Determination of Rainwater Harvesting Potential: A Case Study from Ege University

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Abstract: Rainwater is a valuable resource that provides numerous benefits. The necessity of collecting and reusing rainwater has increased in cities where the effects of climate change are prominent. With little effort and a relatively high initial construction cost, harvesting rainwater can be a cost-effective benefit. In addition to its economic benefits it is an environmentally friendly process that prevents the rainwater from going to waste. In this research the roofs of 24 buildings in an area around Ege University Central Campus (Izmir, Turkey), which has a Mediterranean climate, were selected for a pilot project. The amount of rainwater to be harvested was calculated to be 16.570,30 m^3. This study determined that the potential rainwater to be harvested from the research area throughout the year could provide 11% of the water required for irrigation of the existing green areas throughout the year and 20% of the water required for irrigation from April to October. Therefore, considering the ratio of the potential rainwater that was harvested during the summer season to the potential rainwater amount that could be harvested throughout the year, this experiment showed the potential benefits of storing the harvested rainwater in the rainy spring and winter seasons throughout the year.

Keywords: Campus, Ege University, Rainwater Harvesting, Irrigation

Yağmur Suyu Hasat Potansiyelinin Belirlenmesi: Ege Üniversitesi Merkez Yerleşkesi Örneği

Öz: *Yağmur suyu sayısız fayda sağlayan değerli bir kaynaktır. İklim değişikliğinin etkilerinin öne çıktığı kentlerde yağmur sularının toplanması ve tekrar kullanılması gerekliliği artmıştır. Çok az çaba ve nispeten yüksek ilk inşaat maliyeti ile yağmur sularının toplanması, uzun vadede maliyet etkin bir eylem olarak görülmektedir. Yağmur suyu hasadı, ekonomik faydalarının yanı sıra yağmur sularının boşa gitmesini engelleyen çevre dostu bir süreçtir. Bu araştırmada, Akdeniz iklimi etkisi altındaki İzmir (Türkiye) kentinde yer alan Ege Üniversitesi Merkez Yerleşkesi'nde bulunan 24 binanın çatıları pilot proje alanı olarak seçilmiştir. Araştırma kapsamında hasat edilecek yağmur suyu miktarı 16.570,30 m^3 olarak hesaplanmıştır. Yıl boyunca pilot proje alanından toplanacak potansiyel yağmur sularının mevcut yeşil alanların yıl boyunca sulanması için gerekli olan suyun %11'ini, Nisan-Ekim aylarında yapılacak sulama için gerekli olan kaynağın ise %20'sini karşılayabileceği belirlenmiştir. Bu nedenle, araştırma alanında yaz mevsiminde toplanan potansiyel yağmur suyunun yıl boyunca toplanabilecek potansiyel yağmur suyu miktarına oranı dikkate alındığında bu araştırma, hasat edilecek yağmur suyunun yağışlı ilkbahar ve kış aylarında depolanmasının potansiyel faydalarını göstermiştir.*

Anahtar kelimeler: *Kampüs, Ege Üniversitesi, Yağmur Suyu Hasadı, Yağmur Suyu Hasat Potansiyeli*

INTRODUCTION

The rational use of fresh water, which is a scarce and exhaustible asset, is an issue that sets the agenda today, especially in urban landscapes that are vulnerable to the effects of climate change (Lee et al., 2016; Hernández and Morote, 2019; Doorn et al. 2021). Where local climatic conditions are suitable, rainwater harvesting (RWH) has attracted more and more attention from city managers, planners, designers, and even direct users in many countries. Rainwater is a resource that can be harvested at minimal cost, effortlessly and is a sustainable process (Lee and Kim, 2012). According to Temizkan and Tuna Kayılı (2021), optimum cost implementation of rainwater harvesting systems with short payback periods are important factors in the application of these projects.

