



## NEIGHBOURHOOD SCALE ASSESSMENT OF RAINWATER HARVESTING

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### ABSTRACT

In this study, certain design and analyses have been carried out to create sustainable stormwater management within the boundaries of the study area determined in Balıkesir city. In this context, novel design proposals have been developed for sustainable rainwater management in building and green areas. The potential amount of rainwater that could be harvested from building roof areas has been quantitatively assessed; the capacity of this water to meet the irrigation water needs of public green areas in the surrounding area has been analysed. In consequence of the study, in accordance with the design recommendations that underpin the efficient use of water, the hard floor coverings in the immediate vicinity of the buildings were re-evaluated by transforming them into permeable surfaces within the framework of sustainable urban design principles. In the design of the proposed urban furniture, integrated solar energy systems, rainwater harvesting and reuse, green space integration and user-friendly features are adopted as basic design principles. In the study, the annual rainwater harvest under the existing conditions was calculated as 1,006,724 litres. However, when the area was redesigned within the framework of blue-green infrastructure principles, the rainwater harvesting efficiency and annual water demand were determined as 1,723,104 litres/year and 1,500,000 litres/year, respectively. These results indicate that the proposed design significantly enhances water collection capacity and contributes to the sustainable management of water resources.

**Keywords:** *Landscape planning, rainwater harvest, climate change, urban water management, sustainability and energy efficient design.*

## MAHALLE ÖLÇEĞİNDE YAĞMUR SUYU HASADININ DEĞERLENDİRİLMESİ

### ÖZET

Bu çalışmada, Balıkesir ilinde belirlenen çalışma alanı sınırları içinde sürdürülebilir yağmur suyu yönetimi oluşturmak için belirli tasarım ve analizler yapılmıştır. Bu bağlamda, bina ve yeşil alanlarında sürdürülebilir yağmur suyu yönetimi için yeni tasarım önerileri geliştirilmiştir. Bina çatı alanlarından toplanabilecek yağmur suyunun potansiyel miktarı nicel olarak değerlendirilmiştir; bu suyun çevredeki kamu yeşil alanlarının sulama suyu ihtiyacını karşılama kapasitesi analiz edilmiştir. Çalışma sonucunda, suyun verimli kullanımını destekleyen tasarım önerileri doğrultusunda, binaların hemen çevresindeki sert zemin kaplamaları, sürdürülebilir kentsel tasarım ilkeleri çerçevesinde geçirgen yüzeylere dönüştürülerek yeniden değerlendirilmiştir. Önerilen kentsel mobilya tasarımında, entegre güneş enerjisi sistemleri, yağmur suyu toplama ve yeniden kullanımı, yeşil alan entegrasyonu ve kullanıcı dostu özellikler temel tasarım ilkeleri olarak benimsenmiştir. Çalışmada, mevcut durumda yıllık yağmur suyu hasadı 1,006,724 litre olarak hesaplanmıştır. Ancak alan mavi-yeşil altyapı ilkeleri doğrultusunda yeniden tasarlandığında, yağmur suyu toplama verimliliği ve yıllık su ihtiyacı sırasıyla 1,723,104 litre/yıl ve 1,500,000 litre/yıl olarak belirlenmiştir. Bu sonuç, önerilen tasarımın su toplama kapasitesinde anlamlı bir artış sağlayarak su kaynaklarının sürdürülebilir yönetimine katkı sunduğunu göstermektedir.

**Anahtar Kelimeler:** *Peyzaj planlama, yağmur suyu hasadı, iklim değişikliği, kentsel su yönetimi, sürdürülebilirlik ve enerji verimli tasarım.*

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## 1. INTRODUCTION

In the contemporary era, the integration of energy and water policies at global and national levels is of paramount importance in achieving sustainable development goals. The protection and transfer of natural resources to future generations is supported by various studies, including those on climate change, waste management, transport and sustainable building design (Üstün et al., 2020; Fei et al., 2021; Ufacık, 2024). The observed changes in climate over the past 50 years are predominantly attributed to anthropogenic activities. The accelerated consumption of fossil fuels, industrialisation, urbanisation and changes in land use have been identified as key drivers of global warming, increasing the pressure on water resources (Ugupta et al., 2015; Hernández & Morote, 2019; Srivastav et al., 2021). Increases in global temperatures, heat waves, heavy rainfall, floods, and sudden droughts due to global warming have accelerated temporal and spatial changes in the water cycle by triggering extreme weather events, making climate change a major concern for society (Yang et al., 2021; IPCC, 2023; Kenanoğlu et al., 2024).

The intensification of climate change, characterised by increasing global temperatures, prolonged droughts, floods, and irregular precipitation patterns, has significantly disrupted the global water cycle and intensified water scarcity risks (UNESCO, 2022; Ehtasham et al., 2024). Within the framework of the United Nations 2030 Agenda (2019), the Sixth Sustainable Development Goal (SDG 6), Clean Water and Sanitation, underscores the alarming reality that over 733 million individuals still reside in areas facing high or extreme levels of water scarcity. Consequently, the water crisis has emerged not only as an environmental concern but also as a multidimensional issue that threatens economic stability and social well-being worldwide. In addition, the rapid growth of the global population, coupled with excessive domestic, industrial, and agricultural water consumption, has accelerated the depletion of freshwater reserves and heightened pressure on available resources (Solak et al., 2019; Dosdoğru et al., 2020; Ertop et al., 2023; Mısırlı & Şişman, 2025). In this context, the need for sustainable and integrated water management strategies has become increasingly critical to ensure the continuity of ecosystems and the resilience of human settlements (WWAP, 2015).

