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Bloklarda Yağmur Suyu Hasadı Uygulaması ile Sürdürülebilir Bir Üniversite Kampüsü

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ÖZ

Bu çalışma, İstanbul Aydın Üniversitesi Florya Merkez Kampüsü'ndeki F Blok'ta yağmur suyu hasadı sisteminin uygulanabilirliğini ve etkinliğini değerlendirmektedir. Yağmur suyunun toplanma, depolanma ve kullanım süreçleri, bölgesel yağış verileri ve günlük su tüketim verileri kullanılarak mevsimsel simülasyon ve istatistiksel analizlerle ayrıntılı bir şekilde incelenmiştir. Ortalama (34,45 m³) ve medyan (35,59 m³) değerlerinin yakın olması, veri setinde aşırı uçların sınırlı olduğunu ve yağış miktarlarının genel olarak dengeli bir şekilde dağıldığını gösterir. Ancak, standart sapma (16,37 m³) ve varyans (267,92 m^6) değerlerinin yüksekliği, aylık yağış miktarlarında belirgin dalgalanmalar olduğunu ve bazı ayların ortalamadan önemli ölçüde farklılaştığını ortaya koymaktadır. Değişim katsayısı (%47,52), yıl boyunca yağışların mevsimsel olarak değişkenlik gösterdiğini, çarpıklık (0,24) ve basıklık (-1,23) değerleri ise yağışların çoğunlukla tahmin edilebilir aralıklarda kaldığını göstermektedir. Kurulan sistemin yıllık 413,39 m³ yağmur suyu toplama kapasitesi, F Blok'un su ihtiyacının %65'ini karşılayabilmektedir. Bu sonuçlar, yağmur suyunun kampüs ölçeğinde sürdürülebilir bir su kaynağı olarak kullanılabileceğini ve mevsimsel değişimlere uyum sağlayan su yönetimi stratejileri geliştirilmesine olanak tanıdığını göstermektedir. Yerel meteorolojik verilerin kullanımı ve mevsimsel dalgalanmaların detaylı analizi, su toplama sisteminin performansını optimize etmek için önemli içgörüler sunmaktadır. Çalışma, yağmur suyu hasadı sistemlerinin mevsimsel olarak değerlendirilmesi ve talebe göre uyarlanması sayesinde literatürdeki benzerlerinden ayrılarak kampüs ölçeğinde sürdürülebilir su yönetimi stratejilerine katkıda bulunmaktadır.

Implementing Rainwater Harvesting in Blocks for a Sustainable University Campus

Research Article

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ABSTRACT

This study evaluates the applicability and efficiency of a rainwater harvesting system at the F Block of Istanbul Aydin University's Florya Main Campus. The processes of collecting, storing, and utilizing rainwater were examined in detail using regional rainfall data and daily water consumption data through seasonal simulations and statistical analyses. The proximity of the mean (34.45 m³) and median (35.59 m³) values indicates that outliers are limited within the dataset and that rainfall amounts are generally balanced. However, the high standard deviation (16.37 m³) and variance (267.92 m^6) reveal significant variations in monthly rainfall, with some months differing considerably from the average. The coefficient of variation (47.52%) indicates that rainfall varies seasonally throughout the year, while the skewness (0.24) and kurtosis (-1.23) suggest that the rainfall data is mostly within a predictable range. The installed system's

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annual rainwater collection capacity of 413.39 m³ meets 65% of the annual water demand of F Block. These results demonstrate that rainwater can be used as a sustainable water source on a campus scale, enabling the development of water management strategies that adapt to seasonal changes. The use of local meteorological data and detailed analysis of seasonal variations provides valuable insights for optimizing the performance of the rainwater harvesting system. By evaluating rainwater harvesting systems seasonally and adapting to demand, this study distinguishes itself from similar research in the literature and contributes to sustainable water management strategies at the campus scale.

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1. Introduction

Rainwater harvesting (RWH) is one of the proactive approaches that help in environmental sustainability due to rainwater collection and storage, dealing with water shortage or scarcity, and reducing runoff (Ferreira et al., 2023). This picks up the rain from different catchment areas and then stores it in storage tanks for various purposes, thus suitable for both urban and rural environments. Research shows that there is an increasing interest in the application of RWH for sustainable living (Samzadeh et al., 2021). The feasibility of vertical RWH has been explored, especially in tropical climates, to show how building facades can be optimally utilized to catch wind-driven rain, hence proposing the efficiency of RWH. This is an integration that works well with architectural design for sustainable infrastructure development (Correa et al., 2018). Theoretical models help identify the effective usable rainfall depths and help create systems that function at given needs.

RWH also offers broader environmental gains in terms of drawing the consumption away from treated water supply sources and community environmental footprints (Rahman et al., 2014). In this sense, RWH systems should be integrated into landscape design to maximize collection from various surfaces (Chao-jun et al., 2018). It also allows for the determination of RWH potential through rooftop data with the aid of Geographic Information System (GIS) techniques (Yükselir et al., 2019; Kalıpcı et al., 2021; Uslu and Tuğcu, 2023). The dual use of the RWH in cities and agriculture, particularly in water-scarce regions like Antalya, makes this resource more critical for good water management (Ertop et al., 2023). A review of RWH systems indicates that these systems have the potential to save from 20% up to 65% of potable water and reduce the amount of stormwater runoff by up to 91% (Teston et al., 2022). Even in low rainfall areas like Barcelona in Spain, RWH has been effective for non-potable usages. In India, research into a decentralized water system that combined RWH with wastewater reclamation systems provided a sustainable solution that could meet 39% of campus water needs (Zang et al., 2021).

Research on the technical and financial feasibility of RWH at the Federal University of Para, Brazil underlined that it has potential significant savings in potable water due to its nondrinking purposes. However, the Cost-effectiveness depended on the building type and demand (Cardoso et al., 2020). In Malayer University, Iran, the RWH system was found capable of storing over 10000 cubic meters per year. It was very useful for irrigation in an arid condition for landscaping in a very sustainable way (Saeedi and Goodarzi, 2018). Research undertaken at Valle de las Palmas, Mexico proposed RWH systems to take advantage of winter rains for campus landscaping by demonstrating good water management in a semi-arid region (Ravelo-García et al., 2023).

