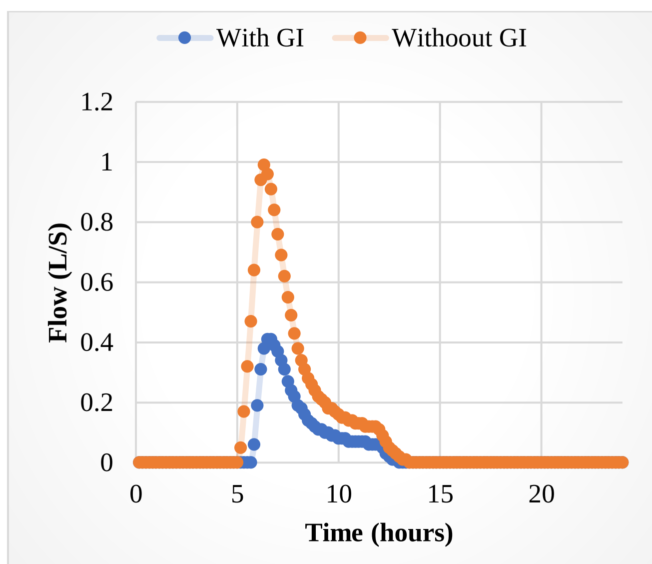

Fig. 10 Effect of integrating G.R& RG on generated runoff.

For PP: The table and graph below describe the effect of the implementation of permeable pavement on the generated volume and runoff flow of one of the sub-catchment areas in the case study. Table 6 below shows the characteristics and the percent of used permeable pavement, and Table 7 shows the effect of using this percent of permeable pavement on the generated runoff volume and flow, and the generated runoff volume and flow in case of not using it for subcatchment.

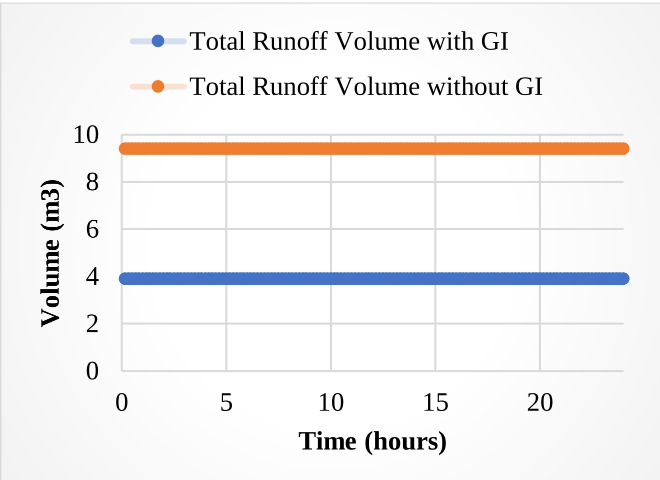

Fig. 11 Effect of integrating G.R and RG on generated volume

Table 6. Subcatchment characteristics

Area(m2)	%impervious	%Pervious Pavement
1185	80	80

Table 7. Effect of using permeable pavement on generated volume and runoff flow

Flow with P.P(L/s)	Volume with P.P(m3)
0.03	0.2
Flow without P.P(L/s)	**Volume without P.P(m3)**
3.83	40.5
%Flow reduction	**%Volume reduction**
99%	100%

The below graph shows the reduction in cost and generated volume between the two systems as a result of a change in the percent of the used GI, Table 8 presents a comparison between the GI system, which incorporates PP, RG, grassed side ditches, and varying percentages of GR coverage, and the traditional system. The cost comparison conducted in this study, which includes the cost of elements for both (GI) and traditional gray infrastructure, is based on data provided by (Mark H).

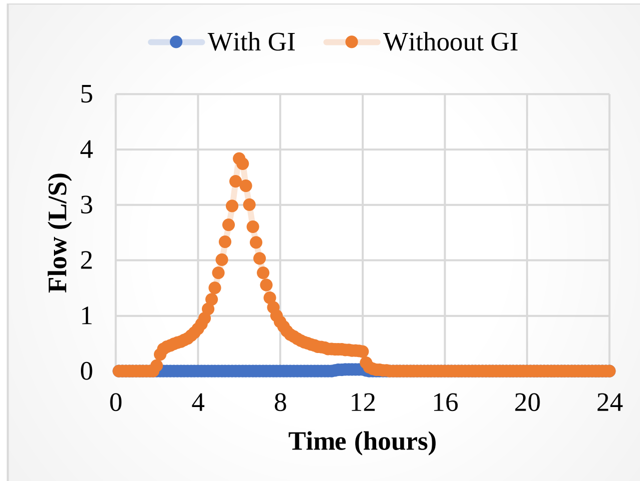

Fig. 12 Effect of using PP on generated runoff

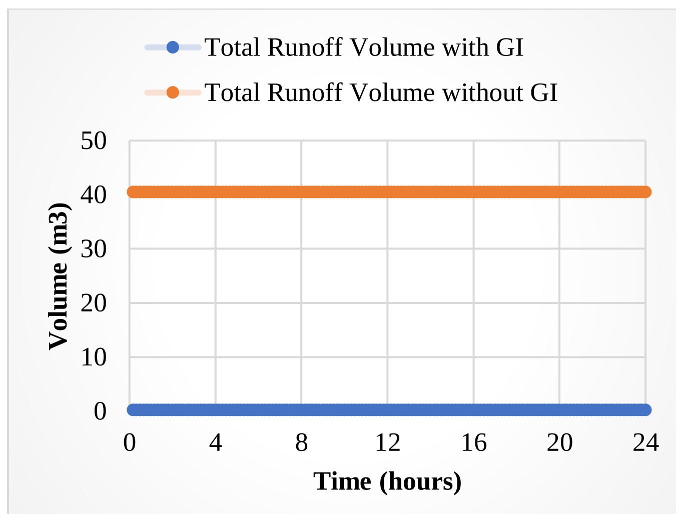

Fig. 13 Effect of using PP on generated volume

Table 8. Cost comparison between GI and traditional system

Traditional Infrastructure System	Green Infrastructure System		%Reduction of Cost
COST(AED)	**% Used of Green Roof**	**COST(AED)**	
2,695,866	25%	1,522,592	44%
	30%	1,702,603	37%
	40%	2,062,626	23%
	50%	2,422,563	10%
	60%	2,782,672	-3%

