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Rainwater Harvesting Potential in Public Buildings: A Case Study in Katip Celebi University

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Rainwater Harvesting, Rainfall, Public Buildings, Green Buildings

Abstract: Due to environmental pollution, population growth, climate change, industry development, and uncontrolled water consumption, the amount of usable water is running out. So, Municipalities are forced to find alternative water sources. For this reason, rainwater harvesting again gains interest among researchers, engineers, etc. In this study, the determination of the rainwater harvesting potential in Izmir Katip Celebi University is studied. The data from the flowmeters installed in the men-women toilets in the central classrooms are recorded, and the catchment area is calculated. According to the data, the amount of rainwater to be collected can meet water use in the toilets flushing. The study shows that the implementation of the rainwater harvesting system in public buildings will contribute to reducing bill costs. Therefore the drinking water resources will be used more efficiently.

Kamu Binalarındaki Yağmur Suyu Hasat Potansiyeli: Katip Çelebi Üniversitesi Saha Çalışması

Anahtar Kelimeler
Yağmur Suyu Hasadı, Yağış, Kamu Binaları, Yeşil Binalar

Öz: Çevre kirliliği, nüfus artışı, iklim değişikliği, sanayi gelişimi ve kontrolsüz su tüketimi nedeniyle günümüzde kullanılabilir su miktarı tükenmektedir. Böylece, Belediyeler alternatif su kaynakları bulmak zorunda kalmaktadır. Alternatif su kaynaklarından biri olan Yağmur Suyu Hasadı araştırmacılar ve mühendisler arasında tekrar ilgi çeken konular arasına girmiştir. Saha çalışması olarak İzmir Kâtip Çelebi Üniversitesinin Yağmur Suyu Hasadı analizleriyle su potansiyelinin belirlenmesi amaçlanmıştır. Merkezi sınıflarda erkek-kadın tuvaletine takılan sayaçların verileri toplanmış ve hasad alanı hesaplanmıştır. Verilere göre, toplanacak yağmur suyu miktarı tuvaletlerin su kullanımını karşılayabilmektedir. Bu çalışma, kamu binalarında Yağmur Suyu Hasadı sisteminin uygulanmasının çevresel ve ekonomik katkıda bulunacağını, böylece içme suyu kaynaklarının daha verimli kullanılacağını göstermektedir.

1. INTRODUCTION

Due to environmental pollution, population growth, climate change, industry development, and uncontrolled water consumption, the amount of usable water is running out. Drinking and daily use waters obtained from freshwater and groundwater resources on the surface are decreasing day by day. Groundwater height decreases more than 1 meter annually worldwide Quayyum et al. [1]. Moreover, it is stated that human beings can only use 3% of the water on Earth Novak et al., [2]. 70% of the usable water resources that we can use are utilized in agricultural areas. Due to the clustering of the country's population in metropolitan cities, municipalities have sought different resources to meet their water needs. In this context, water transport from out of town water basins is one of today's most popular applications. This design, which is a good alternative for today, is expected to have adverse effects on climate, ecology, and economy shortly. For these reasons, the search for alternative water resources continues. The rainwater harvest (RWH), the ancient water collection technique, started to attract interest in the scientific era and became cost-efficient by the developing economic conditions. The collection, storage, and use of rainwater from roofs is a simple method to reduce the demand for public water resources and waste treatment facilities. It is suitable for various services such as toilet flushing, garden irrigation, and laundry without intensive filtering. The capacity of the rainwater tank is significant both economically and operationally Fewkes. A. [3]. RWH systems have three objectives: to deliver water as a strategic response to urban growth; to meet the highest percentage of rainwater demand from a building or neighborhood on a design scale; to achieve the economic, environmental, and social results of the water system.