RWH is one of the best practices for conserving water and overcoming water scarcity. It can be defined as the collection and storage of rainwater through different technologies for future use (Kakoulas et al., 2022). Harvested rainwater can be used for various services such as toilet flushing, garden irrigation, greenhouse cultivation, laundry, livestock feeding, and replenishing groundwater resources without intensive filtration. It is also quite possible to clean up the harvested rainwater to make potable water. Rainwater harvesting, which is an ancient water harvesting technique, has started to gain attention again in modern times and has become cost-effective with the developing economic conditions. Collecting, storing, and using rainwater from the roofs is a simple method to reduce the demand for clean water resources and waste treatment plants (Hari et al., 2018; Hajjar et al., 2020; Temizkan and Tuna Kayılı, 2021). Furthermore, there is a huge potential of RWH in cities where the roofs are a large percentage of the land space.

RWH is the processes of collecting rainwater and storing it for direct use or recharging groundwater resources. There are two types of rainwater harvesting; a) The first is the runoff harvest. Runoff is diverted into the water systems such as ponds, lakes and reservoirs. Harvesting runoff is a good solution to water scarcity, urban flooding and drainage problems and also promotes the recharging of groundwater resources. b) The second type of rainwater harvesting is collecting rainwater from the roofs (Hari et al., 2018).

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Rainwater falling onto roof surfaces is collected for direct use, transported and stored in surface or underground water retention structures. Capturing and harvesting rainwater from the roof is a very simple and cost-effective approach that supports sustainable water management (Hari et al., 2018).

In the city of Izmir the effects of climate change have been felt more strongly every passing day. It has dry, hot summers, cool and rainy winters with extremes such as severe drought periods and urban floods that have been experienced more and more frequently. For instance, it has become commonplace to experience flooding, especially in the coastal zones of the city, following sudden downpours in the winter months. In the summers the city is being faced with temperatures above the seasonal average and long low-rain periods. In this case the importance of the effective use of fresh water in the city becomes a necessity. According to the Izmir Metropolitan Municipality Zoning Regulation (Official Gazette of Turkish Republic, 2021), which was enacted on June 3, 2021, it is a requirement to collect the water from roofs and impervious areas that have a surface area of more than 1,000 m² in the city. The runoff water is to be collected in a cistern or an underground stormwater tank. According to the same regulation, it is a requirement to implement green roof systems in buildings with a total surface area of more than 60,000 m². All these attempts show a dramatic change in the mentality of the city government and are likely to lead to more awareness and change in attitudes in the way the city looks at rainwater harvesting.

In this study, the rainwater harvesting potential of a selected pilot area in the Ege University Central Campus has been measured in order to provide an example for possible harvesting implementations in other areas in the city of Izmir. The two main purposes of this study are; a) to determine the amount of rainwater that can be collected throughout the year from the roof surfaces in the study area, and b) to reveal how much this can contribute to the reduction of water consumption in the campus. This study is the first such research in which rainwater harvesting data has been gathered for the Ege University Central Campus and contributes to the scientific literature on the effects of the use of harvested rainwater in meeting the irrigation needs of the campus during the dry summer season. This study will encourage the harvesting of rainwater throughout the campus landscape and encourage the reuse of this free resource in order to reduce water consumption in the campus.

MATERIAL AND METHODS

Study Area

The study area comprises a group of buildings mainly the Faculties of Agriculture, Fisheries, Dentistry, School of Foreign Languages, Institute of Science, and Central Library buildings that are located on the Ege University Central Campus in Bornova (Figure 1). The reason for choosing this area was heterogeneous roof and green area types that represent the whole campus.