These ratios are based on average estimates reported in previous empirical studies and may vary depending on building characteristics, user behaviour, and climatic conditions. RWH (Rainwater Harvesting) techniques include a range of engineered and nature-based methods designed to capture, store, and reuse rainfall. These techniques comprise storage tanks, recharge wells, percolation pits, infiltration trenches, check dams, and rain gardens. Roofs and other impervious surfaces serve as collection areas that direct rainwater to conveyance and storage components. In this context, surface runoff refers to rainfall that flows over non-permeable or saturated ground before infiltration or collection (Fewkes & Butler, 2000; Yuen et al., 2001; Xie et al., 2017; Teston et al., 2022; Toyran & Var, 2022). These techniques, adaptable to diverse climatic and urban conditions, form a critical element of blue-green infrastructure strategies (Hepcan & Cangüzel, 2024). In the context of rapid urbanisation and increasing water stress, RWH is increasingly recognised not merely as a water-saving practice but as a multi-functional approach that supports urban sustainability through co-benefits such as improved water-supply reliability, reduced stormwater runoff, microclimate regulation, and the enhancement of urban greenery (Liu et al., 2019; de Sá Silva et al., 2022; Alkan & Hepcan, 2022). However, despite the growing global emphasis on sustainable water management, there remains a distinct research gap regarding the neighbourhood-scale quantification of roof runoff potential and its relationship to landscape-irrigation demand, particularly in mid-sized Turkish cities. Addressing this gap is crucial for developing locally adaptive blue-green infrastructure models that strengthen the resilience of urban ecosystems under changing climatic conditions (Bostancı, 2022; Şimşek & Demir, 2023; Dağ & Ay, 2024). Consequently, the necessity for alternative and sustainable water management solutions is on the rise (Campisano et al., 2017; Morales-Figueroa et al., 2023).

The aim of this study is to calculate the quantity of rainwater that could be obtained from the roof areas of the buildings by introducing new design proposals within the scope of sustainable rainwater management in the area determined within the boundaries of Yıldırım neighbourhood of Balıkesir city centre and to analyse the potential of the collected water to meet the water demand in green areas.

## 2. MATERIAL AND METHOD

The main reason for selecting the province of Balıkesir in this study is the increasing drought problem in the region in recent years (Turkish State Meteorological Service, 2025). Balıkesir is located within the borders of the Marmara Region in northwestern Türkiye (approximately 39°39' N, 27°52' E). The Marmara Region forms a transition area between Europe and Asia, connecting the Aegean Sea and the Black Sea. An analysis of drought values in the region has determined that many provinces, including Balıkesir, are at risk (Soydan, 2023). According to the Köppen-Geiger climate classification, the region has a Mediterranean climate (Csa) characterized by hot, dry summers and mild, rainy winters (Turkish State Meteorological Service, 2025).

### 2.1. Materials

The study area is located within the boundaries of Yıldırım Neighbourhood (Figure 1) of Balıkesir city centre. The reason for choosing this area is that it has the potential to examine architectural and landscape areas with different characteristics together. The study area is 13.112 m<sup>2</sup> in total and includes 1 registered mosque (ŞeyhLütfullah Mosque) and cemetery area, 1 registered officer's army house, residential and commercial areas, pedestrian roads, car park and hard ground areas.



Figure 1. Location of the study area.

Şeyh Lütfullah Mosque, located in Balıkesir's Yıldırım neighbourhood, is an early Ottoman-era structure built in 1429. The building was constructed from cut stone in a rectangular plan. The last-prayer porch is reached by a three-step stairway, and the women's gallery positioned at the front gives the façade a two-storey appearance. The minaret rises on a square base with a cylindrical shaft and a single balcony. Situated together with its dervish lodge, cemetery and burial enclosure the mosque occupies an important place in Balıkesir's historical and cultural memory and retains significant spiritual and social value for the local community (Akkuş, 2018; Tibet, 2024). Built in the early years of the Republic (the exact date is unknown), the army house is a two-storey stone building with an attic and a basement and is a listed monument. Originally designed for military purposes, the mass, structural system and heritage status of this building allow for limited intervention scenarios, particularly with regard to roof alterations (Karesi District Governor's Office, 2025).

For the purpose of the rainwater harvesting analysis, the site was characterised in terms of land-use/land-cover (LULC), imperviousness ratio, and surface hydrology, rather than architectural landmarks. Out of the total surface area, approximately 7,754.11 m<sup>2</sup> (59.1%) consists of impervious surfaces, including roofs, asphalt pavements, and concrete-covered areas, while 2,236.58 m<sup>2</sup> (17.1%) represents permeable or green areas such as grassland, soil, and vegetated spaces. The remaining

portion of the site includes built-up and semi-permeable transition zones. The average ground slope ranges between 3–5%, reflecting a gentle topography that facilitates surface runoff towards lower elevations suitable for rainwater collection. The infiltration capacity of the soil, derived from field observations and municipal data, corresponds to moderately permeable loamy soil with an infiltration rate of approximately 15–25 mm/h.

The average temperature, precipitation, and number of rainy days in this region between 1999 and 2024 are shown in Table 1.

Table 1. Meteorological data for the study area for the period 1999-2024 (Turkish State Meteorological Service, 2025).