The fact that rainwater harvesting has turned into an increasing field of the study reveals that the countries with water shortage will increase and become a thought-provoking dimension. Aküzüm et al. [4] pointed out that the need for water increases with the increase of population and technology; therefore, water ecosystems' pollution increases, and now it is necessary to develop new water resources. From the climatic models, it has been observed that most countries may experience water shortage in 2030, and severe water shortage may occur for half of them Lehner et al. [5], Konukcu et al. [6], Öktem [7]. Helmreich and Horn [8] explained that water scarcity is a problem for many developing countries, rainwater is a potential source of drinking water according to the intensity of rainfall, and rainwater collection system can supply water suitable for agriculture and domestic use. It was also emphasized that slow sand filtration and solar technology is the method of reducing pollution for the treatment of rainwater and membrane technology can be a potential disinfection technique for a safe drinking water supply. Morales-Pinzon et al. [9] aim to contribute to urban water planning for smart city development in modeling using a commercial computer program. As a result of the study, it was found that the urban analysis scale was related to rainwater supply, rainwater utilization rate, economic cost, and ecological impact. The use of economic and environmental indicators can make the optimal size of a rainwater tank more restrictive compared to results related to meeting rainwater demand. Pelak and Porporato [10] have developed a formulation for optimum cistern volume that includes fixed and distributed costs of an RWH system to ensure domestic, non-potable uses, taking into account the random nature of the amount and intensity of the Rainfall. Recently, Eren et al. [11] investigated the potential of rainwater harvesting of Sakarya University. They determined the water need that can be met by using rainwater rather than economic analysis. In the financial analysis of rainwater harvesting systems, the study aims to evaluate the location and annual rainfall. Also, water price increase rates should be taken. These are the essential parameters of RWH economic analysis.
In this study it was aimed to determine the potential rainwater harvest by analyzing Izmir Kâtip Çelebi University. According to the General Directorate of Meteorology statistics, the annual amount of rainfall in Izmir between 1938 and 2016 is 697.0 mm. According to academic sources, the regions where the average rainfall is higher than 300 mm are considered suitable for applying rainwater collection systems. The rainwater obtained can be used in various areas such as toilet flushing, toilet sinks, and irrigation. This study's results may lead to significant gains in both the economic and ecological aspects of public structures.. The principles of the planning, design, collection, storage, and discharge systems were studied according to the rainwater harvesting regulation that declares by the Ministry of Environment and Urbanization [12].

2. MATERIALS AND METHODS

2.1. Water Resources in Izmir

According to the Turkish Statistical Institute (TurkStat), the average quantity of water per person per day is 217 liters, while in Izmir, the daily amount of water is 173 liters per person [13]. As significant surface water of Izmir, three rivers – Kucuk Menderes, Bakircay, and Gediz – , lakes – three natural, twelve dam lakes – can be named. Municipality of Izmir uses those water resources in account with underground springs for supplying drinking water, industrial and agricultural utilities. Izmir is a metropolitan city, and water demand increases gradually day by day. Therefore, it is inevitable to look for alternative water resources. Like another metropolitan, Izmir also has several public facilities such as universities, town halls, directories, etc. In those places, most of the water consumption is for toilet flushing and irrigation purposes. For this reason, the rainwater harvesting system can be the right choice for alternative resources due to low filtering and its economic aspect. Using rainwater in public facilities relieves the present pressure on Municipalities to supply enough water to the community.

2.2 Precipitation in Izmir

The region of Izmir has a typical Mediterranean climate due to its geographical location in western Turkey. There are severe differences in the distribution of precipitation by month and season in Izmir, but the average annual rainfall from 1938 to 2019 is 711.1 mm. More than 50 percent of the annual precipitation falls in the winter season while in spring and autumn seasons 40 to 45 percent, and 2 to 4% in the summer season. According to the General Directorate of Meteorology statistics, the maximum and minimum average precipitation is 144.3 mm in December and 4.1 mm in July, respectively. The maximum and the minimum number of rainy days are 12.8 days in December and 0.5 days in July. Both pieces of information are shown graphically in Figures 1 and 2 [14].

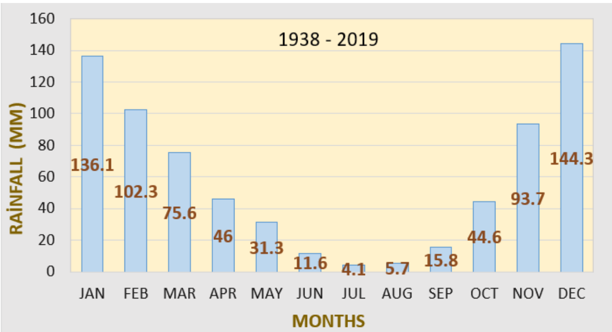

Figure 1. The average monthly precipitation in Izmir (mm) [14]

