



Simulating blue and green infrastructure tools via SWMM in order to prevent flood hazard in an urban area

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Abstract

Flood risk has become the most important problem in urban areas. A pilot study was carried out in the Güzeltepe neighborhood of İzmir Province, located in the west of Turkey, which is an urban regeneration area with poor socio-economic status and insufficient infrastructure services. According to this study, the areas where water collects and the areas where the slope and elevation are low were determined and the rainwater infrastructure system was integrated into the area. Then, the “Low Impact Development” model, which is an effective method for preventing runoff and water pollution, was examined and applied throughout the area. In this context, 8 scenarios were determined according to the characteristics of the area through the mathematical method SWMM 5.2 program and it was determined how much flooding was prevented by which Low Impact Design (LID) tool. According to the study, the runoff rate is significantly high in the absence of LID systems. Without LID interventions, 70% of rainwater is converted to surface runoff. However, the implementation of various LID systems effectively reduces this rate: permeable surfaces decrease runoff by 13%, infiltration trenches by 30%, bio-retention cells by 29%, vegetative swales by 33%, green roofs by 19%, rain gardens by 30%, and rain barrels by 19%. The development of a method to prevent a risky disaster such as flooding by using blue and green infrastructure within the scope of adaptation to climate change in urban regeneration areas with inadequate infrastructure makes this study valuable. The study of integrating blue and green infrastructure systems into the regeneration strategies of unplanned areas in the city makes this study unique. For this reason, the study focuses on the application technique of blue and green infrastructure systems.

Keywords Flood risk · Climate change adaptation · SWMM · GIS

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1 Introduction

The water cycle is affected at all points by the global climate change crisis. Water availability and supply are dwindling, and after all, worldwide water quality, scarcity, and sustainable development are threatened. The water crisis impacts fragile and low-income societies with contributing factors such as population increase, migration crisis, land use change, soil health crisis, biodiversity loss, ecological problems, and groundwater extraction (UN Water 2017). The effects of climate change are the most observed in the water cycle (Kundzewicz 2008). Floods, droughts, and torrential rains can be monitored in many places (OECD 2013). Water management plays a significant role in climate change mitigation. Water management interventions, such as wetland conservation, agriculture protection, and natural-based solutions, are essential for decreasing climate change effects (UN Water 2020). Global climate change negatively affects water resources. For example; evaporation rate, precipitation rate, increased water temperature, and poor water quality (Adams and Peck 2008). In addition to these, urbanization directly affects the water cycle. Floods, droughts, landslides, and heatwaves, which lead to disruption of the water cycle cause loss of population, property, and quality of life (Raju and Kumar 2018). Besides, land use changes transform the natural water cycle. The growing urban territory has threatened natural dynamics and environmental balances.

The flood risk, especially due to the deterioration of the natural system, is one of the most critical natural imbalances (Battemarco et al. 2022). Many countries have created a new approach to flood risk management (Lennon et al. 2014). Urban flooding consists of rivers such as riverine and fluvial flooding, sea such as coastal flooding, and besides, rainfall which are pluvial flooding (Sørensen 2018). These approaches involve strategic, holistic, and long-term characterization for mitigation and adaptation of flood risk management. Besides, these approaches have benefits in socio-economic development and adaptation to river flooding (Lennon et al. 2014). Various studies have been developed for stormwater management. One of the new strategies is best management practices (BMPs), low impact development (LID), sustainable urban drainage systems (SUDS), and water-sensitive urban design (WSUD) for runoff control (Xu et al. 2019). For a Blue and Green Infrastructure system, Low Impact Development (LID) strategies are essential and widely known methods in stormwater management (Leimgruber et al. 2019; Sørensen and Emilsson 2018).

Due to the fact that the growing urbanization causes essential changes in the water cycle, surface flows, runoff volumes discharge peaks started to increase. In many countries, Sustainable Urban Drainage Systems (SUDS) and sewerage networks have been implemented for storm flood management (Rey Valencia and Zambrano Nájera 2019). Pollution of runoff, downstream water bodies, estuaries, and lakes leads to an increase in stormwater runoff. Similarly, an increase in urban development and the expansion of impervious areas cause to increase in stormwater runoff volume. Stormwater management covers runoff quantity control, groundwater recharge control, water quality control, and stream bank erosion control (Bond et al. 2021). With rapid urbanization comes runoff pollution and urban flooding, which causes extreme weather conditions. Traditional urban drainage system is not enough current problems for urban flooding control. Mitigation of urban flooding and development of urban rainwater are significant sustainable urban solutions. In China, Low Impact development (LID) has been used for flooding control (Bai et al. 2019). Also, the Chinese government has improved a sponge city policy for urban stormwater management. The system aims to enhance sustainable urban development and six key processes, which consist of retention, infiltration, storage, purification, discharge, and

utilization, are implemented for sponge city practices (Liu et al. 2022). The aim of flood control measures is to decrease flooding along grey infrastructure such as hard, conventional, and engineering solutions which consist of dikes, dams, embankments, and weird. In many practices, the flood risk approach is defined as three combinations created by hazard, vulnerability, and exposure (Cea and Costabile 2022). Walsh et al. (2013) evaluates low-impact development (LID) practices for reducing the negative effects of stormwater. One of the LID designs is rainwater harvesting (RWH), which involves landscape irrigation, non-potable indoor uses, and potable consumption, which are the most used practices. Low impact development (LID) is the most essential practice for urban stormwater management and involves green roofs, bioretention, and porous pavement. The system helps to develop water quality, and water retention, and also, affects annual flow, and green swale. In addition to these, LID assists to in scrutinizing hydrological impacts and life cycles with bioretention, infiltration trench, porous pavement, rain barrels, and green swale (Chui et al. 2016). Low Impact Development (LID) can be evaluated as an innovative solution and it stores, infiltrates, and retains the stormwater in micro-scale ecological systems like permeable pavement, green roofs, and vegetative swale. The spatial and temporal changes are significant in groundwater for LID. Besides, the infiltration development and the enhancement of groundwater level reflect the spatial and hydrogeological characteristics of LID (Zheng et al. 2018).

The purpose of the study is to reduce flood risk, enhance neighborhood areas, and increase quality of life. Flood risk, which is the hazardous result of climate change, negatively affects water, carbon, and the life cycle. The water cycle is an essential issue for life; thus, the conversation of rainwater is significant for citizens. New strategies are improved for the preservation of urban areas from flooding because the consequences of flooding cause damage to socio-economic and loss of lives. Many studies have developed adaptation and mitigation solutions for the measure. In the study, the negative impact of flooding is reduced and a new regeneration model is proposed. The study is carried out in the Güzeltepe neighborhood, which is a depression zone in İzmir, for the new regeneration decisions with blue and green infrastructure systems. The main aim of the study is to create a sponge neighborhood based on blue and green infrastructure (BGI), thus, literature is contributed with a new regeneration model based on flooding management.

2 Materials and methods

2.1 Materials

2.1.1 Definition of case area

The study area, the Güzeltepe neighborhood, is located west of Turkey, on the boundaries of İzmir city (Fig. 1). The site, where the immigrant community is located, has earthquake risk. Because of this situation, Güzeltepe neighborhood is determined as an urban regeneration area. The urban regeneration process has begun within the scope of the municipality policy No: 5393 owing to the ground structure and infrastructure problems (Çınar et al. 2016). According to TUIK 2021 Data, the total population is 6.623 (TUIK 2021) Generally, houses can be observed at 1 or 2 stories, and a reclamation master plan was implemented in 1985 and 1986 (Bal 2008). 296 independent units are located in the area, which is 21 hectares. 7 different residentials are created with urban regeneration projects. Besides,

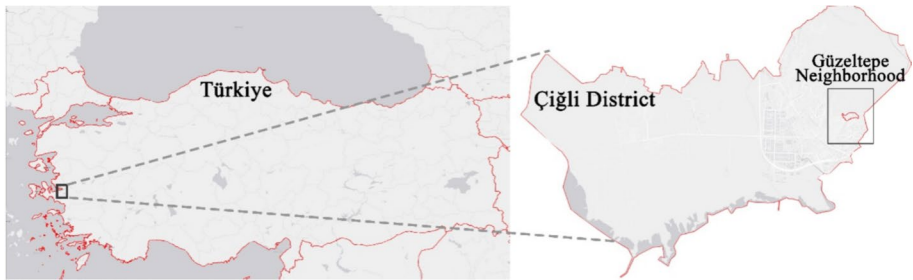


Fig. 1 Location of the study area

commercial units, health facilities, parking lots, children's playground areas, and social and cultural centers are proposed (Anonymous 2023).