Month	Average Temperature (°C)	Average Precipitation (mm)	Average Number of Rainy Days
January	4.8	87.1	12
February	6.2	75.1	10
March	8.8	64.3	9
April	12.9	56.3	8
May	17.7	37.2	7
June	22.7	35.6	4
July	25.6	12	2
August	25.6	4.8	2
September	21.3	27.9	5
October	16	46.2	8
November	10.4	76.1	10
December	6.4	81	10
Annual Average	16.4	603.6	97

According to the Climate Change Action Plan (2024-2030) prepared by Balıkesir Metropolitan Municipality, annual average temperatures in the city have increased by more than 1 °C in the last 100 years. While the average temperature in the city in 2024 was 14.8 °C, this value is estimated to increase to 17 °C according to the projections for 2040. In order to examine the results of climate change and its impact on the city, not only temperature values but also precipitation values should be examined, and future projections should be put forward. As a result of the studies conducted, it is predicted that seasonal distributions in precipitation will show a continuous change after 2024 and the average annual precipitation amount calculated as 675.6 mm in 2024 will decrease by 175 mm to 500 mm by 2050 (Balıkesir Metropolitan Municipality, 2024). The climate data of the region was obtained from Balıkesir Meteorological Regional Directorate and is based on the 25-year measurement station records between 1999-2024. In the light of these data, the average annual precipitation of the region was determined as 603.6 mm.

## 2.2. Method

In this study, new design proposals were developed within the scope of sustainable rainwater management for buildings and green areas within the boundaries of the study area; the quantity of rainwater that could be obtained from the roof areas of the buildings was figured out and the potential of this water to meet the irrigation water needs of the public green areas in the area was analysed. The method of the study consists of 4 stages (Figure 2). These stages are respectively:

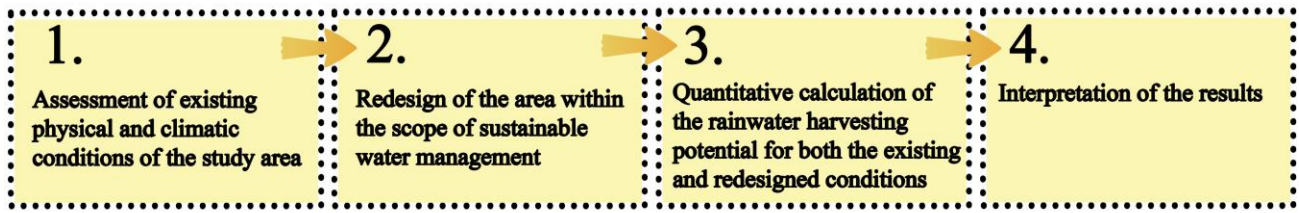


Figure 2. Method flow chart.

In the first stage of the method, the existing characteristics of the study area were identified through the collection and evaluation of various spatial and environmental datasets.

Specifically, the following data were collected and analysed:

- Land-use and settlement data: obtained from the Karesi Municipality Directorate of Zoning and Urbanisation, used to identify the distribution of residential, commercial, public, and open spaces.
- Topographical and surface characteristics: including building footprints, roof surface areas, and the distribution of permeable and impermeable surfaces, digitised using AutoCAD software and satellite imagery.
- Climatic data: the average precipitation, temperature, lowest and number of rainy days in this region for the period between 1999 and 2024 were obtained from the records of the Balıkesir Meteorological Regional Directorate.
- Projected climate change data: derived from the Balıkesir Metropolitan Municipality Climate Change Action Plan (2024–2030).

These datasets formed the empirical basis for assessing the hydrological potential of the area and for subsequent calculations of rainwater harvesting efficiency. In the second stage of the method, design proposals for the blue-green infrastructure in the study area were proposed for the effective creation and management of rainwater harvesting. In addition, the amount of permeable surfaces on the roofs of suitable buildings and permeable surfaces in green areas were calculated by AutoCAD software in order to effectively manage rainwater in the study area.

During the third stage of the study, the potential volume of rainwater that could be harvested was quantitatively estimated for both the existing condition and the redesigned scenario using the rainwater harvesting method. There are national and international companies that carry out the installation, assembly and operation of rainwater harvesting systems, and various regulations are used for these systems, such as DIN 1989 in Germany, BS 8515 in the UK and regulations published in the Official Gazette dated 2017 and 2021 in Türkiye (Dağ & Ay, 2024). Regarding rainwater harvesting in Türkiye, the “Regulation on Rainwater Collection, Storage and Discharge Systems” issued and put into force by the Ministry of Environment, Urbanisation and Climate Change sets out the procedures and principles regarding the design, planning, projecting, construction and operation of these systems; in addition, with the amendment made to the Planned Areas Zoning Regulation, it has become mandatory to install a rainwater collection system in new buildings to ensure underground storage of rainwater collected on roofs. However, taking into account the growing water crisis, the same regulation published in the Official Gazette No. 31373 in 2021 stipulates that rainwater collected on the roofs of all buildings planned to be constructed on plots larger than 2,000 m<sup>2</sup> must be collected in underground storage facilities for green area irrigation or treated and used for building needs (Şimşek & Demir, 2023).