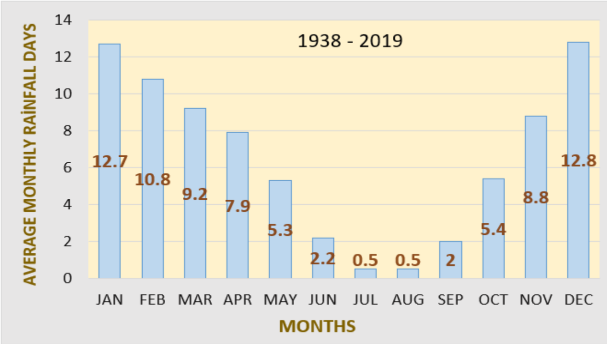

Figure 2. The average monthly rainy days in Izmir [14]

2.3 Roof Shape and Area Calculation

Rainwater harvesting is a system that collects rainwater from the rooftop and stores it in a large cistern. The crucial parameters that affect its efficiency are precipitation, surface – area, materials, runoff coefficients, etc. – the necessary volume of a cistern. The roof type of the studied building is a pitched roof, so the roof area can be calculated by dividing the building's width into right-angled triangles. Mathematical calculations will determine the surface area applied to the triangles. The technical drawings in AutoCAD obtain the size of the flat roof. The catchment surface can be determined by collecting the horizontal surface area, half of the vertical height area, and half of the adjacent wall area [15]. Area of ABCD = roof plan AB$C'D'$ + 1/2* beveled surface C$DC'D'$ + 1/2* side wall ADE (Figure 3).

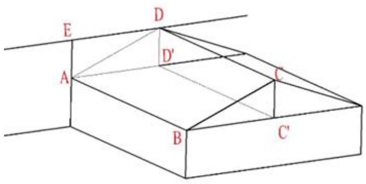

Figure 3. Drawing for Roof Area Calculation [15]

3. RESULTS AND DISCUSSION

In this study, the rainwater harvesting potential is determined based on the total roof area, the average annual rainfall, and the runoff coefficient, which is related to the roof's material. After assessing the potential of the studied rooftop, the water demand of the building should be determined. In the present study, the network system in the basement of the building was examined to measure water quantity used in the toilet reservoir. As a result of the examination, there are two different lines, one leading to the hand sinks and the other leading to the toilet closets. There are two types of flush systems in the study area: pull handles and push-buttons with 9 liters. The flowmeters are connected to the water lines that go to the reservoirs to obtain the daily and weekly measurements. This process was applied separately for male and female toilets to determine optimal divergence. The total number of male and female toilets is 24 in the building. Measurements were taken from two toilets – male and female – and interpolated for the other toilets. Figure 4 shows the flowmeter, which is used in the toilet pipeline.

Figure 4. Used flowmeter in the toilet

3.1. Catchment Area Calculation Using Pitched Roof

The rooftop area was calculated by including the slope using two sections of roof plans. The result gives the roof area that is used for harvesting. The images are added in 2 sections to understand the calculation step by step (Figures 5,6).

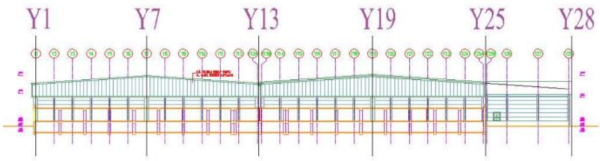

Figure 5.1[st] Section of Central Classes in Izmir Katip Celebi University

Area Y1→ Y7 = roof plan AB C′D′ + 1/2* beveled surface CDC′D′ + 1/2* side wall ADE

$$ABC'D' = 27.375 * 55.43 = 1517.39625 \text{ m}^2$$

$$\frac{1}{2}\ CDC'D' = \frac{1}{2} * 1.9163 * 55.43 = 53.11 \text{ m}^2$$

$$\frac{1}{2}\ ADE = \frac{1}{2} * 27.375 * 1.9163 = 26.229 \text{ m}^2$$

$$\text{Area Y1} \rightarrow \text{Y7} = 1517.39625 + 53.11 + 26.229 = 1596.735865 \text{ m}^2$$

$$\text{Area Y1} \rightarrow \text{Y13} = 1596.735865 * 2 = 3193.47173 \text{ m}^2$$

$$\text{Area Y13} \rightarrow \text{Y25} = \text{Area Y1} \rightarrow \text{Y13} = 3193.47173 \text{ m}^2$$