2.2 Method

Within the scope of the micro-scale study, a literature review was made first. Then, slope, elevation, and drainage density were analyzed through the ArcGIS 10.4 program to calculate the water collection areas since the area did not have infrastructure data. Similarly, (Cebe and İnan 2020) and (Tombul 2022) need to produce slope and elevation maps for the prediction of rainwater flow. Drainage density is produced for determining the accumulation of rainwater. In the study, a digital elevation model (DEM) with a resolution of 12,5 is used from the Alos Palsar data, and the study area was created as the neighborhood boundary (Fig. 2).

After these analyses, the infrastructure systems that store rainwater, reduce runoff, and infiltrate are integrated into the neighborhood scale and the Storm Water Management Model version 5.2 (SWMM 5.2) program is used for calculating stormwater management. LID module is used for simulating and runoff reduction performance. Various LID practices are simulated for the best runoff reduction method. The permeable pavement (PP) model is mostly applied in urban areas due to the reduction of rainwater. (Madrazo-Uribeetxebarria et al. 2022) and (Zhang and Guo 2014) simulated the runoff performance of permeable pavement by using the SWMM module and they analyzed peak and volume performance. SWMM, which was developed by The US Environmental Protection Agency, helps to simulate water and drainage transportation in urban areas taking into consideration elevation, hydrology, and runoff quality. In Norfolk, Virginia, USA, that is seen flood events, the SWMM model was preferred and eight subcatchments, three flow control manholes, and three junctions were used but elevation changes were not considered (Saliba et al. 2020). Hamouz and Muthanna (2018) compared grey and green roof performance for stormwater retention and runoff detention. The researchers used the Stormwater Management Model (SWMM) last version and besides, the Low Impact development module is preferred for measuring hydrological performance. Another method for the reduction of flooding, blue and green infrastructure is used. In Sweden, stormwater control systems are integrated into drainage systems (Sörensen and Emilsson 2018). In Greece, The LID practices, which is the hydrologic-hydraulic model, are chosen for reducing peak runoff and runoff volume. The green roof and permeable pavement that is two different conventional practices are tested for the study (Kourtis et al. 2018). Blue and Green Infrastructure systems are an alternative compared to grey infrastructure. BGI based on the ecosystem is



Fig. 2 Border of Güzeltepe Neighborhood

associated with detention, biological uptake, and infiltration for managing stormwater quality and quantity. The landscape systems include ecosystem services such as urban biodiversity development, water quality treatment, flood risk mitigation, and thermal reduction (Liao et al. 2017). In Hong Kong, China and Seattle, U.S., different rainfall modules are used for stormwater management. Three different LID practices, which consist of green roofs, bioretention, and porous pavement, are preferred (Chui et al. 2016).

In the study, 8 scenarios are determined that consist of blue and green infrastructure systems. In the scope of the study, blue and green infrastructure systems, which are the green roof, permeable pavement, rain barrel, vegetative swale, infiltration trench, rain garden, and bio-retention cell, are preferred due to the modules are the most used and reduced stormwater. First of all, the Non-LID system is measured for infiltration and drainage performance and then, blue and green infrastructure systems are used for testing performance. 20 subcatchments are determined which involve various land use and LID modules are integrated in these subcatchments. Besides, rainwater infrastructure is designed in the area. 84 junctions are implemented in between subcatchments and these junctions are connected with 85 conduits each other. Slope and width features are considered in the study (Fig. 3).

3 Results and Discussion

3.1 Results

Within the scope of the study, slope, elevation, and drainage density were analyzed in the Maltepe stream micro basin scale through the ArcGIS 10.4 program to calculate the

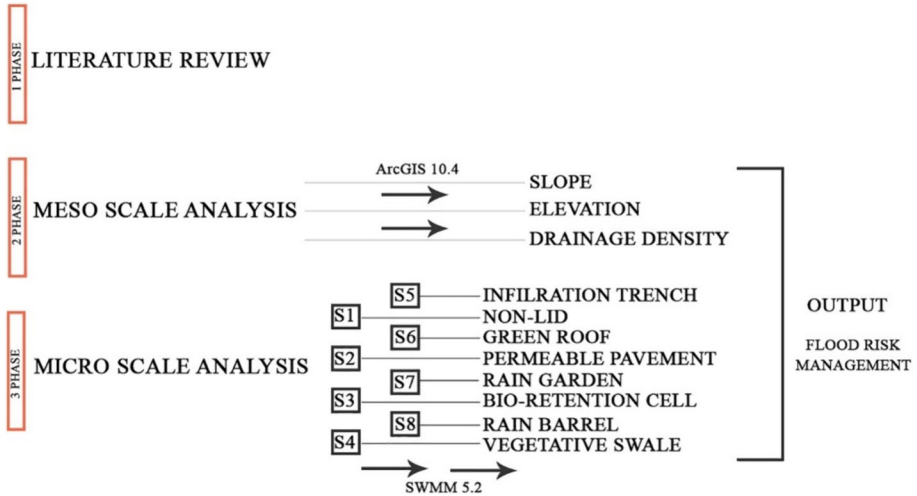


Fig. 3 Research Design and Method

water collection areas since the area did not have infrastructure data. After these analyses, the infrastructure systems that store rainwater, reduce runoff, and infiltrate are integrated into the neighborhood scale and the LID modules with Storm Water Management Model 5.2 (SWMM) are used.

Within the scope of the micro-scale, the micro basin covering the Maltepe stream and the urban regeneration area of the Güzeltepe neighborhood within it were evaluated (Fig. 4).



Fig. 4 Güzeltepe Neighborhood Urban Regeneration Area

Güzeltepe neighborhood is an area where it was decided to carry out an urban transformation work in accordance with Article 73 of the Municipality Law No. 5393, upon the letter dated 10.10.2016 and numbered 12,105.

Within the scope of this study, it was tried to integrate the blue and green infrastructure systems into the urban regeneration study. In this context, first of all, the existing infrastructure of the area was evaluated. Rainwater sewerage infrastructure data were obtained numerically from the Izmir Water and sewerage administration general directorate. However, since the Güzeltepe neighborhood is a slum area, there is no rainwater drainage line. Therefore, the blue and green infrastructure study was prepared according to the drainage depth, slope, and elevation information of the area (Fig. 5). In addition, a blue-green infrastructure study was prepared by including the precipitation data from the 2nd Regional Directorate of Meteorology.