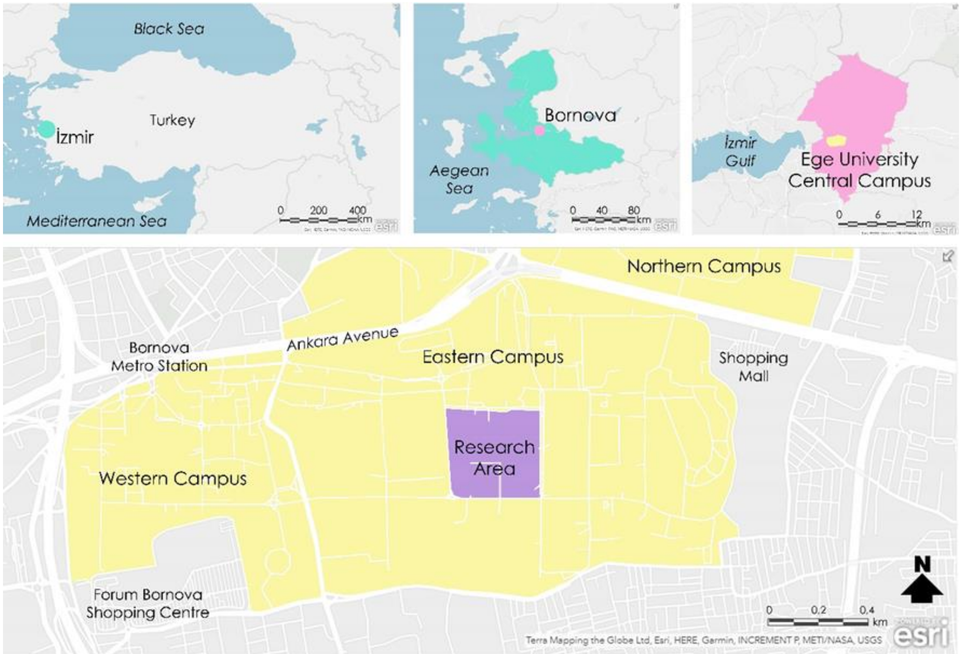

Figure 1. Location of the study area (ESRI 2022)