Area Y25 →Y28:

$$ABC'D' = 20.45 \times 55.43 = 1133.5435 \text{ m}^2$$

$$\frac{1}{2}\ CDC'D' = \frac{1}{2} * 1.4465 * 55.43 = 40.08975 \text{ m}^2$$

$$\frac{1}{2} ADE = \frac{1}{2} * 20.45 * 1.4465 = 14.79 \text{ m}^2$$

Area Y25 →Y28 = roof plan ABC′D′ + $\frac{1}{2}$ beveled surface CDC′D′ + $\frac{1}{2}$ side wall ADE

Area Y25 $\rightarrow$ Y28 $= 1133.5435 + 40.08975 + 14.79 = 1188.42\ \mathrm{m}^2$

Total area Y1 $\rightarrow$Y28 $= 3193.47173 + 3193.47173 + 1188.42 = 7575.36346\ \mathrm{m}^2$

Symmetrically, on the right total area Y1 $\rightarrow$ Y28 $= 7575.36346\ \mathrm{m}^2$

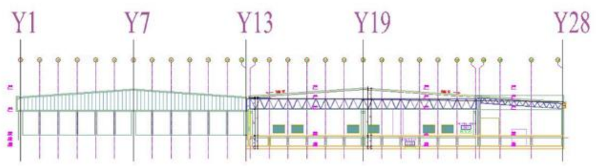

Figure 6. 2nd Section of Central Classes in Izmir Katip Celebi University

No area Y1 $\rightarrow$Y13

Area Y13 $\rightarrow$Y19: Percent slope $= 7\%$; $0.07 = \frac{2.556}{x} \rightarrow x = 36.514\, m$

$ABC'D' = 36.514 * 256.7742 = 9375.85314\ m^2$

$\frac{1}{2}\ CDC'D' = \frac{1}{2} * 2.556 * 256.7742 = 328.15743\ m^2$

$\frac{1}{2}\ ADE = \frac{1}{2} * 2.556 * 36.514 = 46.664892\ m^2$

Area Y13 $\rightarrow$ Y19 = roof plan $ABC'D' + \frac{1}{2}$ beleved surface $CDC'D' + \frac{1}{2}$ side wall ADE

Area Y13 $\rightarrow$ Y19 $= 9375.85314 + 328.15743 + 46.664892 = 9750.675462\ m^2$

Area Y19 $\rightarrow$Y28: Percent slope $= 7\%$; $0.07 = \frac{3.2382}{x} \rightarrow x = 48.0014\, m$

$ABC'D' = 48.0014 * 256.7742 = 12325.52108\, m^2$

$\frac{1}{2}\ CDC'D' = \frac{1}{2} * 3.2382 * 256.7742 = 415.74311\, m^2$

$\frac{1}{2}\ ADE = \frac{1}{2} * 3.2382 * 48.0014 = 77.71907\ m^2$

Area Y19 $\rightarrow$ Y28 = roof plan $ABC'D' + \frac{1}{2}$ beleved surface $CDC'D' + \frac{1}{2}$ side wall ADE

Area Y19 $\rightarrow$ Y28 $= 12325.52108 + 415.74311 + 77.71907 = 12818.98326\, m^2$

There are siz gaps in the middle of the building, the total area of spaces = $2014.112\, m^2$

By deletion the gaps area from building: Y19 $\rightarrow$Y28

Area Y19 $\rightarrow$Y28 without gaps:

$= 12818.98326 - 2014.112 = 10804.87126\ \mathrm{m}^2$

Total effective catchment area $= (7575.36346 * 2) + 10804.87126 = 25955.6056\ \mathrm{m}^2$

3.2. Maximum Rainwater Supply

The volume of harvestable rainwater from the campus rooftop is calculated using Gould and Nissen [16] Formula 1:

$$S = R \times A \times Cr \quad (1)$$

where S is rainwater harvesting potential, A is catchment area in m^2, R is monthly rainfall in mm, and Cr is the runoff coefficient. The runoff coefficient is taken into account because not all the falling water on a rooftop surface area can be collected; the roof type in this study is metal roofing. Therefore, C is taken as 0.9. Interested readers can find the runoff coefficient for other materials roofing in Table 1. Using Gould and Nissen's formula, the potential rainwater harvesting amount is calculated for each month in Table 2.