3.2 Scenarios

After all these studies, the reduction rate of surface runoff water was calculated by using the green and blue infrastructure systems through the Storm Water Management Model (SWMM 5.2) program. As mentioned before, BGI is a new approach and the system is promoted with many kinds of programs and terms like Sustainable Urban Drainage System (SUDS) in the UK, Low Impact Urban Design and Development (LIUDD) in New Zealand, Low Impact Development (LID) in the US, Stormwater Best Management Practices (BMPs) in the US, ABC (Active, Beautiful and Clean) Waters Program in Singapore

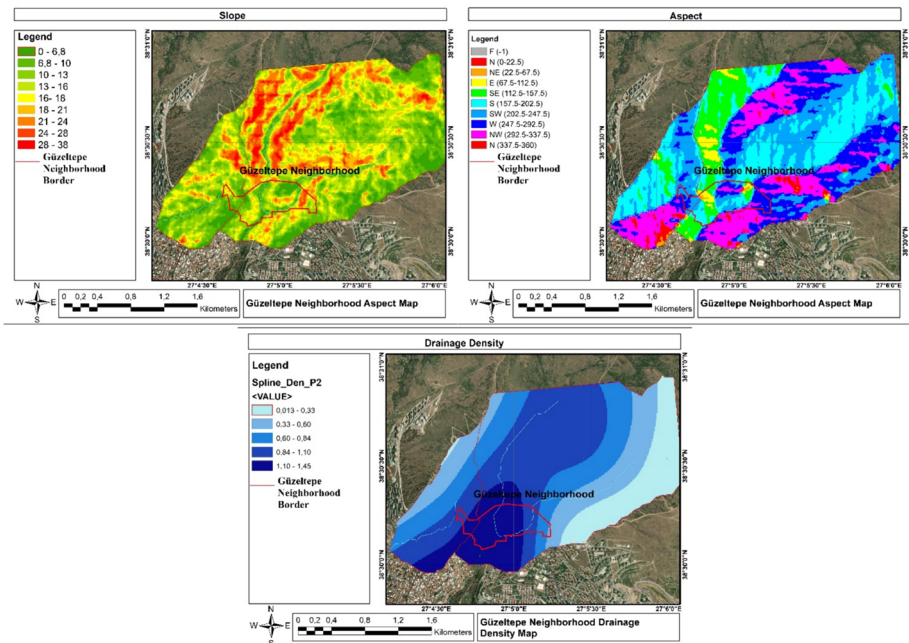


Fig. 5 Slope, aspect drainage density analysis

(Liao et al. 2017). In the study, Low Impact Development (LID) modules are implemented within the neighborhood.

With the help of the SWMM model, surface flow and drainage calculations are made from processes such as infiltration and evaporation of water falling to the ground from precipitation. The basin where the precipitation is collected is divided into sub-basins in multiple irregular ways and different hydrological uses are assigned (Cebe and Inan 2020). The land use of each sub-basin is specified as a percentage, and slope and width calculations are made.

(Width = Area/Length) (Open Swmm 2008).

Five different models are used for the infiltration of precipitation.:

- Classic Horton infiltration
- Modified Horton infiltration
- Green-Ampt infiltration
- Modified Green-Ampt infiltration
- SCS Curve Number infiltration (Rossman and Simon 2022)

In this study, Green Amp infiltration, which is easy and simple to use in field studies, was used. In addition, according to Rossman (2010), this model is preferred because it calculates according to the saturation level in calculating the infiltration of water into the soil in the precipitation-runoff model. SWMM is a discrete-time simulation model. Each input is subjected to a time step. According to the input and output data, outputs are obtained with mathematical equations (Fig. 6).

$$X_t = f(X_{t-1}, I_t, P).$$

$$Y_t = g(X_t, P).$$

X_t = a vector of state variables at time t ,

Y_t = a vector of output variables at time t ,

I_t = a vector of inputs at time t ,

P = a vector of constant parameters,

f = a vector-valued state transition function.

g = a vector-valued output transform function (Rossman 2010).

Within the scope of this study, eight scenarios were developed. In these scenarios, Low Impact Development design tools; Permeable pavement, rain garden, green roof, infiltration trench, rain barrel, vegetative swale, and bio-retention cell were used (Table 1).

As shown in Table 1, the layers properties of LID modules are identified for every blue and green infrastructure system. The infrastructure systems are represented by five main vertical layers: surface, pavement, soil, storage, drain, and drainage mat. In addition, the

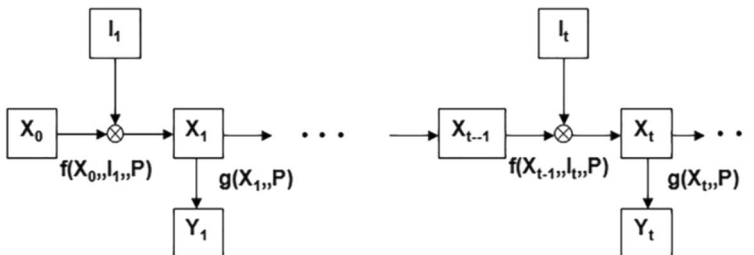


Fig. 6 SWMM Process

Table 1 Layers in LID Units (Reproduced from: Rossman and Simon 2022)

	Surface	Pavement	Soil	Storage	Drain	Drainage mat
Bio-Retention Cell	X		X	X	X	
Rain Garden	X		X			
Green Roof	X		X			X
Permeable Pavement	X	X	X	X	X	
Infiltration Trench				X	X	
Rain Barrel				X		
Vegetative Swale	X					

field was evaluated in its current form without using any LID design tools. Rainwater sewage systems were prepared by creating sub-basins throughout the area. The depth of the manhole is 1.5 m, the maximum depth of the pipes is between 0.4–0.6 m, and the distance between the manholes is 50 m. Every sub-catchment connects to the rain conduit system and manhole. In the rain infrastructure system, 20 sub-catchments, 84 junctions, and 85 conduit systems are created (Fig. 7).

The modules are edited with parameter settings. LID technique is related to infiltration retention, detention, and storage. The study scenarios were created by permeable pavement, infiltration trench, bio-retention cell, vegetative swale, green roof, rain garden, and rain barrel. For reducing flooding, the specific parameters setting are used in LID layers (Table 2).

Each design blue and green infrastructure design tool has specific material properties. The type, thickness, and arrangement of these materials differ from each other and from impermeable surface materials for rainwater infiltration and storage. The surface

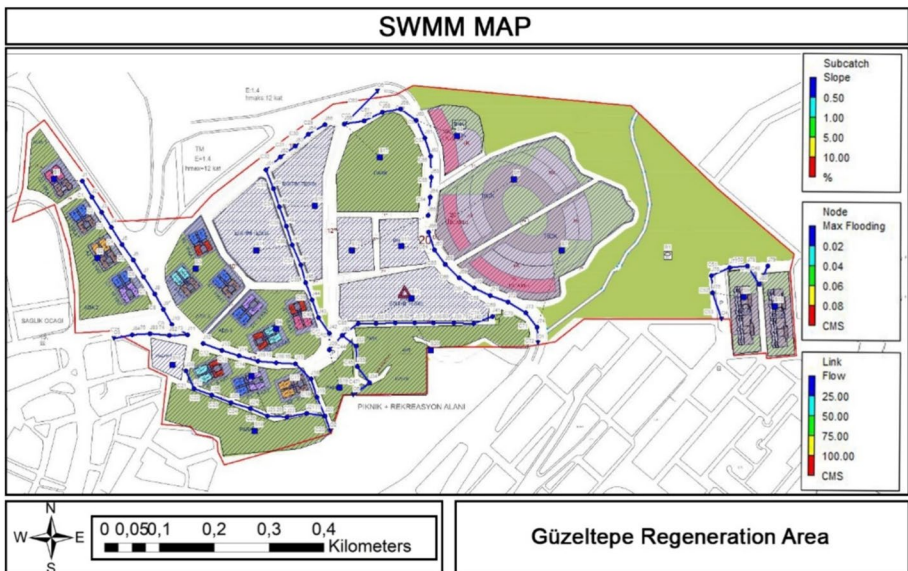


Fig. 7 SWMM Map with Urban Regeneration Plan

Table 2 Parameter setting of LID Modules (Source: (Bai et al. 2019; Men et al. 2020))