In this study, rainwater harvesting calculations for both the existing condition and the proposed design of the study area were conducted in accordance with the German standard DIN 1989-1:2002-04 (DIN, 1989). Rainwater yield was calculated with the following formula (Equation 1):

$$E_R = A_A \times e \times h_N \times n \quad \text{Equation (1)}$$

In this formula,  $E_R$  is the rainwater yield (litres/year),  $A_A$  is the roof area (m<sup>2</sup>),  $e$  is the yield coefficient  $h_N$  is the average annual rainfall of the region (litres/m<sup>2</sup>),  $n$  is the hydraulic filter efficiency coefficient

(if a filter is used). Here, the efficiency coefficient is calculated by taking into account the difference between the amount of rainfall and the amount of water that actually flows out, taking into account the location, slope, orientation and nature of the collection area, and Table 2 shows the efficiency coefficients for different roof and surface areas. Since the roofs in our study area are within the scope of steep slope roofs, the efficiency coefficient is taken as 0.90.

Table 2. Efficiency coefficients for different roof and surface areas (DIN, 1989-1: 2002-04).

Building	Yield coefficient
Metal roof (sloping)	0.90
Concrete Flat roof	0.80
Gravel flat roof	0.60
Green dense roof	0.30
Extensive green roof	0.50
Concrete surface (ground)	0.50
Asphalt surface	0.80

After the calculation of stormwater harvesting, water need and usage areas were determined, and the storage volume of the collected water was calculated. The irrigation water requirement was calculated for the hard soil grassland, which was determined as public area, and was determined over the annual irrigation requirement. The storage volume was calculated considering a 3-week (21-day) rain-free period. The formula used to base on the British Standard BS (2009) (Equation 2):

$$\text{Storage Volume} = \frac{Er}{(A+B) \times 21} \div 365 \quad \text{Equation (2)}$$

In this formula, Er is the rainwater yield (Litres/year) and A+B is the annual water requirement.

### 3. RESULTS AND DISCUSSION

The increase in drought both in Türkiye and worldwide has led to a decrease in access to water and the emergence of certain water-related problems. Rainwater harvesting plays an important role in the efficient use of water (İzmir Metropolitan Municipality, 2024). The study area is located among the intensively used areas in the city centre and has a very low design in terms of water permeability. In the study area, the high number of impervious surfaces and problematic application examples in rainwater discharge cause certain drainage problems. In the study, sustainable design proposals for blue-green infrastructure in buildings and green areas within the boundaries of the study area have been proposed in order to seek solutions to all possible water problems based on possible (Figure 3 & 4). The design details of the blue-green infrastructure systems were developed by drawing inspiration from the implementation principles and technical components of the İzmir Sponge City Project, as well as other examples from around the world. Details and examples of urban furniture proposed within the scope of blue-green infrastructure is presented in Figure 5 and Figure 6. The design decisions related to the study are listed as follows:

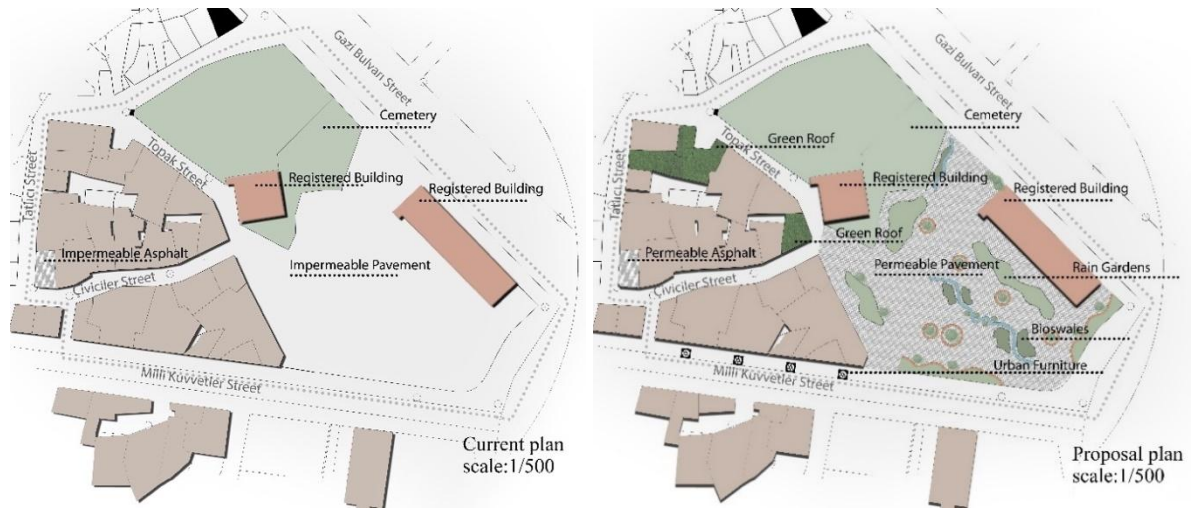


Figure 3. A sustainable design proposal plan for blue-green infrastructure in existing buildings and green spaces with the existing plan within the boundaries of the study area.