Starting with campuses, RWH systems have become examples of attention towards the role in water conservation and sustainability goals. The systems also provide on-campus educational opportunities for students in environmental sciences, engineering, and sustainability curricula, with the development of a commitment to sustainable practices within campus communities (Alharthi et al., 2019; El-Nwsany et al., 2019; Dawodu et al., 2022; Asaad et al., 2024). Possible educational programs involving students, faculty, and staff as well as the larger community have supplemented such green building standards with increased campus beautification using harvested rainwater for landscaping and other purposes.

Several studies focus on RWH practices on campuses. For instance, research has focused on rainwater management for irrigation purposes, toilet reserves, and landscaping (Saygın and Ulusoy, 2011). A study designed, tested and validated an RWH system for greenhouse irrigation capable of meeting peak irrigation demands to support student-managed gardens (Islam et al., 2013). Research on optimal storage solutions has also been explored in the literature, such as modeling appropriate sizes for RWH tanks (Temizkan and Kayılı, 2021). Other studies looked at the rooftop RWH potential through rainfall statistics (Anchan and Prasad, 2021; Ozeren Alkan and Hepcan, 2022), and the recharge of groundwater with collected rainwater (Ariyani et al., 2021). When there is a successful implementation of rainwater collector systems, capture rates have gone as high as 75% for non-potable uses such as toilet flushing and fire suppression (Dawodu et al., 2022), while the MyRAWAS system recorded a 60% reduction in potable water demand (Hanafiah, 2018).

In Mahasarakham University, rooftop RWH in Thailand had provided 7% of the conventional water needs, with potential cost savings in water treatment (Chaimoon, 2013). Other studies have identified that rainwater collected from campuses can easily be treated up to drinking water standards (Rahman et al., 2014). Again, followed by Anthony et al. (2020), RWH may be attractive in promoting green campus governance and sustainable development in higher education, with the treated rainwater being a safe alternative source (Han, 2013). Socioeconomic factors influencing the adoption of RWH on campuses serve to indicate that educational institutions can successfully use this system as a strategic water management tool, especially within regions with scarce water resources perspectives (Msuya, 2022).

RWH was known to be one of the feasible water solutions at universities in Turkey. Katip Celebi University research has identified several economic and environmental benefits of RWH (Hajjar et al., 2020).

In addition, numerous similar studies have been conducted at Sakarya University and Ege University, with demonstrated potential to reduce dependency on municipal supplies and conservation of water done by Ozeren Alkan and Hepcan 2022, and Eren et al. 2016, respectively. Economic analysis also allowed emphasizing that a significant percentage of irrigation needs could be covered with rooftop RWH. Besides, RWHS at universities in Turkey have also been helping reduce surface runoff and increasing the resiliency towards extreme weather events (Ulker and Tasci, 2022).

Studies at the Khulna University of Engineering and Technology (KUET) in Bangladesh illustrated the viability of small-scale systems for drinking water production within the campus (Chakrabarty and Mohiuddin, 2024), while that on the Isabela State University Campus in the Philippines demonstrated the viability of roof RWH systems to supplement water demand on a university campus (Abalos and Opiña, 2024). In this line, RWH was integrated with greening infrastructures such as rain gardens, at the University of British Columbia, Canada, for stormwater management and climate change adaptation (Zhou et al., 2024). In the same way, Wachemo University in Ethiopia and Ryerson University in Canada have complemented the effectiveness of RWH in meeting water needs within campuses during dry seasons and enhancing functional water retention (Abreham et al., 2024; Adity, 2024).

At Teuku Umar University, studies showed that cistern-based RWH systems supplied significant volumes of water for daily collection (Silvia et al., 2021). It is also found in research at the University of Pancasila that RWH with infiltration wells can meet additional water demand in arid seasons (Ariyani et al., 2021). Similarly, research at Amity University in Mumbai, and in other Indian universities, has focused on the advantages of RWH systems in dealing with water deficiency and improving the level of groundwater recharge (Ali and Jain, 2014; Akash et al., 2020; Mishra et al., 2020). Investigations at the University of Life Sciences, Estonia, focused on integrating RWH systems with new waste collection systems and emphasized how infrastructure on campus may be optimized for the handling of water in a better manner with the help of RWH practices (Seppor, 2024). A geospatial study in Islamabad presented the potentials of RWH in university rooftops by analyzing using GIS techniques and demonstrated how rainwater can be harnessed in urban campuses for sustainable water management (Saleem et al., 2024). The novelty of this article is twofold. First, it creates social awareness, and second, it does not require any sophisticated advanced tools to conduct the study. The novelty stems from its use of an installed RWH system to demonstrate environmental consciousness and raise awareness among university students. To address a gap in the Turkish literature, this study examines the role of rainwater harvesting systems in promoting sustainability on university campuses. A section of Istanbul Aydin University's Florya Central Campus has been chosen as a case study to assess how much rainwater can contribute to overall water consumption, and the second one is about data collection without using advanced tools.

2. Materials and Methods

2.1. Case Study Building

Istanbul Aydin University, a private university, is located in Istanbul. The university has several campuses across different neighborhoods, with the main campus located in Florya. The case study focuses on Block F, on the main campus. Figure 1 shows the map of the country and illustrates the map of Istanbul Aydin University. Additionally, Figure 2 provides a satellite image of Block F, and Figure 3 displays the rooftop of Block F.