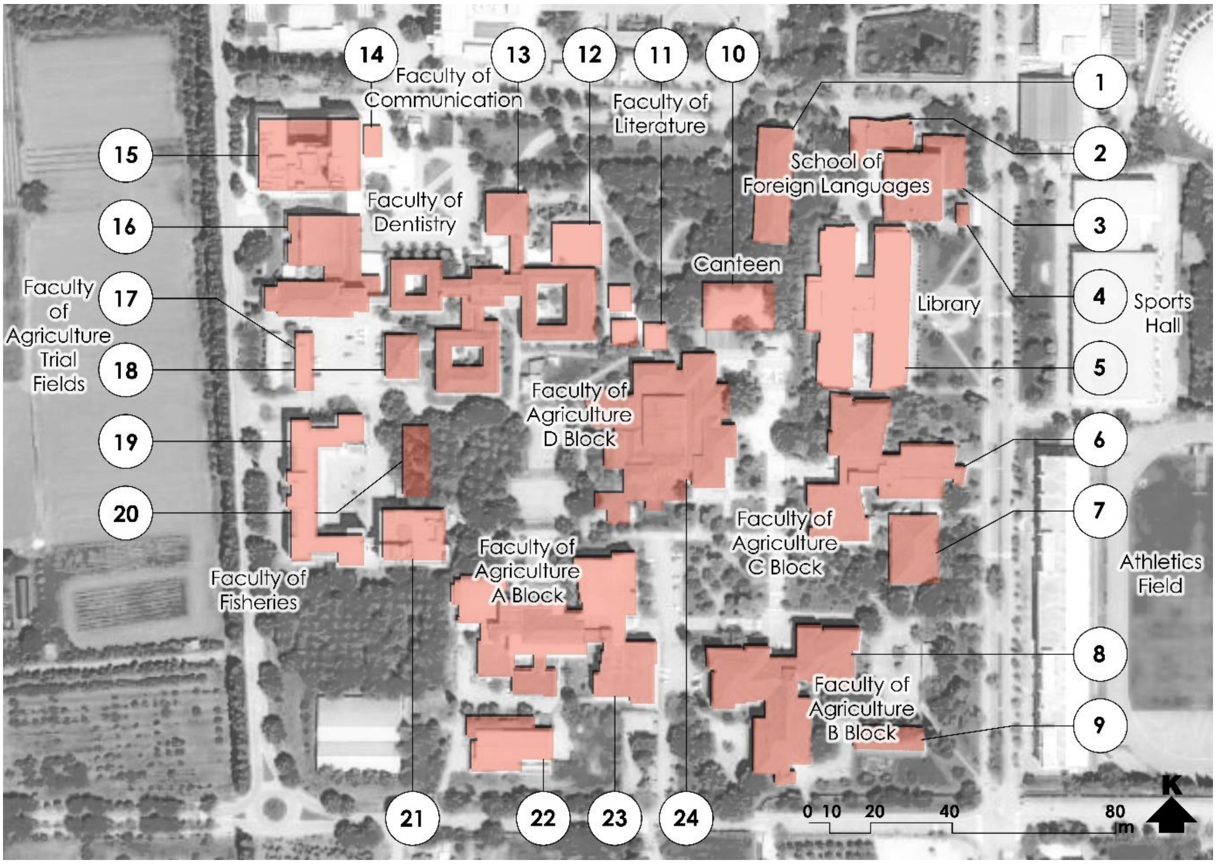

Figure 2. Buildings in the study area (ESRI 2022)

Table 1. Average monthly precipitation and average number of rainy days in Izmir (between 1938 and 2020) (TSMS 2021).

Months	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Average monthly precipitation (mm)	135.0	101.9	75.4	46.1	31.8	12.0	4.1	5.6	15.5	44.8	92.6	145.7	**710.5**
Average monthly rainy days	14.0	11.7	10.7	9.1	7.0	3.5	0.7	0.9	2.7	6.6	10.1	14.4	**91.4**

There is a total of 32,777.93 m^2 of roof surfaces on 24 buildings in the research area and a green area of 50,869.67 m^2 between the buildings (Figure 2).

It is important to consider city in terms of climatic conditions and precipitation, which are the key variables that guide the rainwater harvesting process. According to the data recorded between 1938 and 2020 in the city where the Mediterranean climate is dominant, the average temperature is 17.9 °C. The average highest temperature (33.2 °C) is in July, and the average lowest temperature (5.7 °C) is in January. The average number of rainy days in the city is 91.4 and the average annual total precipitation is 710.5 mm (Table 1). December is the month with the most rainy days and July is the month with the least (TSMS, 2021).

In the study, AutoCAD LT 2022, Microsoft Excel 2010, and Adobe Photoshop CS5 software were used in data processing, analysis and presentation, along with satellite imagery.

The method of the study consisted of five stages;

a) The data collection phase included the selection of the roofs, the field observation to determine the roof types, the acquisition of precipitation data to be used and the literature review on the subject.

b) The data processing phase calculated the surface areas by converting the selected roofs and green areas in the study area to vector format in AutoCAD LT 2022 using satellite images by ESRI (2022).

c) The data analysis phase calculated the potential amount of rainwater to be harvested using Microsoft Excel 2010 with the precipitation data, roof area data, and surface runoff coefficient data according to the roof types. The Rooftop Catchment Method, produced by Gould and Nissen-Petersen (1999), was used to calculate the rainwater harvesting potential of the study area. The amount of rainwater to be harvested from the study area was calculated according to the equation below (Gould and Nissen-Petersen, 1999):

$$S = R.A.C_r$$

According to the formula S represents the potential amount (volume) of rainwater to be harvested (m^3), R represents the average annual precipitation (mm), A represents the rain collection area (m^2), and Cr represents the runoff coefficient. The rain catchment area is the sum of the surface areas of the roof surfaces from which the rainwater will be harvested. The runoff coefficient on the other hand, is a constant and a unitless value that comes into play because it is not possible to collect all the rainwater falling onto the roof surface (Gould and Nissen-Petersen, 1999). Some of the rainwater falling onto the roof surface is absorbed by the roofing material, evaporates, and may overflow from the gutter while being transported (Farreny et al., 2011). It takes a value between 0 and 1 depending on the type of roofing material (Table 2).