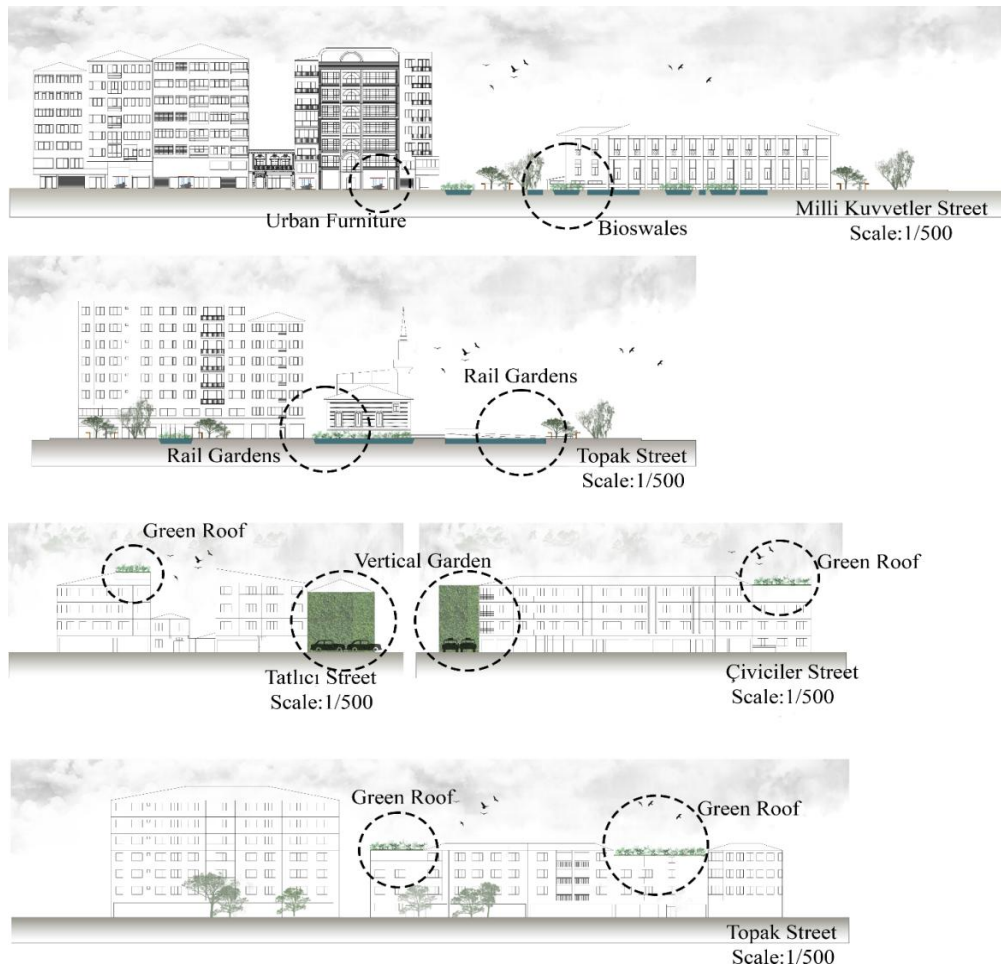


Figure 4. Sustainable design proposal for blue-green infrastructure in existing buildings and green spaces with the existing building design proposal.

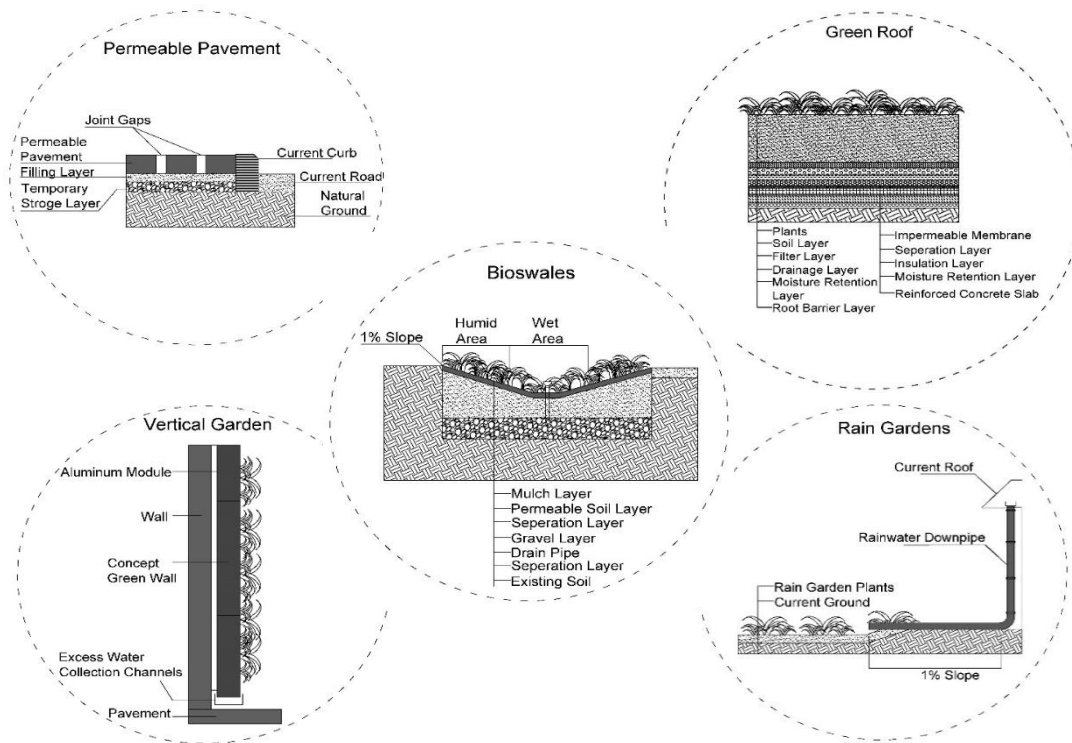


Figure 5. Sustainable design proposals for blue-green infrastructure in buildings and green spaces.



Figure 6. Sustainable design proposals for blue-green infrastructure in urban furniture design.