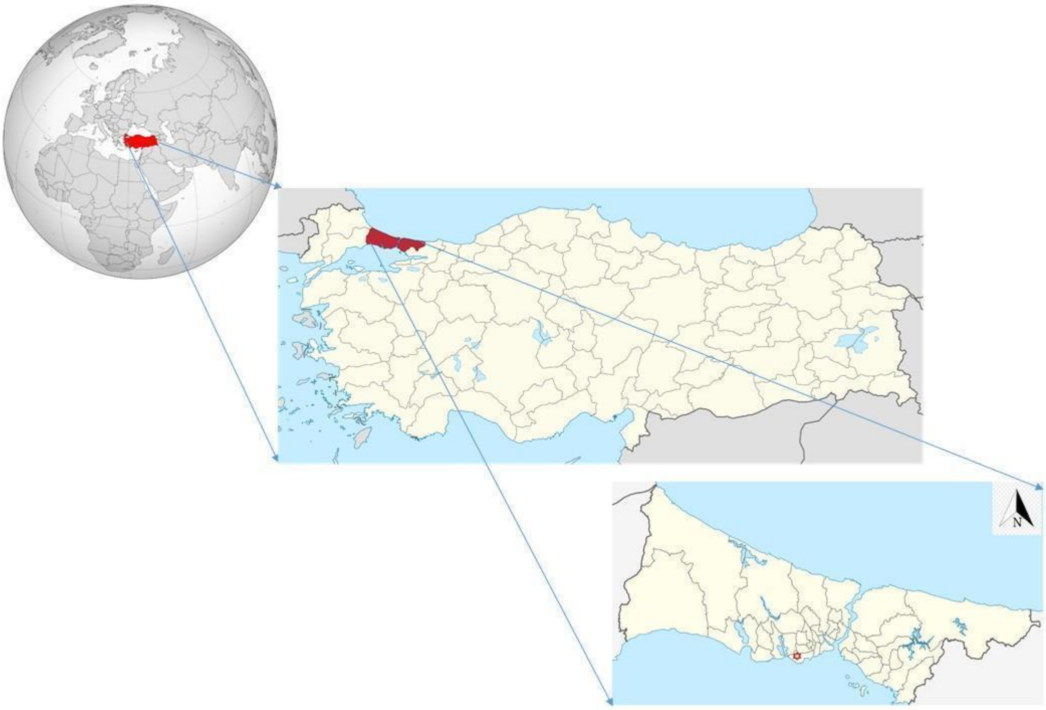

Figure 1. The location of Istanbul Aydin University on the Türkiye and Istanbul map (Modified from Wikimaps, 2023)

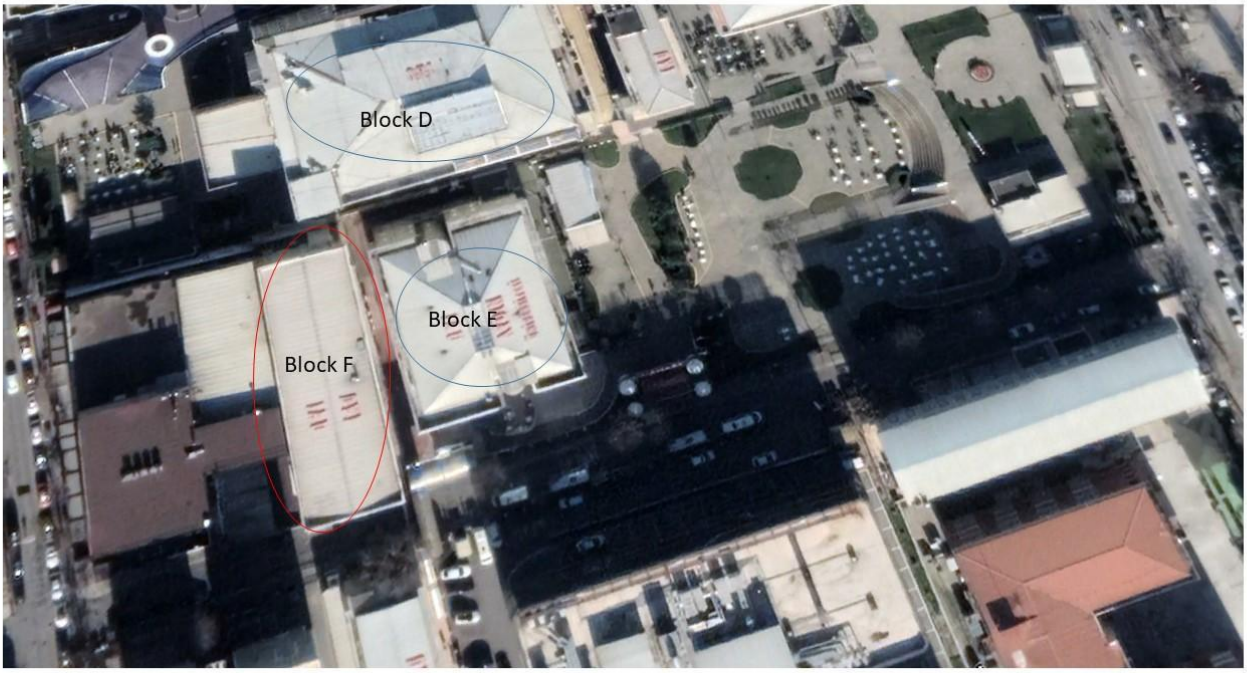

Figure 2. Satellite image of Block F (modified from Google Earth, 2024)

Figure 3. Rooftop of block F

2.2. Water Consumption of the Case Study Building

An analysis of the consumption meter data from the University's Department of Construction and Technical Affairs revealed that Block F has an average monthly water consumption of 53 m^3, amounting to an annual consumption of 636 m^3.

2.3. Climatic Conditions of the Case Study Building Location

Istanbul's unique and diverse climate is influenced by its geographical location at the intersection of Europe and Asia and its proximity to the Black and Mediterranean Seas. Table 1 presents meteorological data for Istanbul from 1950 to 2022, highlighting the significance of precipitation information for assessing potential rainwater collection.

Table 1. Rainfall data of Istanbul between 1950 and 2022 (Turkish State Meteorological Service)

Period	Average Monthly Total Rainfall (mm)
January	89.7
February	70.5
March	63.1
April	47.5
May	32.6
June	27.9
July	22.5
August	24.6
September	40.5
October	66.7
November	76.0
December	99.3
Annualy	660.9

2.4. *Determining the RWH Potential of the Case Study Building*

To calculate the RWH potential of the roof of the selected block, the following equation is used (Gould and Nissen-Petersen, 1999):

$$S = R \times A \times Cr \tag{1}$$

Where S is the RWH potential (m^3), R is monthly rainfall (m), A is roof area (m^2), Cr is runoff coefficient.