LIDs Type	Construction	Parameter option	Parameter value	
Permeable Pavement	Surface	Berm height (mm)	3	
		Surface roughness (Mannings N)	0.012	
		Surface slope (%)	1	
	Pavement	Pavement	Thickness (in or mm)	120
			Void Solids (voids/Solids)	60
			Permeability (mm/hr)	0.13
			Impervious Surface Fraction	200
			Clogging Factor	0
			Regeneration Interval	0
			*Regeneration Fraction	0
	Storage	Storage	Thickness (mm)	250
			Void ratio (voids/Solids)	0.43
			Seepage rate (mm/hr)	600
			Clogging Factor	0
			Soil	Soil
	Porosity	0.5		
	Field Capacity	0.1		
Wilting Point	0.024			
Conductivity Slope	10.0			
Infiltration Trench	Surface	Suction Head	3.5	
		Berm height (mm)	150	
		Vegetation Volume Fraction	0.00	
		Surface Roughness (Mannings n)	0.24	
	Drain	Drain	Surface Slope (percent)	1.0
			Flow Coefficient	0.69
			Flow Exponent	0.5
			Offset (in or mm)	6
			Open Level (in or mm)	0
			Closed Level (in or mm)	0
	Storage	Storage	Thickness ((in or mm)	600
			Void Ratio (Voids/Solids)	0.5
			Seepage Rate (in/hr or mm/hr)	24
Bio-Retention Cell	Surface	Clogging Factor	0	
		Berm height (mm)	150	
		Vegetation Volume Fraction	0.12	
		1		
	Drain	Drain	Surface Roughness (Mannings n)	0.1
			Surface Slope (percent)	0.1
			Flow Coefficient	0
			Flow Exponent	0.5
		Offset (in or mm)	150	

Table 2 (continued)

LIDs Type	Construction	Parameter option	Parameter value		
	Storage	Open Level (in or mm)	0		
		Closed Level (in or mm)	0		
		Thickness (in or mm)	260		
		Void Ratio (Voids/Solids)	0.75		
		Seepage Rate (in/hr or mm/hr)	80		
		Clogging Factor	0		
	Soil	Thickness (in or mm)	500		
		Porosity (Volume Fraction)	0.5		
		Field Capacity	0.2		
		Wilting Point	0.07		
		Conductivity (in/hr or mm/hr)	110		
		Conductivity Slope	10.0		
		Suction Head	3.5		
Vegetative Swale	Surface	Berm height (mm)	6		
		Vegetation Volume Fraction	0.85		
		Surface Roughness (Mannings n)	0.24		
		Surface Slope (percent)	1		
		Swale Side Slope (run/rise)	7.33		
Green Roof	Surface	Berm height (mm)	50		
		Vegetation Volume Fraction	0.2		
		Surface Roughness (Mannings n)	0.13		
		Surface Slope (percent)	1.0		
	Drainage Mat		Thickness (in or mm)	60	
			Void Fraction	0.43	
			Roughness (Mannings n)	0.03	
			Thickness (in or mm)	200	
			Porosity (Volume Fraction)	0.5	
			Field Capacity	0.3	
	Soil		Wilting Point	0.1	
			Conductivity (in/hr or mm/hr)	0.5	
			Conductivity Slope	10.0	
			Suction Head	3.5	
Berm height (mm)			150		
Vegetation Volume Fraction			0.1		
Surface Roughness (Mannings n)			0.12		
Surface Slope (percent)			0.3		
Rain Garden	Storage	Thickness (in or mm)	0		
		Void Fraction	0.75		
		Seepage Rate (in/hr or mm/hr)	400		
	Soil		Thickness (in or mm)	500	
			Porosity (Volume Fraction)	0.3	
			Field Capacity	0.2	
			Wilting Point	0.1	
			Conductivity (in/hr or mm/hr)	500	

Table 2 (continued)

LIDs Type	Construction	Parameter option	Parameter value
Rain Barrel	Drain	Conductivity Slope	10.0
		Suction Head	87.5
		Flow	
		Coefficient	0.68
		Flow Exponent	0.5
		Offset (in or mm)	125
		Drain Delay (hr)	5.8
	Storage	Open Level (in or mm)	0
		Closed Level (in or mm)	0

thickness of these materials is specially designed for easy passage of rainwater. The soil structure does not consist of particles that are eroded in the rain, it has a structure that retains water or provides easy absorption into the ground.

Annual precipitation is 654.8 m³ in 2021, 246.9 m³ in 2022 and 233.6 m³ in 2023. The total depth of precipitation is 1120,800 mm for each year. The measurements cover a 28-month period from January 1, 2021, to April 6, 2023. Annual, monthly, and hourly precipitation data are taken from the observation network of Karşıyaka district of Izmir province. The analysis was measured at a recording frequency of 60 s. “Green Ampt” was used as an infiltration method. “The Rain Gage” was positioned on the area at the XY coordinates “10,402.235/5374.302”. A total of 20 subcatchments were identified in the area, 84 nodal points (J) were created, 85 connection pipes (C) were created and 6 rainwater outfall points were identified. The area size and slope of each subcatchments are different from each other. Consequently, the results of the low-impact development tools used to prevent flooding differed from each other. According to the land use classification, there are green areas, commercial areas, residential areas, education areas, and forestation areas in the area. The application rates of LID systems to be used according to land use also differ from each other. Across the study area, the rate of the permeable area is 52.7% and the ratio of impermeable area is 47.3%. Impervious areas are also determined as concrete and roof surfaces. The roof area is 27.6%; the concrete area is 19.7%. More detailed information about the subcatchment is given in Table 3.

Table 3 presents the impact of blue and green infrastructure design tools, specifically Low Impact Development (LID) systems, on surface runoff. The first column provides baseline data, showing the proportion of total precipitation that transitions into surface runoff and infiltration without the implementation of LID systems. The subsequent columns display the changes in these proportions when LID systems are applied, detailing the modified percentages of water contributing to surface runoff, infiltration, and drainage. The values highlighted in bold within Table 3 are used to emphasize the key data points that demonstrate the most significant changes in water distribution due to the implementation of LID systems. By presenting these values in bold, the table clearly identifies the critical differences in runoff and infiltration rates before and after the use of LID systems, making it easier for readers to quickly recognize and interpret the impact of these sustainable design practices. According to the ratios of permeable area, roof area, and concrete area, the percentage of area LID systems to be

used is determined. Therefore, these ratios are very significant. The study area is an urban regeneration area where the infrastructure is unfavorable and the risk of flooding is the highest. A new transformation is being created in this area. The originality of this study is that the adaptation of an urban regeneration area to climate change is achieved through the water cycle. In this way, a major disaster such as flooding will be prevented and a living space will be created with blue and green infrastructure. In this context, 8 different scenarios were developed. The first scenario was developed without using any low impact development model. The second scenario was designed using only permeable surfaces, the third scenario was designed by creating an infiltration trench, the fourth scenario used bio-retention cells, the fifth scenario used vegetative swale, the sixth scenario used only green roof design tools, the seventh scenario used rain gardens and the last scenario used rain barrel. No low impact development (LID) module was used in scenario one. Accordingly, total rainfall is 1120,800 mm in depth, infiltration loss is 342,373 mm, surface runoff rate is 773,191 mm, and total rainwater storage rate is 5,884 mm. As can be seen in the data, 70% of the rainwater goes with surface runoff. This causes flooding and rainwater flows without being utilized. In Scenario 2, a permeable pavement in units of 5 m² was used in each subcatchment. With the use of this tool, the runoff rate decreased to 641,214 mm and the infiltration loss was determined as 472,194. Accordingly, 57.2% of the rainwater passed to surface runoff, the rest was infiltrated underground and groundwater supply was provided. In this case, there was a rainwater gain of 13%. In the third scenario, an infiltration trench was used. This module was designed to be integrated into green areas by creating 20 m² unit areas. Accordingly, the infiltration of rainwater towards the underground has increased more. The surface runoff rate was determined as 451,191, which indicates that 40.2% of the rainwater passes to surface runoff. In this case, it shows that there is a gain of 29.8% of rainwater compared to the case without LID and the proportion of rainwater passing to the subsurface has increased. In the fourth scenario, bio-retention cells consisting of 15 m² units were used. The proportion of rainwater stored in this module is very high. In addition, the surface runoff is at a depth of 624,020 mm. 55.6% of rainwater is in the runoff, in this case, the runoff rate is reduced compared to the case of not using LID tools. In the fifth scenario, the vegetative swale tool was used in units of 30 m² in each subcatchment. A significant reduction in runoff is observed compared to other LID uses. According to the data, there is 414,852 mm of runoff, which indicates a runoff rate of 37%. While the runoff was 70% without LID, this rate decreased to 37% with the vegetative swale. This is an important measurement in terms of preventing flood risk. The sixth scenario was created using a green roof. With the green roof tool, rainwater can be infiltrated as well as drained. The runoff rate was determined as 575,697 mm, according to this value, 51.3% of the rainwater is runoff. According to the seventh scenario, rain gardens were created in units of 30 m². Only subcatchment 16 was designed in units of 5 m², this is because it can be divided into whole numbers according to the width of the area. According to the measurement, the runoff rate of the rainwater is 452,850 mm, which means that 40.4% of the rainwater has passed into the runoff. There is a gain of approximately 30% compared to the case without LID. In the eighth and last scenario, rain barrels were used. 7 m³ capacity water tanks were designed in 25 m² units in the area. The calculation of the rain barrel is designed by taking into account the percentage of the roof surfaces as in the green roof system. According to the calculations, the runoff rate was calculated as 574.423 mm. 51.2% of the runoff is surface runoff.