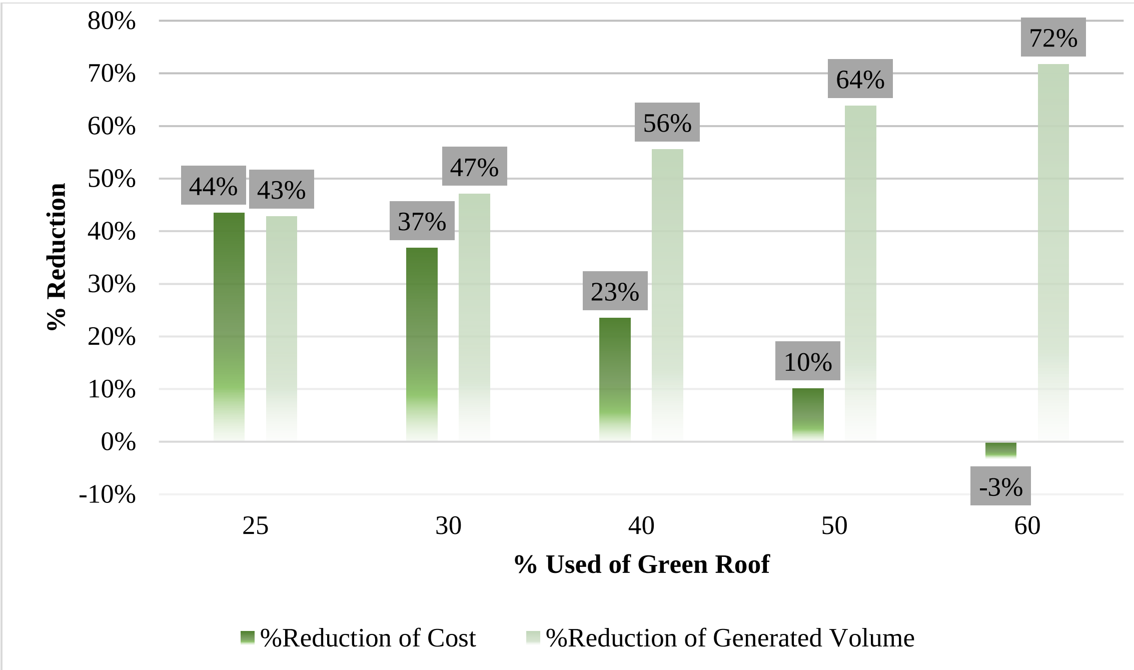

Fig. 14 Cost reduction and generated runoff volume

5. Conclusion

The impact of using GI on generated Volume and generated runoff is clear, and each element has an effect that differs from the other. As described in the upper section, more effect can be gained when more than one element is integrated, for example, when GR and RG are used together. This integration will have a noticeable effect on generated runoff and will, therefore, impact any project's Triple Bottom Line (TBL) Economic, Environmental, and Social.

Economic: represented in reducing or replacing costly gray infrastructure, as described in Figure 14. The reduction in cost between the two systems due to changes in the percent of the used GRs and this effect will be noticeable and clear with big values more than this mentioned one in the big areas as in this study, the used positive system is a local system with diameter "315mm and 400mm" so the cost of using the GI almost the same when 60% of the plot roof area is used as a GR also the generated runoff volume reduced by 72% than the concrete roof, as the compare with a positive system with pipe diameter up to 400mm, significant cost reductions will be observed in large areas and extensive stormwater networks with large diameters In such cases, the cost of the positive system becomes significantly higher than the GI system due to the large diameter and depths of the network.

Also, in the case study, the area is not big enough to declare the reduction effect between the two systems, but cost reduction still exists. For example, when 50% of the plot roof area is used as a GR, the cost reduction is 10%. The reduction in generated runoff volume was 64%, and when 30% of the plot roof area was used as GR, the cost reduction was 37%, and the reduction in generated runoff volume was 47%. Also, increasing groundwater resources, as most of the rainfall will be infiltrated via these elements, will reduce water treatment costs and the added value of the developed area.

Environmentally, represented in flood risk reduction, for the whole case study area, the total generated runoff volume was reduced by 79%, as well as delayed stormwater runoff volume, increased groundwater recharge, improved water quality, and carbon reduction.

Socially represented in improving air quality, recreation, resilience to climate change, and reducing urban heat stress and related public health benefits.

Data Availability

Data supporting this study are included within the article and/or supplementary materials.

Abbreviations

GI	Green infrastructure.
TBL	Triple bottom line.
LID	Low impact development.
SUDS	Sustainable urban drainage systems.
WSUD	Water-sensitive urban design.
SWMM	Stormwater management modeling.
GR	Green Roof.
RG	Rain Garden.
PP	Pervious Pavement.

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