Table 1 provides the rainfall data. The roof of Block F has a plan area of 695 m^2 and features a gable roof design. The ridge height is not significant enough to affect the area calculation. The roof is covered with sandwich panels made from galvanized iron sheets. Table 2 presents the runoff coefficients for other types of roof materials.

Table 2. Runoff coefficient for different roof types (AFPRO-UNICEF, 2006)

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

2.5. *RWH System Components for the Case Study Building*

A proposed RWH system for Block F involves straightforward yet effective equipment. The process begins on the roof, making the selection of roofing material critical. Metal roofs are preferred over wood or tile because they minimize dirt accumulation in shingle gaps and prevent rust when painted. In contrast, asphalt shingles can release chemicals over time, contaminating the water supply and reducing water quality, even with filtration.

Figure 4 illustrates the fundamental components of the rainwater harvesting system, showing the journey of harvested water from the roof to the storage tank.

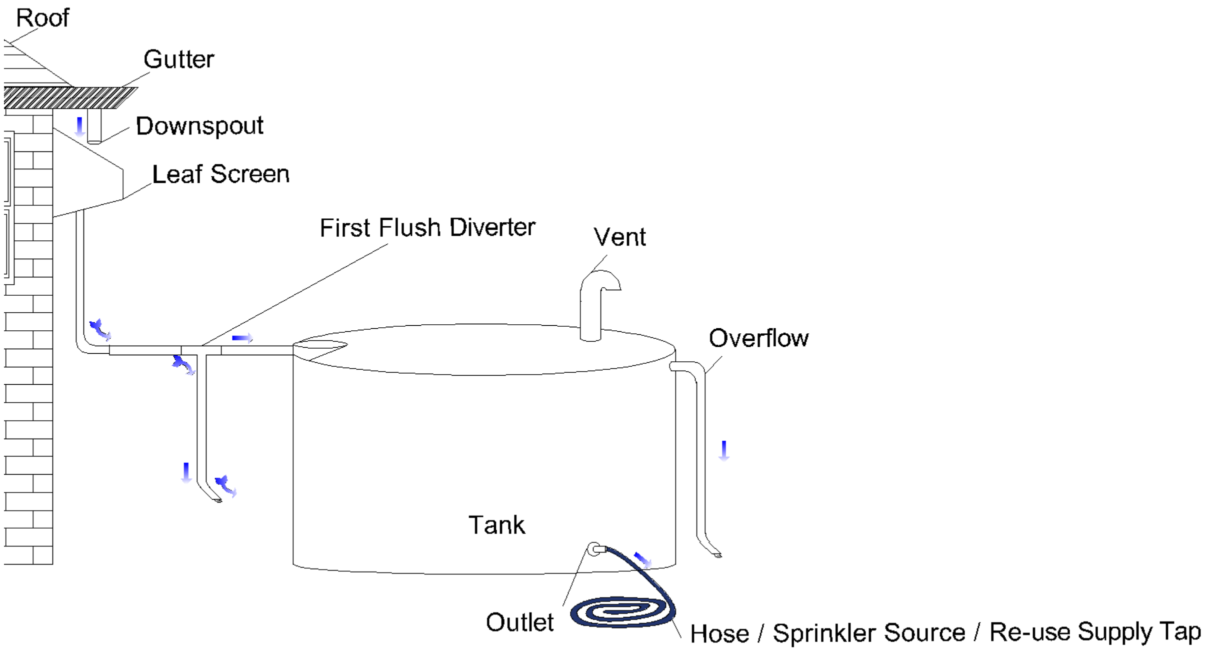

Figure 4. Fundamental RWH components (Muftuoglu and Oral, 2024)

Rainwater from the roof flows through gutters designed to handle heavy rain runoff, as shown in Figure 5 below. To prevent blockages caused by debris in the gutters, the mesh leaf screen filters out larger particles such as leaves and twigs. The screen captures most contaminants, but smaller particles may still pass through. With a mesh size that filters particles larger than 1-2 mm, the screen ensures that cleaner water flows into the storage tank while preventing downspout blockages. The flow rate that this design can manage is dependent on the dimensions and size of the mesh and screen, making it adaptable for varying levels of rainfall intensity.

Figure 5. The leaf screen

The water travels through a first flush diverter en route to the tank, efficiently eliminating heavy pollutants that the leaf screen would have overlooked. Figure 6 illustrates this diverter.

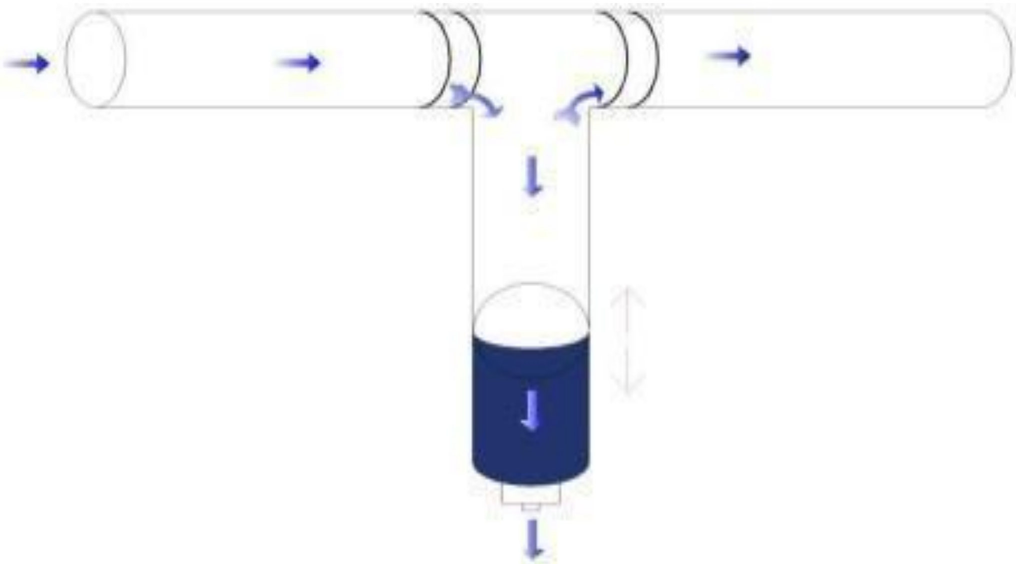

Figure 6. The first flush diverter (Müftüoğlu, 2024)

Utilizing a ball valve within a vertical pipe, the first flush diverter serves to obstruct and segregate contaminated water from the clean flow directed toward the tank. Once the ball valve reaches capacity, it seals off the pipe, effectively trapping the majority of dirt and impurities. The collected water can then be used for irrigation purposes with a slow-release valve or nozzle. While this method may not achieve complete purity, it significantly enhances water quality. Further improvements can be made through additional filtration, desalination, and purification processes.