Table 2. Runoff coefficients of some roofing materials

Roof Material	**Runoff Coefficient (C_r)**	**References**
Asbestos	0.85	Hari et al., 2018
	0.60-0.80	Biswas and Mandal, 2014
Concrete	0.70	Temizkan and Tuna Kayılı, 2021
	0.95	Hari et al., 2018
Tile	0.80-0.90	Biswas and Mandal, 2014
Galvanized sheet	0.90-0.95	Biswas and Mandal, 2014
Brick/Clay tiles	0.50-0.60	Biswas and Mandal, 2014
	0.75	Temizkan and Tuna Kayılı, 2021
Metal	0.90	Temizkan and Tuna Kayılı, 2021
Corrugated metal sheet	0.70-0.90	Biswas and Mandal, 2014
PVC	0.98	Hari et al., 2018
Soil	0.00-0.30	Biswas and Mandal, 2014
Green cover	0.05-0.10	Biswas and Mandal, 2014

At this stage the irrigation requirement was calculated using the green area data in the study area. Considering the conditions of the Mediterranean climate with hot and dry summers and mild and rainy winters in the coastal part of the Aegean Region, the amount of irrigation per square meter has been determined to be 7.80 lt/m^2 (Sarıkoç, 2007).

d) In the evaluation of the data phase the findings obtained from the analysis of the data were evaluated, and the potential amount of rainwater to be harvested was correlated with the irrigation requirements of the existing green areas.

e) In the synthesizing phase, conclusions and recommendations were obtained from the evaluations and presented.

RESULTS AND DISCUSSION

This study determined that the roofs of 24 buildings selected in the study area are covered with 7 different roofing materials, namely asphalt, bitumen, glass, tile, galvanized sheet, and tile and pitch. The roofing materials of these buildings and their surface area are given in Table 3. Accordingly, the total rain collection area in the study area was 32,777.93 m^2. The rainwater potential that can be harvested from the roofs of the buildings in the study area during the year was estimated to be 16,570.30 m^3. While 53.85% of this amount is expected to be obtained in winter, it has been determined that 21.58% and 21.52% of this amount can be collected in spring and autumn, respectively (Figure 3). In summer this rate is 3.06% due to the low amount of precipitation.

The amount of water required throughout the year to irrigate the green area of 50,869.67 m^2 in the study area is 144,825.95 m^3. However, considering the rainfall situation of the city, it was determined that the irrigation requirement of the green areas is mostly between April and October. Accordingly, the amount of water required to irrigate the green areas in the study area during the dry 7 months was 83,323.80 m³ (Table 4).

It was determined that the potential rainwater to be harvested from the study area throughout the year could provide 11% of the water required for irrigation of the existing green areas throughout the year and 20% of the water required for irrigation during the 7 dry months (April — October). This is an advantage for the city of Izmir, which experiences this dry season