Since subcatchment 16, 17, 18, 19, and 20 consist of green areas, permeable surfaces, infiltration trenches, green roofs, and rain barrels were not used in these subcatchment.

Table 3 Results of LID Modules

Station ID	First date	Last date	Recording frequency	Periods w/Precip	Periods Missing
18,446	01/01/2021	04/06/2023	60 min	793	0
	Runoff Quantity Continuity		Volume hectare-m		Depth mm
	Total Precipitation		10.098		1120.800
	Evaporation Loss		0.000		0.000
	Infiltration Loss		3.085		342.373
	Surface Runoff		6.966		773.191
	Final Storage		0.053		5.884
	Continuity Error (%)		-0.058		
PERMEABLE PAVEMENT					
	Runoff Quantity Continuity		Volume hectare-m		Depth mm
	Initial LID Storage		0.009		0.730
	Total Precipitation		13.359		1120.800
	Evaporation Loss		0.000		0.000
	Infiltration Loss		5.628		472.194
	Surface Runoff		7.643		641.214
	Final Storage		0.102		8.581
	Continuity Error (%)		-0.041		
INFILTRATION TRENCH					
	Runoff Quantity Continuity		Volume hectare-m		Depth mm
	Total Precipitation		13.359		1120.800
	Evaporation Loss		0.000		0.000
	Infiltration Loss		7.963		668.084
	Surface Runoff		5.378		451.191
	LID Drainage		0.001		0.071
	Final Storage		0.023		1.953

Table 3 (continued)

Station ID	First date	Last date	Recording frequency	Periods w/Precip	Periods Missing
BIO-RETENTION CELL					
	Continuity Error (%)			-0.044	
	Runoff Quantity Continuity		Volume hectare-m		Depth mm
	Initial LID Storage		hectare-m		mm
	Total Precipitation		0.216		18.088
	Evaporation Loss		13.359		1120.800
	Infiltration Loss		0.000		0.000
	Surface Runoff		7.438		624.020
	Final Storage		5.489		460.540
	Continuity Error (%)		0.652		54.710
			-0.033		
VEGETATIVE SWALE					
	Runoff Quantity Continuity		Volume hectare-m		Depth mm
	Total Precipitation		13.359		1120.800
	Evaporation Loss		0.000		0.000
	Infiltration Loss		8.158		684.432
	Surface Runoff		4.945		414.852
	Final Storage		0.010		0.860
	Continuity Error (%)		1.843		
GREEN ROOF					
	Runoff Quantity Continuity		Volume hectare-m		Depth mm
	Initial LID Storage		0.066		5.517
	Total Precipitation		13.359		1120.800
	Evaporation Loss		0.000		0.000
	Infiltration Loss		2.891		242.546

Table 3 (continued)

Station ID	First date	Last date	Recording frequency	Periods w/Precip	Periods Missing
RAIN GARDEN	Surface Runoff			6.862	575.697
	LID Drainage			3.330	279.422
	Final Storage			0.347	29.091
	Continuity Error (%)			-0.039	
	Runoff Quantity Continuity		Volume hectare-m		Depth mm
	Initial LID Storage		0.314		26.357
	Total Precipitation		13.359		1120.800
	Evaporation Loss		0.000		0.000
	Infiltration Loss		7.625		639.778
	Surface Runoff		5.397		452.850
Final Storage		0.655		54.993	
Continuity Error (%)		-0.040			
RAIN BARREL	Runoff Quantity Continuity		Volume hectare-m		Depth mm
	Total Precipitation		13.359		1120.800
	Evaporation Loss		0.000		0.000
	Infiltration Loss		2.910		244.171
	Surface Runoff		6.846		574.423
	LID Drainage		3.127		262.388
	Final Storage		0.479		40.155
	Continuity Error (%)		0.030		

Vegetative swale, rain gardens, and bio-retention cells were used in all subcatchment. Detailed data of the scenarios are given in Table 4.

When all these measurements are considered, it is seen that with the use of low-impact development models, the surface runoff of rainwater is reduced and the water is brought back into usable forms through techniques such as storage, underground filtration, and infiltration. Among the techniques used, the vegetative swale system was identified as the most efficient tool. Following the vegetative swale system is the infiltration trench. In general, all systems provide efficient use of rainwater according to their techniques. The rainwater storage rate of rain barrels, green roofs, and bio-retention cell systems is quite high. The performance of all systems in reducing surface runoff is quite high. Percentages of permeable and impermeable areas are important for the implementation of these systems. Since the green roof and rain barrel collect water from the roof, the percentage of roof area is important, the percentage of concrete area is important in permeable surface applications, and the percentage of vegetated area is important in infiltration trench, bio-retention cells, vegetative swale, and rain garden applications. Accordingly, blue and green infrastructure systems can be applied throughout the area. Within the scope of this study, water management can be provided through blue and green infrastructure systems in a neighborhood with inadequate infrastructure and flood risk. On the other hand, flood risk cannot be completely eliminated using Low Impact Development. Particularly as a result of the analysis, risky areas located at the intersection of the Maltepe stream branches in Güzeltepe neighborhood are determined. Flood risk in the region is not prevented by using blue and green infrastructure design tools.

The study is important in that it emphasizes the integration of blue and green infrastructure systems into planning and design strategies within the scope of climate change adaptation for an area undergoing urban regeneration. Because climate change adaptation strategies are ignored in urban regeneration studies. At this point, the study has an original value. In addition to all these, water profiling was attempted by cross-sections of stormwater channels (Fig. 8).

With the use of blue and green infrastructure systems, the proportion of water in the water channels has decreased. The fact that there is no overflow indicates that these systems use rainwater efficiently with their own techniques such as storage, retention-detention, and infiltration. In addition, when the rainwater runoff graph in each subcatchment is analyzed, it is seen that the runoff is higher in subcatchment where the percentage of structural area is high and the percentage of the green area is low. This is especially the case in subcatchment 6 and subcatchment 16 areas with the more structural surface in spring and winter months when rainfall is highest.