Water storage tanks, made from various materials such as plastic, concrete, or metal, share several fundamental components. Although the inflow pipe is not critical for water transport, the primary essential component is the access port for maintenance, which facilitates cleaning and repairs. The second crucial element is the ventilation opening, which relies on fluid mechanics principles to prevent vacuum formation and implosion when water enters or exits. The third element is the overflow opening equipped with a pipe equal to or larger than the inflow, preventing pressure buildup during heavy rainfall. This overflow can also be connected to adjacent tanks to provide additional storage capacity and prevent overflow.

The fourth essential component is the outlet used for distribution or various applications. For instance, a hose can be used for irrigation, or the system can be connected to devices like sprinklers through pumping facilities. The tank material must withstand environmental factors such as humidity and sunlight and be resistant to chemicals and biological growth that could compromise water quality, such as mold and algae. The presence of sludge at the tank's base can impede efficiency, so positioning the outlet above the sludge or at the base helps prevent clogging issues. Additionally, extending the inlet pipe beyond the first flush diverter, with a gap, minimizes the impact of sludge accumulation. The essential components of the storage tank are presented in Figure 7.

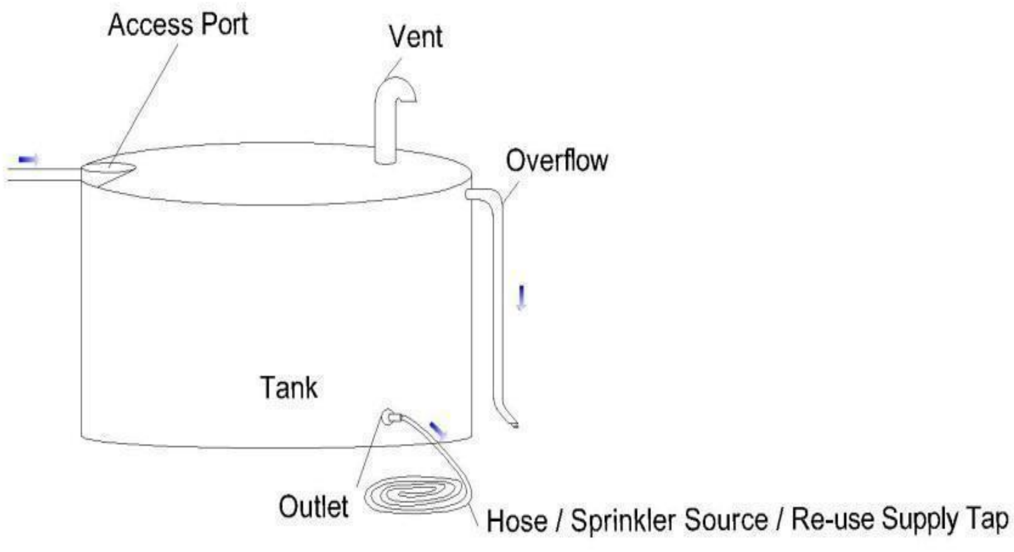

Figure 7. The tank and the related components (Müftüoğlu, 2024)

3. Results

The network water used in Block F is only for indoor purposes (such as toilets and cleaning) and does not include any garden irrigation or similar activities. Therefore, water consumption for this block remains consistent throughout the seasons. The rainwater harvesting potential of Block F is calculated using Equation 1. When considering an annual average precipitation of 660.9 mm, a roof surface runoff coefficient of 0.9 (galvanized iron plate), and a roof area of 695 m^2, the monthly and annual rainwater harvesting potential for Block F is presented in Table 3.

Table 3. Monthly and annual rainwater harvesting potential for Block F

Period	Rainwater Harvesting Potential (m^3)
January	56.10
February	44.09
March	39.46
April	29.71
May	20.39
June	17.45
July	14.07
August	15.38
September	25.33
October	41.72
November	47.53
December	62.11
Annually	413.39

Various statistical analyses can be utilized to explore patterns, trends, and variations in rainwater harvesting potential across different months. Descriptive statistics serve as essential tools for summarizing and understanding the characteristics of a dataset. These include measures such as the mean, median, standard deviation, range, variance, coefficient of variation (CV), skewness, and kurtosis. The mean, calculated as the sum of all values divided by the number of observations, provides a central or typical value for the dataset. In the context of rainwater harvesting, the mean monthly value represents the typical potential for rainwater harvesting that can be expected in an average month. This information is valuable for planning and resource allocation in rainwater harvesting systems. A mean value that deviates significantly from expectations may suggest generally lower or higher rainfall throughout the year, impacting harvesting strategies.

$$Mean(\mu) = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{2}$$

Where:

x_i is the individual value (e.g. monthly rainwater potential)

n is the number of values (12 for months in this case)

The median represents the middle value of a dataset when the values are arranged in ascending order. If the dataset contains an even number of values, the median is calculated as the average of the two middle numbers. Unlike the mean, the median is less influenced by extreme values or outliers, making it a more robust measure when the data includes months with exceptionally high or low rainwater harvesting potential. For instance, if one month exhibits unusually high harvesting potential, the mean may become skewed, but the median will still provide a representative value for a typical month. When the median is close to the mean, this indicates a relatively symmetrical distribution of rainwater harvesting potential across the months. To calculate the median, data are to be ordered in ascending sequence and the value of the middle determined. If the number of data is odd, then the median is the value of the middle. If it is even, then median is taken as the average value of the two middles.

Standard deviation is the measure of the dispersion of values that fall outside the mean of a data set. The higher the standard deviation, the greater the variability; if the standard deviation is low, it will be when the values become more concentrated around the mean. This measure provides an insight into the variability of rainwater harvesting potential in time. A high standard deviation suggests substantial fluctuations in the value of harvesting potential between months, and this would have to be met with more flexible planning strategies.