Firstly, the objective is to ensure the conservation of registered buildings in the area and to enhance the physical environment surrounding these structures, taking into consideration their historical context. In this context, a re-evaluation of the hard floor coverings in the immediate vicinity of the buildings was undertaken, with this re-evaluation being conducted within the framework of sustainable urban design principles.

Existing impermeable surface materials have been superseded by permeable surface materials that facilitate the absorption of water by the substrate. This development has been accompanied by the incorporation of sample applications in this direction. Following the meticulous undertaking of measurements, the area encompassed by the registered buildings was ascertained to be 785.14m<sup>2</sup> in total. The application's objectives are twofold: firstly, to reduce surface runoff, and secondly, to restore rainwater to its natural cycle.

The walkways, asphalt surfaces and pavements in the area cover a total area of 4,252.35m<sup>2</sup>, and all of them currently consist of impermeable tile material. This phenomenon hinders the absorption of rainwater by the soil, leading to the accumulation of surface water. It is therefore proposed that permeable floor coverings be used in these areas. In addition to the aforementioned recommendations, the existing car park area, which features impermeable asphalt pavement, underwent renovation using permeable asphalt material. This material facilitates the percolation of rainwater into the soil. This approach facilitates water infiltration into groundwater resources and contributes to the mitigation of the urban heat island effect. Furthermore, a vertical green wall has been installed on the deaf facade of the building adjacent to the car park area. This provides both an aesthetic contribution and an ecological surface that improves the microclimate on the facade. Moreover, green infrastructure solutions such as rain ditches and rain gardens are proposed to contribute to sustainable water management strategies. The utilisation of these systems not only facilitates the management of water resources but also contributes to the enhancement of the microclimate and the promotion of biodiversity.

Moreover, the primary components of the urban furniture design, predicated on sustainability and the multifunctional utilisation of public spaces, encompass an integrated solar energy system, a rainwater collection and reuse mechanism, green areas, and user-friendly seating units. The integration of solar panels on the top cover enables the collection of energy during daylight hours, subsequently utilised for evening illumination. The rainwater that is directed through the central aperture is utilised for the purpose of irrigating the plants and in the water reservoir that has been created for stray animals. Concurrently, it proffers a design solution that integrates with the urban ecology by providing rest and socialisation opportunities with seating units.

The total roof surface of the buildings in the study area was calculated as 3,307.30 m<sup>2</sup>. A substantial proportion of these roofs contribute to surface runoff in the urban environment. Within this total, an area of 382.95 m<sup>2</sup> was identified as suitable for the installation of green roofs. These areas correspond to flat-roofed residential and commercial buildings located in the southern and central sections of the study area, where structural conditions and load-bearing capacities allow for the integration of additional vegetation and substrate layers. The remaining roofs consist primarily of pitched (gable) roofs and heritage structures such as the Şeyh Lütfullah Mosque and the registered officer's house, which were excluded from the intervention to preserve their architectural integrity. The integration of green roofs within urban planning offers several key benefits. Firstly, they enhance the retention of water, thereby reducing the volume of runoff and improving the city's water quality. Secondly, they contribute to the enhancement of energy efficiency in buildings, leading to a reduction in cooling costs and a consequent decrease in energy consumption. Thirdly, green roofs mitigate the urban heat island effect by moderating temperature of the city's surface and reducing the contrast between urban and natural temperatures. Finally, green roofs enhance the aesthetic value of urban areas by integrating them harmoniously with the green fabric. The strategic design of these roof surfaces serves two main functions: first, to prevent rainwater from being discharged directly into the city's sewer system; and second, to promote water retention and its reuse for the irrigation of green areas.

The quantities (m<sup>2</sup>) of the significant design decisions that were determined for the study area in the existing and proposed design are shown in Table 3.

Table 3. Quantification of key design decisions in the existing and proposed design.

<b>Important areas in design decisions</b>	<b>Currently existing</b>	<b>Recommended</b>
Registered building footprint area	785.14 m <sup>2</sup>	785.14 m <sup>2</sup>
Roof areas	3,307.30 m <sup>2</sup>	2,924.35 m <sup>2</sup>
Green roof areas	-	382.95 m <sup>2</sup>
Permeable surfaces (pavements, asphalt, green infrastructure)	-	4,252.35 m <sup>2</sup>
Cemetery	2,236.58 m <sup>2</sup>	2,236.58 m <sup>2</sup>
Impermeable surfaces (pavements, roads)	7,754.11 m <sup>2</sup>	3,501.76 m <sup>2</sup>

Under the existing conditions, the rainwater harvesting potential was evaluated by analysing the green and permeable open spaces within the study area that are suitable for runoff collection. The total

effective catchment area was identified as 2,366 m<sup>2</sup>, and based on long-term mean annual precipitation data, the total annual rainwater yield was estimated at approximately 1,006,724 litres.

In the proposed design scenario, rainwater harvesting calculations were performed by incorporating the expanded collection surfaces, including building roofs, pedestrian pathways, and newly designed permeable zones. The total annual rainwater yield was determined to be approximately 1,723,104 litres, representing a substantial enhancement in potential collection capacity relative to the existing condition. The irrigation water requirement was calculated for a total area of 10,000 m<sup>2</sup> of hard soil grassland designated as a public area. The annual irrigation requirement was determined to be 1,500,000 litres per year, at a rate of 150 litres per m<sup>2</sup>.