In the study, low-impact development (LID) modules were used together with information from the literature. This method is an important method in terms of taking into account land use, typological characteristics of the land, and efficient use of water. Low-impact development technologies were calculated using the “Storm Water Management Model” (SWMM) 5.2 program. First, as in many other studies, maps of slope, elevation, and drainage densities were calculated and mapped through the ArcGIS 10.4 program. Then, rainwater sewage systems were applied by finding the points where the water accumulates. Low-impact development (LID) technologies such as permeable pavement, green roofs, rain barrels, bio-retention cells, vegetative swales, infiltration trenches, and rain gardens were applied to 20 different subcatchments throughout the area. In addition, as in other studies, rainwater infiltration and drainage measurements were first made without LID systems. The selected low-impact improvement systems are those that have been applied in other studies and have had positive results, so they are preferred. According to

Table 4 The rate of subcatchment area

	Permeable surface			Impermeable surface			Total Area
	Total area	Green Area		Roof Area	Concrete Area		
		Amount (m ²)	Percent (%)		Amount (m ²)	Percentage (%)	
S1	2578 m ²	1564 m ²	60,6	430 m ²	16,7	584 m ²	1014 m ²
S2	7236 m ²	4236 m ²	58,5	1190 m ²	16,5	1810 m ²	3000 m ²
S3	6505 m ²	3542 m ²	54,4	1122 m ²	17,2	1841 m ²	2963 m ²
S4	7214 m ²	4042 m ²	56,1	1145 m ²	15,9	2027 m ²	3172 m ²
S5	6364 m ²	3464 m ²	54,5	1214 m ²	19	1686 m ²	2900 m ²
S6	12,446 m ²	4196 m ²	33,7	4020 m ²	32,3	4230 m ²	8250 m ²
S7	12,692 m ²	3927 m ²	31	4932 m ²	38,8	3833 m ²	8765 m ²
S8	3133 m ²	1047 m ²	33,5	1086 m ²	34,6	1000 m ²	2086 m ²
S9	2931 m ²	1206 m ²	41,2	1094 m ²	37,3	631 m ²	1725 m ²
S10	2931 m ²	1206 m ²	41,2	1094 m ²	37,3	631 m ²	1725 m ²
S11	7960 m ²	2000 m ²	25,1	4470 m ²	56,2	1490 m ²	5960 m ²
S12	2376 m ²	100 m ²	4,2	1500 m ²	63,2	776 m ²	2276 m ²
S13	2512 m ²	500 m ²	20	1500 m ²	59,7	512 m ²	2012 m ²
S14	6667 m ²	1367 m ²	20,5	4000 m ²	60	1300 m ²	5300 m ²
S15	6902 m ²	2402 m ²	34,8	2500 m ²	36,2	2000 m ²	4500 m ²
S16	712 m ²	0	0	600 m ²	84,3	112 m ²	712m ²
S17	9139 m ²	9139 m ²	100	0	0	0	0
S18	7817 m ²	7817 m ²	100	0	0	0	0
S19	2303 m ²	2303 m ²	100	0	0	0	0
S20	8771 m ²	8771 m ²	100	0	0	0	0

the results obtained, the most efficiency was obtained from the permeable pavement, infiltration trench, bio-retention cell, rain garden, and rain barrel modules. In these systems, the surface flow is reduced by 32%. By using the vegetative swale tool, the runoff was reduced by 11%, and in the green roof application, the runoff was reduced by 31%. These modules have been applied to 50% of the area's basins, corresponding to the 25 square meter unit ratio of each subcatchment. The importance of using green and blue infrastructure systems in urban areas is seen in this study and previous studies. Table 5 shows the rate of infiltration, drainage, and storage of LID modules.

In this study, blue and green infrastructure systems incorporating low-impact development (LID) technologies were utilized. Precipitation data from January 2021 to March 2023 were obtained from the Karşıyaka meteorology station, located in the Karşıyaka district of İzmir province. These data were used to create scenario studies addressing potential flood risks due to heavy rainfall. The study revealed that only 30% of the precipitation can infiltrate underground in the absence of LID systems. However, various LID systems demonstrated higher infiltration rates: permeable pavements allowed for 57.2%, infiltration trenches 40.2%, bio-retention cells 41%, rain gardens 40.4%, and rain barrels 51.2%. Additionally, vegetative swales facilitated 37% infiltration, while green roofs achieved 51.3%. These figures highlight the positive impact of these systems on efficient rainwater use. Consequently, the integration of such systems into urban and rural areas is highly recommended. In summary, LID systems significantly reduce the proportion of storm water entering surface runoff. They enable rainwater to be stored and reused, infiltrate underground to replenish groundwater, or enhance urban ecology through the creation of small-scale ponds.

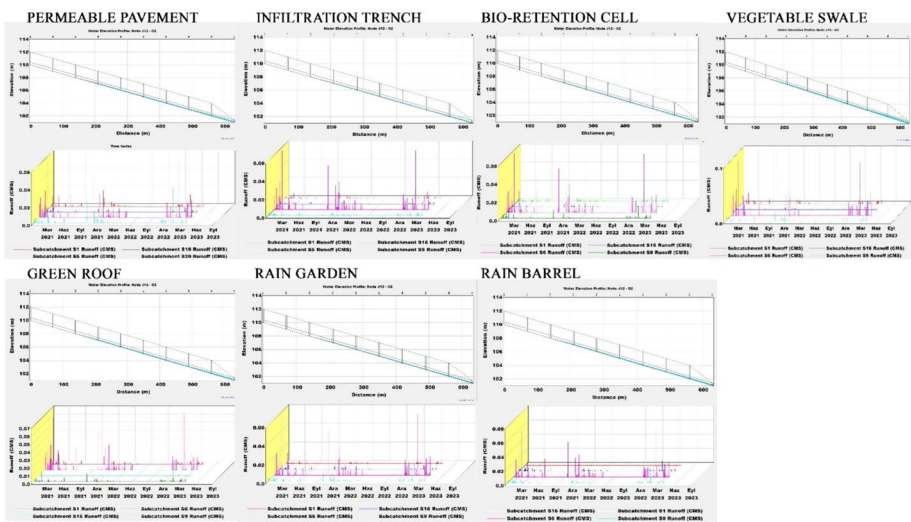


Fig. 8 Rainwater profile with LID Tools

4 Discussion

In urban areas, flooding, which is the most negative result of climate change, is the main global challenge because of severe rainfall and unstable runoff regimes. As a result of the situation, many countries try to solve this problem by using green infrastructure. The purpose of a green infrastructure system is to repair, recreate and restore the hydrological cycle (Green et al. 2018). In addition to green infrastructure, blue infrastructure is essential for urban areas. Green is related to vegetation and blue includes hydrological features with urban design projects. Blue and green infrastructure systems involve hydrological and ecological water enhancement. The systems cover engineering and design tools such as bioswale, rain gardens, detention and retention lakes and swales, green roofs, and infiltration systems (Ramboll 2016). The benefits of green infrastructure are ecological, economic, and social advantages with natural-based solutions. Blue and green infrastructure (BGI) is a key element for rainwater management. The system, which is different from grey infrastructure, proposes to reduce flood risk and increase water quality and urban biodiversity (Demircan et al. 2020). In many countries, blue and green infrastructure-based solutions are implemented. Dinçer (2022) aims to reduce problems caused by intense rainwater by using Low Impact Development (LID) modules such as green roofs, rain barrels, permeable pavement, and rain gardens with the ArcGIS program and Stormwater Management Modules (SWMM). The result of the research shows surface runoff is reduced with green roofs (2, 15%), rain barrels (8, 10%), permeable pavement (6, 60%), and rain gardens (6, 60%). In Semnan Province/Iran, flooding causes a lot of fatal catastrophe problems. Due to this reason, it is aimed to reduce flood risk by using LID modules with the SWMM program and SCS method. Infiltration trenches and rain barrels are the most efficient tools because peak flow and flow volume are reduced to the lowest level (Sadeghianzhad 2019). In China, a sponge city is tried to create by using a LID combination such as permeable pavement, green roof, and vegetative swale, with the preferences-inspired co-evolutionary algorithm (PICEA-g algorithm). Also, the modules are compared with the NSGA-II method, and the peak flow reduction rate, runoff reduction rate, and SS pollutants are decreased (Men et al. 2020). In Korea, infiltration trenches and permeable pavement are used from LID systems. The LID systems are combined with the TOPSIS method. In the method, many LID practices are prioritized. Besides, the study emphasizes calculating social and economic criteria for sustainable plans (Song and Chung 2017). The other