On the other hand, if the standard deviation is small, it means that rainwater harvesting potential does not vary widely, hence making the design and management of the system less complicated. When huge variations in potential are considered, then the standard deviation becomes of utmost importance to be fully prepared for months when rainfall might be way higher or lower than the average.

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \mu)^2} \tag{3}$$

Where:

σ is the standard deviation

μ is the mean

x_i is the individual value

n is the number of values

The range is a measure of the spread in a dataset. It is understood to be, merely put, the difference between the maximum and minimum values. A measure of the spread indicates the total variation present within a dataset. In rainwater harvesting, therefore, the range stretches to mean how far apart the months of wettest and driest rainfall have been. This information is critical for planning how much storage capacity should be developed and for developing strategies on usage. The broad range of 14.07 m^3 in July to 62.11 m^3 in December indicates that storage solutions must be adaptable to meet the potential variance in rainwater collection. Knowing the range furthers the ability to anticipate and manage fluctuations in rainwater harvesting potential throughout the year.

$$Range = x_{max} - x_{min} \tag{4}$$

Where:

x_{max} is the maximum value

x_{min} is the minimum value

Variance is, in some sense, the average of the squared deviations from the mean value, and it serves as one way to quantify the dispersion of individual data from the mean. Whereas the standard deviation quantifies the same dispersion as the units of the variable being measured (e.g., m^3), variance quantifies dispersion about squared units but generally yields a more abstract, yet equally valid, interpretation of variability. It forms a very important basis for quantifying overall variability in a dataset. Other statistical analysis depends on its calculation. In rainwater harvesting, a high variance would indicate that for some months during the year, values are well below the mean. This, in turn, signifies an uneven distribution of the harvesting potential throughout the year. Variability like this often affects system planning and resource management strategies.

$$\sigma^2 = \frac{1}{n}\sum_{i=1}^{n}(x_i - \mu)^2 \tag{5}$$

Where:

σ^2 is the variance

μ is the mean

x_i is the individual value

n is the number of values

The coefficient of variation (CV) is simply a statistical measure that expresses the ratio of the standard deviation to mean as a percentage. In essence, this parameter provides a relative measure of the magnitude of variation in a dataset concerning its mean. The CV is useful in comparing variability across different data sets that are measured using different units or scales. In the context of rainwater harvesting, CV quantifies the variability in the harvesting potential relative to the mean monthly value. A high CV implies very large variability in the month-to-month rainwater harvesting potential that may be in need of planning strategies for balancing the water collection and usage throughout the year to maintain consistency in resource management.

$$CV = \frac{\sigma}{\mu}\, x\ 100 \tag{6}$$

Where:

σ is the standard deviation

μ is the mean

Skewness is a statistical metric used to describe the asymmetry of a data distribution. A skewness value near zero indicates a symmetrical distribution, while positive or negative skewness reveals an asymmetrical pattern. Recognizing the skewness in data is essential for understanding its central tendency. In the context of rainwater harvesting potential, positive skewness, characterized by a longer right tail, indicates that certain months have unusually high harvesting potential. In contrast, negative skewness suggests that a few months display much lower potential. The presence of positive skewness, for example in months such as December and January, suggests significantly elevated rainwater harvesting potential, which may influence strategies for resource distribution and management.

$$Skewness = \frac{n}{(n-1)(n-2)}\sum_{i=1}^{n}\left(\frac{x_i-\mu}{\sigma}\right)^3 \tag{7}$$

Where:

n is the number of values

μ is the mean

σ is the standard deviation

x_i is the individual value

Kurtosis is a statistical measure that describes the "tailedness" of a data distribution, indicating whether the dataset has heavier or lighter tails compared to a normal distribution. High kurtosis suggests the presence of more outliers, or data points that deviate significantly from the mean. This measure is particularly valuable for identifying whether extreme months, characterized by unusually high or low rainwater harvesting potential, occur more frequently than anticipated. Understanding kurtosis helps in preparing for abnormal rainwater harvesting events. A high kurtosis would imply the occurrence of some months with exceptionally high or low harvesting potential, necessitating contingency plans to accommodate such extremes.

$$Kurtosis = \frac{n(n+1)}{(n-1)(n-2)(n-3)}\sum_{i=1}^{n}\left(\frac{x_i-\mu}{\sigma}\right)^4 - \frac{3(n-1)^2}{(n-2)(n-3)} \tag{8}$$

Where:

n is the number of values

μ is the mean

σ is the standard deviation

x_i is the individual value

The results of the descriptive statistics for the rainwater harvesting potential data are given in Table 4 below.

Table 4. Descriptive statistics for the rainwater harvesting potential for Block F

Statistic	Value
Mean	34.45 m^3
Median	35.59 m^3
Standard Deviation	16.37 m^3
Variance	267.92 m^6
Range	48.04 m^3
Minimum	14.07 m^3
Max	62.11 m^3
Coefficient of Variation	47.52%
Skewness	0.24
Kurtosis	-1.23

In general, the average potential for rainwater harvesting in facilities is around 34.45 m^3, which is representative of rainwater collected in a month on average. It gives an overall idea about the potential water availability throughout a year. Designers need to consider the storage capability to be able to hold a minimum of 34.45 m^3 every month by providing sufficient capacity through most months.

The median is 35.59 m^3, slightly higher than the mean, indicating that half of the months have a rainwater harvesting potential above this value and half below. Since the median is close to the mean value, the distribution of RWH would, therefore, be relatively symmetric with no major skewness. This correspondence between the mean and median is close enough to reassure that, in fact, the months more or less equidistribute between high and low values without any notable outliers that would distort the data.

The standard deviation is 16.37 m^3, which shows the standard deviation of the variability in monthly rainwater harvesting potential to be simply moderate. That is to say, the potential is different from the mean value by approximately 16.37 m^3. Hence, some months may have huge potentials that may be far above or below the average. This variability speaks to the need for a systemic design versatile enough to handle those months of high or low water collection. This therefore means one would have to plan for about 16.37 m^3 of deviation from the mean to ensure efficiency in storage and resource allocation.