Table 3. Rainwater harvesting potential of the buildings in the research area

Average annual precipitation (mm) = 710,5

Number of the Building	Roofing Type	Roof Catchment Area (m^2)	C_r Coefficient	Amount of rainwater to be harvested (m^3)
1	Brick	955.81	0.60	407.46
2	Pitch	467.88	0.70	232.70
3	Brick	1,290.39	0.60	550.09
4	Brick	56.76	0.60	24.20
5	Tile	1,595.05	0.85	963.29
	Galvanized sheet	1,469.10	0.95	991.61
6	Brick	759.04	0.60	323.58
	Pitch	1,911.09	0.70	950.48
7	Brick	769.33	0.60	327.97
8	Brick	2,823.73	0.60	1,203.76
9	Brick	356.57	0.60	152.01
10	Galvanized sheet	766.38	0.95	517.29
11	Galvanized sheet	397.70	0.95	268.44
12	Galvanized sheet	467.37	0.95	315.46
13	Brick	3,305.46	0.60	1,409.12
14	Galvanized sheet	115.08	0.95	77.68
15	Tile	1,656.32	0.85	1,000.29
16	Bitumen	654.33	0.70	325.43
	Brick	1,172.89	0.60	500.00
17	Galvanized sheet	234.62	0.95	158.36
18	Brick	320.35	0.60	136.57
19	Tile	1,324.97	0.85	800.18
20	Asphalt	419.78	0.90	268.43
21	Tile	719.49	0.85	434.52
22	Brick	200.74	0.60	85.58
	Galvanized sheet	702.52	0.95	474.18
23	Brick	522.84	0.60	222.89
	Pitch	3,274.61	0.70	1,628.63
	Glass	224.22	0.90	143.38
24	Brick	3,305.46	0.60	1,409.12
	Pitch	538.05	0.70	267.60
TOTAL		**32,777.93**		**16,570.30**

Campuses are prominent public places with their open spaces and roof potentials. The calculation of rainwater harvesting potential in college campuses with large green areas yielded effective and more importantly, efficient results. Hajjar et al. (2020) conducted a study aimed at determining the rainwater harvesting potential of the roof of a single-storey building in Izmir Katip Çelebi University (Turkey). It revealed that the amount of rainwater to be collected could meet the needed water for all of the toilets. Temizkan and Tuna Kayılı (2021) have calculated the appropriate tank size for the design of a rainwater collection system for rainwater that can be obtained through rainwater harvesting from the square and the roof of the Social Life Center located on the Karabük University Campus (Turkey).

Almeida et al. (2021) have investigated the feasibility of rainwater harvesting systems in order to partially meet the daily non-potable water demand in university buildings by selecting one building each at the University of Aveiro and the University of Lisbon (Portugal).

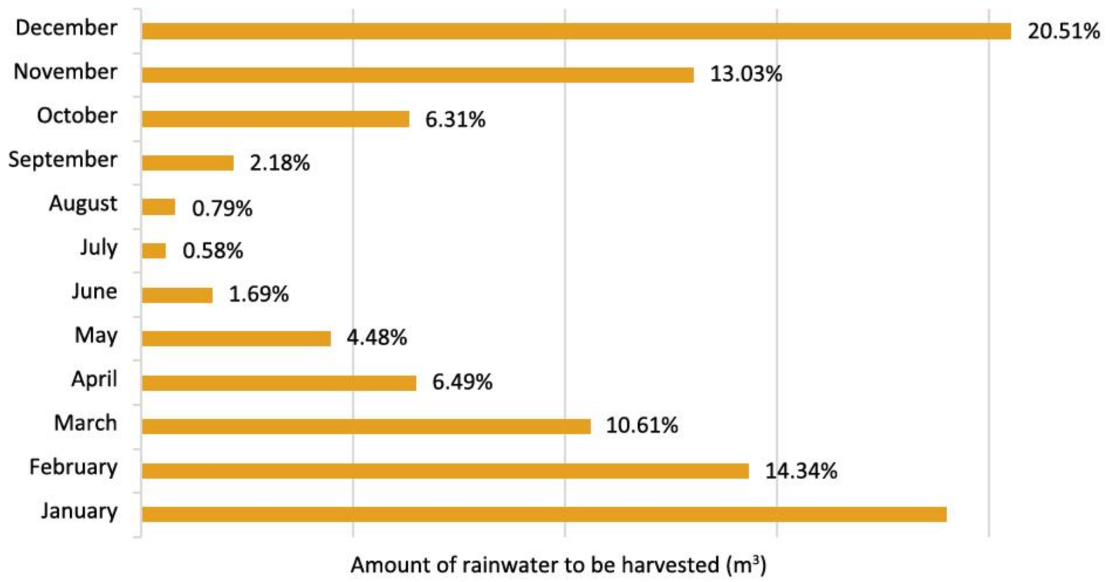

Figure 3. Distribution of rainwater to be harvested from the research area during the year by months