In the course of the study, the irrigation need was the sole consideration taken into account, since no need was defined in grey water usage areas such as offices, schools and toilet facilities. Furthermore, the total annual process water requirements in specific landscaping areas, whether existing or newly designed as part of the study, were calculated in accordance with the particular annual requirements as defined by the German standard DIN 1989-1:2002-04. These requirements are outlined in Table 4.

Table 4. Total annual process water requirements in green areas (DIN, 1989-1: 2002-04).

Irrigation Type	Special annual requirements (l/m <sup>2</sup> )	Area (m <sup>2</sup> )	Process water requirements (l/year)
Garden irrigation rain gardens	60	700	42,000
Vertical walls for pastures with soft soils	200	125	25,000
Cemetery for pastures with hard soil	150	2,336	350,400
Total process water requirement			417,400

In calculating the required storage capacity for the efficient utilisation of the collected rainwater, a three-week dry period was taken into account. Accordingly, the minimum necessary storage volume was estimated to be 38,614 litres under the existing conditions and 66,092 litres under the proposed design scenario. Collected rainwater can be integrated into indoor systems for grey water use, as well as effectively used for watering public green areas such as parks, squares and roadsides. According to data obtained from the Balıkesir Metropolitan Municipality (2025), irrigation activities in urban green areas begin in the second week of May and are completed by the end of October. During this period, the irrigation of the designated 3,040 m<sup>2</sup> cemetery and rain garden areas is carried out every day of the week for a total of 5 months (approximately 153 days).

## 5. DISCUSSION

When the results of the study have been evaluated, it has been found that integrating blue-green infrastructure principles into urban design can significantly increase the efficiency of rainwater management and strengthen the resilience of local ecosystems. However, the current configuration of the study area with its scarcity of permeable surfaces and lack of integrated storage infrastructure restricts rainwater collection to 1,006,724 litres annually, well below the 1,500,000 litres irrigation demand. This pronounced deficit underscores the inefficiency of the existing urban water management system.

In contrast, the proposed design scenario characterized by expanded collection surfaces including building roofs, pedestrian corridors, and newly designed permeable zones significantly enhances system performance. The total rainwater harvesting potential increased to 1,723,104 litres annually, surpassing the irrigation water requirement and thereby establishing a self-sufficient water cycle within the study area. This improvement underscores the technical and ecological advantages of adopting decentralized water management strategies aligned with international sustainability frameworks, such as the United Nations Sustainable Development Goals (2019).

Accounting for a three-week dry spell in the storage capacity estimation underscores the need for hydrological systems capable of maintaining performance under fluctuating rainfall regimes. The calculated storage requirements 38,614 litres under existing conditions and 66,092 litres under the

proposed design demonstrate the adaptability of the proposed system to periods of low precipitation, ensuring continuity in landscape irrigation without reliance on municipal water supplies.

These findings highlight that blue-green infrastructure not only alleviates urban water stress but also delivers multiple co-benefits, including groundwater recharge, microclimate regulation, and biodiversity enhancement. The results align with an expanding body of literature supporting nature-based solutions as effective and sustainable alternatives to conventional grey infrastructure. The implementation of such approaches within urban green areas such as parks, cemeteries, and rain gardens provides a replicable model for medium-sized cities confronting similar climatic and hydrological challenges.

## 6. CONCLUSION

Climate change causes global warming and temperature increases, as well as significant effects such as changes in precipitation patterns. The hydrological system is greatly affected by climatic conditions on the earth's surface, and these effects can be direct or indirect. Changes in precipitation patterns can lead to disasters such as droughts, floods, and landslides, as well as problems with plant patterns and growth rates. Changes in the natural water cycle highlight the need to re-plan, design, and manage urban blue-green infrastructure systems. Although the concept of sustainability has gained increasing importance in recent years, impervious surfaces still cover large areas in many cities. The decrease in urban active and passive green spaces, coupled with the increase in concrete surfaces, results in rainwater being unable to reach groundwater due to impermeable surfaces. Instead, it flows over the surface and is collected in specific areas through rainwater harvesting or sewer systems. This situation significantly impacts all living beings in cities and urban land use.

In this study, new design proposals have been developed for sustainable rainwater management in the building and landscape areas of the study area. The study also analysed the quantity of rainwater that could be collected from the roof areas of buildings and the potential of this water to meet the irrigation needs of public green areas in the region. Existing impermeable surface materials have been replaced with permeable surface materials that allow water to infiltrate into the ground, and blue-green infrastructure systems such as rain gardens and rain swales have been proposed to contribute to sustainable water management strategies. Additionally, vertical green wall designs have been created to form an aesthetic and ecological surface and reduce the effects of the urban heat island. Within the scope of effective water use and management, the results obtained from calculating rainwater harvesting yield and annual water demand have been determined as 1,723,104 litres/year and 1,500,000 litres/year, respectively. When the results are evaluated, it is quite important in terms of ecological and economic sustainability that the annual rainwater collected in the study area is significantly higher than the annual irrigation water requirement. A properly designed and planned blue-green infrastructure plays a significant role in sustainable urban design and planning studies.

Consequently, rainwater harvesting provides benefits in terms of water conservation, measures against water scarcity, reduction of disaster risks, replenishment of groundwater, and reduction of energy consumption.