The variance, representing the dispersion of the data set, is 267.92 m^6, representing the deviation of the monthly rainwater harvesting potential from the mean. This is a great dispersion, and since the standard deviation suggested moderate variability, that also argues for adaptable system design due to wide fluctuation in rainwater harvesting potential.

The range from the maximum rainwater harvesting potentials in December at 62.11 m^3 and minimum potential in July at 14.07 m^3, is 48.04 m^3. This large variation shows the full swing of seasonal variation from very wet to very dry months. For this reason, the system needs to handle volumes of rainwater that are far higher during December, while needing a significantly lower capacity in drier months such as July.

July has the lowest rainwater harvesting potential, which is 14.07 m³. This would usually be representative of the driest month and is very critical in planning for those periods when there is low water availability. During these months-for example, July-the rainwater harvesting systems should be able to be supported by other sources of water, since the harvesting potential will be very low.

Since the highest rainfall is in the month of December, the harvesting potential yields a maximum value of 62.11 m³; hence, it is the month of highest rainwater availability. Maximum collection should be done during such high-potential months to store excess rainwater arising in these months for use during low-potential months-for example, July. This is where planning should be done on how to utilize effectively the water stored from high-potential months and manage it for the months with low rainwater harvesting potentials.

The coefficient of variation, as a variability measure relative to the mean in percent, is 47.52%, stating that there is quite a high variation in rainwater harvesting potential for each month. Because of this high variability, the rainwater harvesting system should be designed keeping in mind the fluctuations of the potential. A flexible system is required with adaptable storage capacity in order to handle peak and low collection months. This is very important for surplus storage during the high potential months like December, reserving some in the months with the lowest potential like July, so that it will be able to operate the whole year efficiently.

The former skewness value, which is 0.24, indicated slight positive asymmetry about the distribution of monthly rainwater harvesting potential. Even though it is close to being symmetric, the longer right tail would indicate that there are a few months with higher-than-average harvesting potential. This slight positive skewness would suggest that system design should recognize months of unusually high collections of rainwater. For the most part, however, this distribution is reasonable, with a balance that will enable reliable predictions and planning using the mean and standard deviation.

The kurtosis value of -1.23 indicates that the distribution has lighter tails (platykurtic) than a normal distribution and is less likely to generate extreme values either at low or high levels. It is thus a very stable data set with few outliers or extreme months. Hence, for design purposes, the system can be planned according to average conditions rather than overestimating those few high or low values, which enables efficient resource and storage planning.

In general, the distribution of rainwater harvesting potential is very uneven, with 48.47% coefficient of variation and spherical distribution of 48.04 m³.

This variability underscores the need for a system design that can accommodate both peak and low months. Storage capacity must be sufficient to handle the highest potential months, such as December, while alternative sources or water-saving strategies may be necessary during low-potential months like July. A system designed to handle fluctuations around the mean of 34.45 m³, and prepared for the extremes indicated by the range and standard deviation, would be ideal for efficient rainwater management.

The skewness value of 0.11 confirms that the data distribution is approximately symmetric, indicating no significant outliers that could distort the overall pattern. This symmetry allows for system design to focus on central tendencies, such as the mean, ensuring more predictable and efficient management of rainwater harvesting potential.

The kurtosis value of -1.25, reflecting a relatively flat distribution, indicates that extreme outliers are unlikely to occur. With fewer outliers, the system's capacity can be more predictable and optimized, reducing the need to overcompensate for rare extreme fluctuations. This allows for balanced and efficient planning that prioritizes average conditions over rare events.

In Figure 8, compensation, surplus, and deficit of harvested rainwater concerning water consumption is presented.

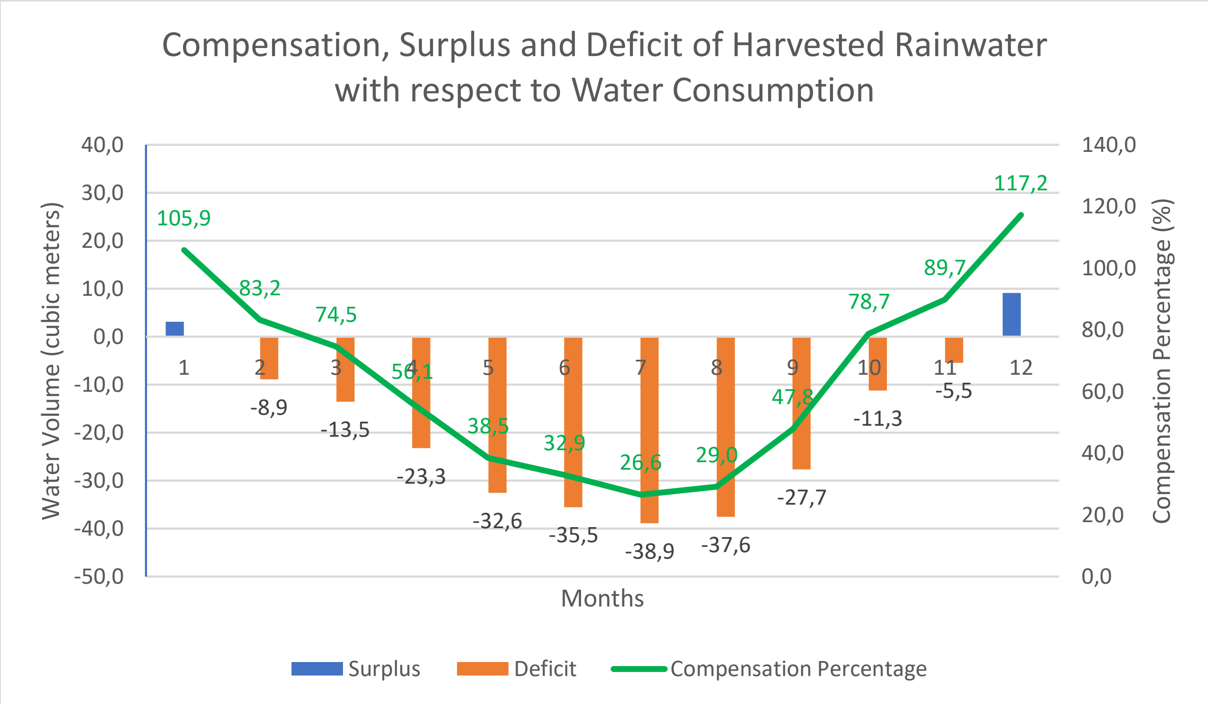

Figure 8. Compensation, surplus, and deficit of harvested rainwater concerning water consumption

If the annual water consumption for Block F is considered as 636 m^3, in that case, the ratio of the annual city water consumption in this block being met with harvested rainwater will be 65%.