Table 4. Calculation of irrigation water requirement and coverage ratio

Irrigation water requirement						Potential amount of rainwater to be harvested	Rate of meeting requirements over the year	Rate of meeting requirements during the dry 7 months
Green area (m^2)	Water requirement (L/m^2)	Daily		Over the year	During the dry 7 months	Over the year		
		L	m^3	m^3	m^3	m^3		
50.869,67	7,80	396,783.43	396.78	144,824.70	83,323.80	16,570.30	11%	20%

They found that if 50% of the rain catchment area is covered with large green roofs, the volume of retained water could be increased by 15%. Bayramoğlu and Büyükkurt (2020) have calculated the amount of rainwater that can be collected from the roofs of the buildings in four sections at the Karadeniz Technical University Kanuni Campus (Turkey). In that study in which the amount of green space and the water requirement of the green areas for these regions have been calculated, the recreational use of the harvested water has been determined.

In the calculation of the water requirement of green areas, the amount of water for each irrigation area varies according to different studies, different climatic conditions and various assumptions. It is a changing process because of the reason mentioned above. Sarıkoç (2007) calculated this value to be 4.27 lt/m^2 for Trabzon (Northern Turkey), 5.43 lt/m^2 for Ankara (Central Turkey) and 7.80 lt/m^2 for Antalya (Southern Turkey). Küçüksayan et al. (2011) found this value to be 6.00 lt/m^2 for Ankara. Eren et al. (2016) accepted it as 5.00 lt/m^2 for Sakarya (North-Western Turkey) and 5.00 lt/m^2 for Bursa (North-Western Turkey) by Yalılı Kılıç and Abuş (2018). Based on Sarıkoç's (2007) research which considered the climatic similarities of the cities of Antalya and İzmir, the amount of water for each irrigation area was accepted to be 7.80 lt/m^2 for the calculation of the water requirement of the green areas.

In the present study it has been determined that 11% of the water required throughout the year for the irrigation of green areas in the pilot area at the Ege University campus can be met with the potential rainwater that can be obtained from the roof surfaces. It is obvious that 20% of the irrigation water needed during the 7-month dry summer can be obtained in a similar way. This is an advantage for the city of Izmir, where the dry season is observed.

CONCLUSIONS

In this study the potential rainwater amount that could be collected for irrigation has been evaluated by calculating the rainwater harvesting potential of a selected pilot area of the Ege University Central Campus. Two conclusions have been reached by this study: the amount of rainwater that could be collected from the roofs and how much could contribute to the reduction of water consumption on the campus for irrigation purposes.

This study has been conducted not only to provide an easy method to guide and encourage rooftop rainwater harvesting both for the campus and the city of Izmir but also to support the recent legislation that has come into force about rooftop harvesting by the Izmir Metropolitan Municipality as mentioned in the introduction.

Rainwater is a free resource and a very precious natural asset that can affect the urban landscape. Rainwater management would help the city deal with the unpredictability of climate change. The alternative would be to ignore any water management plans with the result of continued urban floods and damage to city structures and the loss of valuable assets to the city.

This project conducted at Ege University looked at the rain patterns over the years. This study shows that there is a benefit to storing the rainwater to be harvested in the rainy spring and winter seasons throughout the year. It has been determined that a significant amount of precipitation water can contribute to the irrigation of green areas on the campus.

In conclusion, it is recommended this system be extended to the entire campus. In addition, to support this system, it is important to design planting schemes that require less irrigation. And finally to facilitate the access of rainwater into the green areas on campus some curbs on the side of roadways and walkways should be removed.

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