Table 5 Results of low impact development modules

	Total precipitation	Surface runoff	LID drainage (mm)	Final storage (mm)	The rate of surface runoff
Non-LID	1120.800	773.191	–	5.884	%70
Permeable Pavement	1120.800	641.214	–	8.581	%57,2
Infiltration Trench	1120.800	451.191	0.071	1.953	%40,2
Bio-Retention Cell	1120.800	460.540	–	54.710	%41
Vegetative Swale	1120.800	414.852	–	0.860	%37
Green Roof	1120.800	575.697	279.422	29.091	%51,3
Rain garden	1120.800	452.850	–	54.993	%40,4
Rain Barrel	1120.800	574.423	262.388	40.155	%51,2

study compared the performance of vegetative swale and bio-retention cells. According to the study, the alteration of LID structure and the parametric calibration are more enhanced in the vegetative swale tool. On the other hand, the bio-retention cell calibration is not advanced (Bond et al. 2021). In Jiangsu province, China, four LID scenarios such as green roofs, permeable pavement, concave greenbelt, and rain gardens are performed in the same locations. A green roof is the best practice for decreasing runoff. However, the rain garden tool has the lowest performance (Bai et al. 2018; Chui et al. 2016) compared LID applications based on green roofs, bio-retention cells, and porous pavement performance between the cities of Hong Kong and Seattle. The peak runoff reduction/thousand Dollars of LID modules in Hong Kong was found to be lower than in Seattle. Many articles have proven that BGI systems and solutions, consisting of rain gardens, green roofs, permeable pavement, as well as vertical greening systems, make a positive contribution to urban hydrology (Pochodyła et al. 2021). In Bangkok, Thailand, flooding is a catastrophic problem, because of the trouble, long-term and short-term soft and hard engineering solutions are developed. Low Impact Development systems are preferred to reduce the negative effect of flooding because the technologies enhance water quality, and also, a reasonable and sustainable approach. Single and multiple scenarios are improved and the study helps to reduce sewer overflow volume, pollutants, and surface flooding (Chaosakul et al. 2013). An experimental study with the SWMM program in Brazil, Sao Paulo has shown that infiltration trenches and green roofs are efficient tools that can be used to reduce the risk of flooding (Mattos et al. 2017). Low-impact development and sponge city implementations are valuable, especially for urban land use. Besides, It is shown that development capacity, supporting facilities, urban design guidance, ecology, building construction, and environmental protection are regulated with LID modules in a variety of areas such as squares, urban water systems, and urban roads (Ji and Bai 2021).

5 Conclusion

Within the scope of this study, the destructive effects caused by the flood risk were tried to be minimized through green and blue infrastructure systems. Low-impact development technologies, which are a new and modern system, reduce surface runoff and allow rainwater to pass underground. These systems have been developed as an alternative to the traditionally called gray infrastructure and can be easily integrated into cities. Integrating low-impact development technologies into impermeable surfaces is very valuable in terms of adapting cities to climate change in the future. It is important to include blue and green infrastructure systems in urban design and urban regeneration project guides and to support these practices with various policy decisions. Because urban floods cause economic, social, and vital damages. As the permeable pavement ratio decreases in cities, the problem of flood risk increases at the same rate. Thinking of a solution only in green areas causes an incomplete study on the basis of design and planning studies. Therefore, the use of blue infrastructure systems is essential to complete adaptation to climate change. Undoubtedly, increasing the green areas in the cities will greatly reduce the flood rate, in addition, the collection and effective use of rainwater is an effective method.

In the calculations made according to the 60-s time step, it was determined as a result of the analysis that the flood risk was not observed even on the days when the precipitation rate was high using the LID technique. It has been observed that it gives efficient results in 30 and 15-s time periods. As a result of the research, it was determined that the

commonly used systems of the blue and green infrastructure gave efficient results in the measurements. The study, which takes into account the number of rainy days for approximately 2.5 years, shows that even in the case of heavy rainfall, the risk of flooding can be prevented by using these systems. The modules can be integrated into buildings, pavements, building roofs, building walls, gardens, and urban parks. The article explores which modules should be used and which techniques have good performance to mitigate floods. Integrating blue and green infrastructure systems in the transportation networks and urban squares where the city is heavily used will reduce the effects of heavy rain. In addition to these, the applications are low-cost applications, so they can be included in short and long-term planning studies. There is likely to be a risk of flooding at the time of precipitation and after precipitation, so long-term planning studies are valuable for prevention. The use of rainwater harvesting systems in health, commercial, residential, and educational buildings, as well as the creation of rain gardens or vegetative swales on a large or small parcel of land, are major impact studies on a small scale.

Climate change adaptation strategies are often ignored when planning urban regeneration efforts. Therefore, it is a situation that has not adapted to changing climatic conditions and is likely to wear out over time. In particular, neighborhoods located on stream beds and areas with steep slopes are defined as places where flood risk is most common. In addition to topographical features, if adequate infrastructure works have not been carried out in that region, it is inevitable that the neighborhood or region will be damaged due to flooding. For this reason, when determining urban regeneration planning and design strategies, climate change adaptation strategies should be included in the first items. From flooring to roofing materials, tools suitable for climate change should be used. This study has an original feature in terms of showing and describing how the neighborhood in the urban regeneration process will be designed in accordance with the climate. It shows which criteria will be taken into consideration when redesigning neighborhoods, streets, and cities.

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Consent to participate The author(s) declared to approve of participation.

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References

- Adams RM, Peck DE (2008) Effects of climate change on water resources. *Choices* 23(1):12–14
- Anonymous. *İzmir Büyükşehir Belediyesi*. 2023. <https://kentseldonusum.izmir.bel.tr/tr/Projeler/17/21>.
- Bai, Y, N Zhao, R Zhang, and X Zeng (2018) "Storm Water Management of Low Impact Development in Urban Areas Based on SWMM." *Water*, <https://doi.org/10.3390/w11010033>.
- Bai, Y, R Li, R Zhang, N Zhao, and X Zeng (2019) "Comprehensive Performance Evaluation System Based on Environmental and Economic Benefits for Optimal Allocation of LID Facilities." *Water*, 11, 341; <https://doi.org/10.3390/w11020341>.
- Bal, Ö H (2008) "İzmir'de Kentsel Dönüşüm Sürecinin İzmir-Cennetçeşme Mahallesi Üzerinden İrdelenmesi." *Master Thesis*. İzmir: Dokuz Eylül University Natural and Science Institute.
- Battemarco, B P, et al (2022) "Water dynamics and blue-green infrastructure (BGI): Towards risk management and strategic spatial planning guidelines". *Journal of Cleaner Production*, 1–14.
- Bond J, Batchabani E, Fuamba M, Courchesne D, Trudel G (2021) Modeling a Bioretention Basin and Vegetated Swale with a Trapezoidal Cross Section using SWMM LID Controls. *Journal of Water Management Modeling*, ISSN 2292–6062(29):474. <https://doi.org/10.14796/JWMM.C474>
- Cea L, Costabile P (2022) Flood Risk in Urban Areas: Modelling, Management and Adaptation to Climate Change. A Review. *Hydrology* 9(3):50. <https://doi.org/10.3390/hydrology9030050>
- Cebe, K, and A Inan (2022) "Havran Baraj Gölüne Dökülen Yüzeysel Akışın SWMM ile Tahmini." *European Journal of Science and Technology Special Issue* 152–160
- Chaosakul T, Koottatep T, Irvine KN (2013) Application of Low Impact Development (LID) Scenarios to Assess Localized Flood Reduction: A Case Study of Rattanakosin Village, Thailand. *Journal of Water Management Modeling*. <https://doi.org/10.14796/JWMM.R246-18>
- Chui TF, Liu X, Zhan W (2016) "Assessing cost-effectiveness of specific LID practice designs in response to large storm events." *J Hydrol* 2016(533):353–364. <https://doi.org/10.1016/j.jhydrol.2016.05.011>
- Çınar, A K, Y Akgün, and N K Akıncı (2016) "Çiğli-Güzeltape Mahallesi için Kentsel Dönüşüm Modeli Önerisi." *Ege Mimarlık*, 42–45.
- Demircan N, Aksu A, Kuzuluğil AC (2020) Mavi-Yeşil Altyapı Kapsamında Erzurum Kent Merkezinin Değerlendirilmesi. *Bartın Orman Fakültesi Dergisi* 22(2):409–421. <https://doi.org/10.24011/barofd.696955>
- Diñçer T (2022) Yeşil Altyapı Sistemleri Kapsamında Yağmur Suyu Yönetimi: Malatya Kent Örneği. *Türk Tarım Ve Doğa Bilimleri Dergisi* 9(4):1088–1101. <https://doi.org/10.30910/turkjans.1177827>
- Erdoğan, S, A Akgün, and S Erzincan (2007) "Gediz Delta Management Plan [Gediz Deltası Yönetim Planı]". Ministry Of Environment And Forest General Directorate Of Nature Conservation And National Parks, 1–452
- Green D et al (2018) Green infrastructure: The future of urban flood risk management? Wiley. <https://doi.org/10.1002/wat2.1560>
- Hamouz, V, and T M Muthanna (2018) "Modelling of Green and Grey Roofs in Cold Climates using EPA's Storm Water Management Model". 11th International Conference on Urban Drainage Modelling. Italy 1–6
- Ji M, Bai X (2021) Construction of the sponge city regulatory detailed planning index system based on theSWMMmodel. *Environ Technol Innov*. <https://doi.org/10.1016/j.eti.2021.101645>
- Kourtis, I K, V A Tsihrantzis, and E Baltas (2018) "Simulation of Low Impact Development (LID) Practices and Comparison with Conventional Drainage Solutions". *Proceedings*, 1–8. 2 640 <https://doi.org/10.3390/proceedings2110640>
- Kundzewicz ZW (2008) Climate change impacts on the hydrological cycle. *Ecohydrol Hydrobiol*. <https://doi.org/10.2478/v10104-009-0015-y>
- Leimgruber J, Krebs G, Camhy D, Muschalla D (2019) Model-Based Selection of Cost-Effective Low Impact Development Strategies to Control Water Balance. *Sustainability*. <https://doi.org/10.3390/su11082440>
- Lennon M, Scott M, O'Neill E (2014) Urban Design and Adapting to Flood Risk: The Role of Green Infrastructure. *J Urban Des*. <https://doi.org/10.1080/13574809.2014.944113>
- Liao, K H, S Deng, and P Y Tan (2017) "Blue-Green Infrastructure: New Frontier for Sustainable Urban Stormwater Management". In *Greening Cities: Forms and Functions*, by P Y Tan and C Y Jim, 203–226. Singapore: Springer Nature Singapore Pte Ltd.
- Liu, Q, W Cui, Z Tian, Y Tang, M Tillotson, and J Liu (2022) "Stormwater Management Modeling in "Sponge City" Construction: Current State and Future Directions". *Frontiers in Environmental Science* 1–16.