As previously mentioned in the introduction section, the novelty of the study is relevant to creating an environmental consciousness and awareness on-site for university students throughout their studies.

Therefore, to fill this gap in the literature for Turkey, we compared our results with the literature, but unfortunately, we could not find any study findings covered as ours. However, for the technical comparison, we found a study conducted at Zonguldak Bulent Ecevit University Campus (Özölçer, 2016), that RWH systems can be used to lower the campus area's water usage from 22500 m^3. Similar to our study findings, a galvanized iron plate at one of the university campuses in Izmir uses a roof surface runoff coefficient of 0.9. The authors reported that 16606.65 tons of water could be collected, respectively, based on a calculation of the amount of water that could be collected from precipitation on rooftops (Hajjar et al., 2020). An estimated 16570.30 m^3 of rainwater must be collected from the rooftops of 24 buildings located on the Ege University campus in Izmir. The results of this study indicate that the research area may provide 11% of the water required for irrigation of the existing green spaces and 20% of the water required for irrigation from April to October due to its potential for year-round rainwater gathering (Ozeren Alkan and Hepcan, 2022). According to research findings evaluating the potential as a resource for rooftop rainwater collection, the Jordanian districts of Al-Jubiha and Shafa-Badran could potentially yield 1.17 and 0.526 million m^3/year, respectively (Al-Houri et al., 2014). Anchan and Prasad (2021) stated that an Indian investigation revealed the possibility of collecting 113678.9 m^3 of rainwater from the rooftops of 19 building units of South Indian University. A study carried out in Ethiopia claims that 320 sizable public entities were selected and divided into 11 groups. Of these, 25–30% of the 588 representative rooftops were digitalized, and a rainfall dataset covering ten years was used to assess the potential RWH volume. When comparing the resulting RWH potential to the volume of water utilized, it is possible to supply up to 2.3% of the yearly supply of potable water. Reusing only within one's company can yield sufficiency rates between 0.9 to 649% (Adugna et al., 2018).

4. Discussion and Conclusion

Universities' RWH systems can serve as an example for instructional goals. It provides practical, hands-on instruction in environmental sciences and sustainable environment engineering. RWH systems give academic institutions a special chance to promote sustainability by allowing students to be involved in all phases of the process, from preparation and implementation to monitoring. The results obtained in this study are similar to the results obtained by Saygın and Ulusoy (2011); Alharthi et al. (2019); Dawodu et al. (2022); Asaad et al. (2024); as a result of the evaluation made in the literature.

The next generation of environmental leaders and practitioners will benefit greatly from the practical skills acquired via its hands-on implementation. Because they can increase economic growth in addition to reducing water waste. Universities that deploy RWH systems have the chance to set an example for other organizations and communities. Additionally, by demonstrating the benefits of RWH methods from both a practical and financial standpoint, universities will be able to influence how these practices are implemented throughout society. The widespread use of this phenomenon has the potential to yield significant improvements in the implementation of various urban water management measures, hence enhancing the overall security and resilience of our water resources.

Overall, the vast amount of university research on RWH, especially in Turkey, demonstrates its many advantages, ranging from increased environmental sustainability to financial savings and better water quality. Institutes can promote long-term sustainability objectives in addition to meeting immediate water requirements by incorporating RWH into campus infrastructure. Adopting RWH techniques is crucial for fostering sustainability and resilience in higher education as institutions deal with issues like water scarcity and climate change. In addition to these advantages, RWH helps institutions in the financial sustainability domain by offering low costs. Although using city water on campus requires some infrastructure and costs, this approach offers sustainability. One example of social sustainability is environmental awareness, particularly among students in higher education.

The results of this study show that a significant proportion (around 65%) of annual city water consumption in Block F at Istanbul Aydin University is offset by harvested and potentially commercial-grade rainwater. This illustrates the ability of RWH systems to significantly reduce dependence on municipal water resources, thus supporting local conservation and sustainability efforts throughout the university community.

The data source of the study indicates that rainwater collection can be a lifesaver throughout most of the year and emphasizes how effective it can be in supplying water needs. Because of this, high compensation percentages in Months 1 and 2 further demonstrate the effectiveness of rainwater collection during these months, while Months 11 and 12 highlight the possibility of achieving even greater surplus amounts than requests through such systems. Although MS3–10 problems are present throughout this time, this indicates potential areas for rainwater collecting and storage system upgrades. By making such infrastructural and technological investments, these shortages might be reduced, maximizing the advantages of rainwater gathering and supplying more water during dry periods. The fact that this study was conducted without using any sophisticated or advanced datalogger can be shown as the novelty of the article as it sets an example for everyone interested in this subject.

Infrastructure investments can be expensive initially, but over time, RWH will fulfill these financial objectives since water rates will drop and less money will be used to cover possible stormwater management expenses. Additionally, this balances the amount of water utilized for municipally treated waters' distribution and treatment.

Institutions that are inspired by this study and will use it as a model can first figure out how much water they need on campus in addition to city water, then determine which roofs can be used to set up the system, and finally develop a plan that outlines the steps for replicating the data collection techniques used in this study.

5. Limitations of the Study

The most fundamental limitation of this study is the climate and geographical features where the study was carried out. The technical characteristics of the block employed in this investigation are another limitation. Block F is not like the other buildings on the Istanbul Aydin University campus. An additional limitation is the short collection time of the data, which implies that it is not very old. The building of Block F is scheduled to begin in the early 2010s. In terms of technology, more sophisticated dataloggers might have been used to collect the data.

Conflict of Interest Statement

The authors declare that there is no conflict of interest between them.

Summary of Researchers' Contribution Rate Declaration

The authors declare that they have contributed equally to the article.

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