Tablo 1. Coefficient of Runoff for different Roof Types [17]

Type of Roof	Runoff Coefficient
Galvanized Iron Sheet	0.90
Asbestos Sheet	0.80
Tiled Roof	0.75
Concrete	0.70

Tablo 2. Monthly amounts of harvestable rainwater

Central Classes Monthly Rainfall (1938 - 2019)	Total Catchment Area m^2 (A)	Average Monthly Rainfall mm (B)	Runoff Coefficient C	Rainwater Supply m^3 (A × B × C)
January	25955.6	136.1	0.9	3179.30
February	25955.6	102.3	0.9	2389.73
March	25955.6	75.6	0.9	1766.02
April	25955.6	46	0.9	1074.56
May	25955.6	31.1	0.9	726.50
June	25955.6	11.6	0.9	270.98
July	25955.6	4.1	0.9	95.78
August	25955.6	5.7	0.9	133.15
September	25955.6	15.8	0.9	369.09
October	25955.6	44.6	0.9	1041.86
November	25955.6	93.7	0.9	2188.84
December	25955.6	144.3	0.9	3370.85
Annual Rainfall	25955.6	710.9	0.9	16606.65

3.3 Water Demand

The main campus classrooms' water demand is met from the local water distribution network operated by the Municipality. Several buildings construct the university. However, the building with laboratories and classrooms was selected in this study due to most water consumption. The university has a total of 13438 students, and they are populated in this chosen building. The flowmeters were installed for sinks and toilet-urinals of the men and women toilet in the main campus center to measure their water consumption. Data of one toilet were obtained daily for a month. There is no significant deviation between days. When it is noticed, it is started to be collected weekly throughout the semester. The average weekly demand is 12.62 tons of water. The total number of academic weeks is 14 weeks in one semester and six weeks for the summer semester, so the total water demand throughout the year for 24 toilets is estimated at 10,297.92 tons of water. Total water demand was obtained through multiplying the average weekly need of all the toilets by the number of academic weeks. The weekly average water consumption in toilet flushing and hand washing in male toilets are 17.46 and 0.92 tons of water.

On the other hand, in the female toilets, the values are 5.87 and 0.99 tons of water. As can be seen, the majority of the water used is in toilet flushing. Water used in toilet flushing is needed low process of filtering and disinfection compared to handwashing or tap water usage. Therefore, it is only toilet flushing consumption taken into account in this study. The average water consumption throughout a year for toilet flushing is 10,297.92 tons of water in the central classroom.

4. CONCLUSION

Rainwater harvesting system is a very cost-effective solution for public facilities such as municipal buildings, schools, hotels, hospitals, restaurants, and other such, that is due to their large surface area. The amount of precipitation in Turkey is the essential impulse that boosted the thought of setting up the rainwater harvesting systems in all the facilities, whether public or private. The plumbing, pumping, and electricity costs for the rainwater harvesting system in single-story buildings are fewer than such required in multi-story buildings.

This study was conducted in one single-story building - the main campus center of classes in Izmir Katip Celebi University - which its surface area was found sufficient to meet their toilet flushing needs. The savings of the rainwater harvesting system were assessed by the economic analysis that proves the worth of the implementation of rainwater harvesting systems in Turkey's universities and public buildings.

The implementation of the rainwater harvesting system on the campus will contribute to reducing bill costs, and therefore the water resources will be used more efficiently for avoiding future risk. The most suitable structures, where rainwater harvesting systems can be utilized, are public buildings. The water demand has been determined by installing the flowmeter for sinks and toilet-urinals of the men and women toilet in the main campus' center of classes. Observation of water consumption in both toilet flushing and sink usage shows that toilet flushing takes a major portion of the consumption. Therefore, it is more economical and efficient to focus only on flushing toilet consumption throughout the year. The average water consumption throughout a year for toilet flushing is 10,297.92 tons of water in the central classroom. Calculation of rainwater harvesting from rooftop shows that the potential water harvesting from precipitation is 16,606.65 tons of water. If the first flushing, and the overflow due to lack of cistern volume are taken into account, the potential harvesting water can only sustain toilet flushing demand. According to Izmir Municipality, the water price is 7.47₺ in the third quarter of 2020; therefore, the average annual of savings is estimated at 76,926.00₺. In addition to excess annual savings that can be used for irrigation purposes that are about 47i128.00₺. The rainwater harvesting system's cost depends on the number of cisterns, pumps, filters, and the electricity to operate, so the average initial cost of the rainwater harvesting system in the building was estimated at 248,880.00₺. This system can pay back in around two years in the current situation, which is a reasonable return rate for investors such as government or self constructor. This study shows an excellent start to harvest rainwater in public buildings for both economic and environmental aspects.

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