- Madrazo-Uribetxebarria E, Antín MG, Berrondo JA, Andrés-Doménech I (2022) Modelling Runoff from Permeable Pavements: A Link to the Curve Number Method. *Water* 15(160):1–19. <https://doi.org/10.3390/w15010160>
- Mattos, R N, R P Reis, and M S Ilha (2017) “Use of Storm Water Management Model for on lot drainage”. *CIBW062 Symposium 2017*. Haarlem, 1–13.
- Men H, Lu H, Jiang W, Xu D (2020) Mathematical Optimization Method of Low-Impact Development Layout in the Sponge City. *Hindawi Mathematical Problems in Engineering*, Article. <https://doi.org/10.1155/2020/6734081>
- OECD (2013) The Organisation for Economic Co-operation and Development. OECD, Water and climate change adaptation an OECD Perspective
- Open Swmm. *Swmm Knowledge Base*. 2008. <https://www.openswmm.org/Topic/3818/estimating-subcatchment-width>.
- Pochodyła, E, K Glińska-Lewczuk, and A Jaszczak (2021) "Blue-green infrastructure as a new trend and an effective tool for water management in urban areas." *Landscape Online – transdisciplinary journal bridging science, policy and practice*, 1–20. <https://doi.org/10.3097/LO.202192>.
- Raju KS, Kumar DN (2018) *Impact of Climate Change on Water Resources*, Springer Climate. Springer. https://doi.org/10.1007/978-981-10-6110-3_1
- Ramboll (2016) *Enhancing Blue-Green Infrastructure & Social Performance In High Density Urban Environments*. Involved Universities And Researchers.
- Rey Valencia, D, and J Zambrano Nájera (2019) "Application Of Rain Barrels For Flood Control In An Urban Mountain Basins." *E-proceedings of the 38th IAHR World Congress September 1–6, 2019*, Panama City, Panama: ISSN 2521–7119 (Print)-ISSN 2521–716X (Online)-ISSN 2521–7127 (USB) <https://doi.org/10.3850/38WC092019-0906.1276–1284>.
- Rossman LA (2010) *StormWater Management Model User's Manual, Version 5.0; National Risk Management Research Laboratory*. USA: Office of Research and Development, US Environmental Protection Agency: Cincinnati, OH.
- Rossman LA, Simon MA (2022) *Storm Water Management Model User's Manual Version 5.2*. Washington: United States Environmental Protection Agency. Washington, D. C.
- Sadeghinazhad, S (2019) “Low Impact Development (Lid) Practices In Flood Control Of Urban Areas Using Swmm (Storm Water Management Model)”. *Master Thesis*. İstanbul: İstanbul Technical University Graduate School of Science Engineering and Technology.
- Saliba SM, Bowes BD, Adams S, Beling PA, Goodall JL (2020) Deep Reinforcement Learning with Uncertain Data for Real-Time Stormwater System Control and Flood Mitigation. *Water* 1–19(12):3222. <https://doi.org/10.3390/w12113222>
- Song JY, Chung ES (2017) A Multi-Criteria Decision Analysis System for Prioritizing Sites and Types of Low Impact Development Practices: Case of Korea. *Water* 9:291. <https://doi.org/10.3390/w9040291>
- Sörensen, J (2018) “Urban, pluvial flooding: Blue-green infrastructure as a strategy for resilience. [Doctoral Thesis (compilation), Division of Water Resources Engineering]”. Faculty of Engineering (LTH), Lund University., 1–83
- Sörensen, J, and T Emilsson (2018) “Evaluating Flood Risk Reduction by Urban Blue-Green Infrastructure Using Insurance Data”. *American Society of Civil Engineers*, 145(2): 04018099. 1–11
- Tombul, M (2022) “Event-Based Urban Flood Modelling With Swmm Program”. *Master Thesis*, 1–66.
- TÜİK (2021) *31 Aralık 2021 Tarihli Adrese Dayalı Nüfus Kayıt Sistemi (Adnks) Sonuçları Mahalle Nüfusları*. Türkiye: TÜİK.
- UN Water (2017) *Climate Change and Water UN-Water Policy Brief*. Switzerland: UN-Water Technical Advisory Unit.
- UN Water (2020) *The United Nations World Water Development Report 2020 'Water and Climate change'*. United Nations Educational, Scientific and Cultural Organization.
- Walsh, T C, C A Pomeroy, and S J Burian (2013) “Hydrologic modeling analysis of a passive, residential rainwater harvesting program in an urbanized, semi-arid watershed”. *Journal of Hydrology*, 240–253. <https://doi.org/10.1016/j.jhydrol.2013.10.038>.
- Xu C et al (2019) Benefits of coupled green and grey infrastructure systems: Evidence based on analytic hierarchy process and life cycle costing. *Elsevier* 2019:1–10. <https://doi.org/10.1016/j.resconrec.104478>
- Zhang, S, and Y Guo (2014) “SWMM Simulation of the Storm Water Volume Control Performance of Permeable Pavement Systems”. *American Society of Civil Engineers*, 1–6. [https://doi.org/10.1061/\(ASCE\)HE.1943-5584.0001092](https://doi.org/10.1061/(ASCE)HE.1943-5584.0001092)
- Zheng, Y, S Chen, H Qin, and J J Jiao (2018) “Modeling the Spatial and Seasonal Variations of Groundwater Head in an Urbanized Area under Low Impact Development”. *Water* 1–17. <https://doi.org/10.3390/w10060803>

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