## EXTENDED ABSTRACT

### *Research Problem & Purpose*

*The increasing effects of climate change over time have led to detailed discussions of environmental problems worldwide, with water scarcity being one of the most important issues. In particular, rapid population growth in urban areas, urban expansion, industrial growth and climate irregularities are increasing pressure on existing water resources. In order to reduce the increasing pressure on water resources, it is necessary for all countries to thoroughly evaluate their existing water management policies. In this context, rainwater harvesting has emerged as a noteworthy and innovative solution in the field of sustainable water management. In order to implement rainwater harvesting in urban areas, it is necessary to first determine comprehensive and sustainable planning, design, and management principles and criteria. Based on this importance, this study aims to propose new design recommendations within the scope of sustainable rainwater management in the area defined within the boundaries of Yildirim neighbourhood in*

the city centre of Balıkesir, calculate the amount of rainwater that can be obtained from building roofs, and analyse the potential of the collected water to meet the water needs of landscape areas.

### **Methodology**

In the study method, new design proposals were developed for sustainable rainwater management for buildings and landscape areas within the study area boundaries, the amount of rainwater that can be obtained from the roof areas of buildings was calculated, and the potential of this water to meet the irrigation water needs of public green areas in the region was analysed. The study method consists of four stages.

In the first stage of the method, a settlement map was obtained from the Karesi Municipality Urban Planning and Urban Development Directorate, and climate data based on 25 years of measurement station records from 1999 to 2024 were obtained from the Balıkesir Meteorology Regional Directorate. In the second stage of the method, the permeable surfaces of suitable buildings and the amount of permeable surfaces in landscape areas were calculated using AutoCAD software to effectively manage rainwater in the study area, and a design proposal was made for the blue-green infrastructure in the study area to effectively collect and manage rainwater.

In the third phase of the method, the potential amount of water that can be recovered using the rainwater harvesting method was calculated based on the German standard DIN 1989-1:2002-04, which is the most commonly used standard in rainwater harvesting. In the subsequent phase, the storage volume of the collected water was calculated. The storage volume was calculated considering a 3-week (21-day) rainless period and based on the British Standard BS (2009). Finally, all the results obtained in the study were interpreted within the scope of sustainable water management in urban areas.

### **Findings**

In the study area, the number of impermeable surfaces and examples of problematic rainwater discharge practices are causing specific drainage issues. In this study, sustainable design proposals for blue-green infrastructure were presented for buildings and landscapes within the study area boundaries, aiming to find solutions to all potential water problems based on possible issues. First, the preservation of registered buildings in the area and the improvement of the physical environment around these structures, taking into account their historical context, were targeted. In this context, the hard surface coverings immediately surrounding the buildings were re-evaluated, and this re-evaluation was carried out within the framework of sustainable urban design principles.

Existing impermeable surface materials have been replaced with permeable surface materials that facilitate water absorption by the subgrade. This development has been accompanied by the inclusion of exemplary applications in this direction. Following careful measurements, it was determined that the total area covered by the registered buildings is 785.14 m<sup>2</sup>.

The walking paths, asphalt surfaces, and pavements in the area cover a total of 4,252.35 m<sup>2</sup> and are currently composed entirely of impermeable tile materials. This prevents rainwater from being absorbed into the soil, leading to surface water accumulation. Therefore, the use of permeable ground coverings in these areas is recommended. In addition to the above recommendations, the existing parking area with impermeable asphalt pavement has been renovated using permeable asphalt material, and a vertical green wall has been designed on the blind facade of the building adjacent to the parking area. Additionally, design proposals for green infrastructure solutions such as rainwater ditches and rain gardens have been presented. The total roof area of the buildings in the study area has been calculated as 3,307,30 m<sup>2</sup>. These roofs constitute a significant portion of surface runoff in urban areas. In this context, a total roof area of 382.95 m<sup>2</sup> has been redesigned in accordance with green roof design principles to evaluate the rainwater collection potential of the roofs. An important part of the study involves estimating the required storage capacity for collecting and storing water. In the proposed design scenario, rainwater harvesting calculations were performed by incorporating the expanded collection surfaces, including building roofs, pedestrian pathways, and newly designed permeable zones. The total annual rainwater yield was determined to be approximately 1,723,104 litres, representing a substantial enhancement in potential collection capacity relative to the existing condition. The irrigation water requirement was calculated for a total area of 10,000 m<sup>2</sup> of hard soil grassland designated as a public area. The annual irrigation requirement was determined to be 1,500,000 litres per year, at a rate of 150 litres per m<sup>2</sup>. In calculating the required storage capacity for the efficient utilisation of the collected rainwater, a three-week dry period was taken into account. Accordingly, the minimum necessary storage volume was estimated to be 38,614 litres under the existing conditions and 66,092 litres under the proposed design scenario

### **Conclusions**

The study presents sustainable blue-green infrastructure design proposals aimed at improving rainwater management in urban areas, followed by calculations of rainwater yield. Within this scope, the results obtained from calculating rainwater collection yield and annual water demand were determined as 1,723,104 litres/year and 1,500,000 litres/year, respectively. When interpreted, these results indicate that the annual rainwater collected in the

study area significantly exceeds the annual irrigation water demand, highlighting the importance of blue-green infrastructure designs in establishing climate-resilient and sustainable cities.

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#### Author Contribution Declaration

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**A.** Idea and editing    **B.** Literature Review    **C.** Writing  
**D.** Data Collection    **E.** Analysis    **F.** Critical Review

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Figen ALTINER: A/B/C/D/E/F

Eda Nur AYDEMİR KUTLUER: A/B/C/D/E/F

İrem DERELİ: A/B/C/D/E/F

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