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A Preliminary Investigation of Rainwater Harvesting Potential in Emergency Healthcare Facilities: Case Study of Yeşilköy Prof. Dr. Murat Dilmener Hospital

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ABSTRACT

Rainwater harvesting (RWH) is a sustainable approach to addressing water scarcity and promoting efficient water management in critical infrastructure. This study evaluates the RWH potential of Yeşilköy Prof. Dr. Murat Dilmener Emergency Hospital, a 1000-bed facility, using a simplified analytical approach. Satellite imagery and regional precipitation data were employed, categorizing roof sections based on size, type, and material, with aggregated segments simplifying the calculations. The analysis estimated an average monthly RWH potential of 1261.00 m³, with December and January demonstrating the highest potential at 2273.57 m³ and 2053.77 m³, respectively, and July recording the lowest at 515.16 m³. Seasonal variability was quantified through a standard deviation of 586.94 m³, a coefficient of variation (CV) of 46.54%, a positive skewness of 0.50, and a kurtosis of -1.36, indicating moderate variability and relatively stable harvesting conditions. The study also shows that RWH can contribute between 2.77% and 12.22% of the hospital's monthly water demand, translating into thousands of cubic meters of annual water savings. While these percentages may appear modest, the benefits of RWH extend beyond immediate water contributions, providing resilience during droughts or water supply disruptions and fostering sustainable practices within healthcare management. This preliminary assessment, conducted under conservative assumptions such as treating sloped roofs as flat surfaces, underscores the feasibility of implementing RWH systems even with limited data. Future studies incorporating precise roof measurements, material analyses, and dynamic rainfall simulations are expected to reveal even greater potential. By demonstrating the viability of RWH, this study provides a foundation for decision-makers, including government authorities and hospital management, to integrate RWH into emergency healthcare infrastructure, advancing sustainable water management practices.

Acil Sağlık Tesislerinde Yağmur Suyu Hasadı Üzerine Bir Ön Araştırma: Yeşilköy Prof. Dr. Murat Dilmener Hastanesi Örneği

Araştırma Makalesi

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ÖZ

Yağmur suyu hasadı (YSH), su kıtlığını ele almak ve kritik altyapılarda su yönetiminin verimliliğini artırmak için sürdürülebilir bir yaklaşımdır. Bu çalışma, 1.000 yatak kapasiteli Yeşilköy Prof. Dr. Murat Dilmener Acil Durum Hastanesi'nin YSH potansiyelini basitleştirilmiş bir analitik yaklaşım

kullanarak değerlendirmektedir. Uydu görüntüleri ve bölgesel yağış verileri kullanılarak çatı bölümleri boyut, tür ve malzeme bazında kategorize edilmiş ve hesaplamaları kolaylaştırmak için benzer segmentler birleştirilmiştir. Analiz, ortalama aylık YSH potansiyelinin 1261,00 m³ olduğunu ve Aralık (2273,57 m³) ile Ocak (2053,77 m³) aylarının en yüksek hasat potansiyelini, Temmuz'un ise en düşük potansiyeli (515,16 m³) kaydettiğini göstermiştir. Mevsimsel değişkenlik, 586,94 m³ standart sapma, %46,54 değişim katsayısı (CV), 0,50 pozitif çarpıklık ve -1,36 basıklık değeri ile hesaplanmış ve bu durum, orta düzeyde bir değişkenliğe ve nispeten sabit hasat koşullarına işaret etmektedir.
Çalışma ayrıca YSH'nin hastanenin aylık su talebinin %2,77 ila %12,22'si arasında bir katkı sağlayabileceğini, bunun yıllık binlerce metreküp su tasarrufuna dönüştüğünü göstermektedir. Bu yüzdeler mütevazı görünebilse de, YSH'nin faydaları anlık su katkılarının ötesine geçerek kuraklık veya su temininideki kesintiler sırasında direnç sağlamakta ve sağlık yönetiminde sürdürülebilir uygulamaları teşvik etmektedir. Eğimli çatılar düz yüzeyler olarak ele alınarak yapılan muhafazakâr varsayımlar altında gerçekleştirilen bu ön değerlendirme, sınırlı verilerle bile YSH sistemlerinin uygulanabilirliğini vurgulamaktadır. Gelecekteki çalışmalar, hassas çatı ölçümleri, malzeme analizleri ve dinamik yağış simülasyonlarını içerecek şekilde bu potansiyeli daha da geliştirebilir. Bu çalışmayla YSH'nin uygulanabilirliğini göstererek, hükümet yetkilileri ve hastane yönetimi gibi karar vericilere YSH'nin acil sağlık altyapısına entegrasyonunu teşvik edecek bir temel sağlanmakta ve sürdürülebilir su yönetim uygulamaları desteklenmektedir.

Anahtar Kelimeler:
İstanbul
Yağmur suyu hasadı
Sürdürülebilir su yönetimi
Sürdürülebilirlik
Sürdürülebilir şehirler ve toplumlar

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Introduction

The issue of water scarcity is one of the most significant problems faced by the world today, due to the rapid urbanization of cities, the increase in the world population, and global warming. Rainwater Harvesting (RWH) has become a sound and sustainable solution to the water shortage by collecting, storing, and reusing rainwater for nonpotable, and in some cases potable, use. RWH not only reduces dependence on conventional water supply systems but also mitigates urban flooding and enhances environmental sustainability. Despite its demonstrated benefits in various urban and rural settings, the application of RWH in emergency healthcare facilities has received limited attention in academic and practical domains. Given the large roof areas typically available in hospitals and the significant rainfall in many regions, these facilities present considerable opportunities for implementing RWH systems.

This study focuses on Yeşilköy Prof. Dr. Murat Dilmener Emergency Hospital as a case study to assess the feasibility and potential of RWH in an emergency healthcare setting. Using a simplified analytical approach, the study integrates roof area, material type, and regional precipitation data to estimate RWH potential. Roof sections were categorized and grouped based on size, type, and material to streamline calculations, while assumptions such as flat roof surfaces were made to ensure a timely and preliminary assessment. Although these assumptions introduce some limitations, they highlight the significant promise of RWH, even under conservative conditions.

The primary aim of this study is to provide a foundational understanding of the potential benefits of RWH in emergency hospitals and to encourage decision-makers, including government authorities and hospital management, to integrate RWH strategies into healthcare infrastructure. By showcasing potential water savings and sustainability benefits, the findings serve as a stepping stone for future, more detailed analyses that incorporate roof slopes and precise dimensions. Ultimately, this research underscores the role of RWH in advancing sustainable water management practices within the healthcare sector.

RWH systems in healthcare facilities also support broader urban sustainability goals. RWH systems have demonstrated significant water and energy savings, particularly in hospital environments. Guidelines for water safety and quality in healthcare premises emphasize the importance of ensuring reliable water supply systems, which aligns with the potential of RWH systems to improve water management in hospital settings (Scottish Health Technical Memorandum 04-02, 2015).

RWH systems at hospital building sites have shown tremendous potential for both water and energy savings, especially when combined with metal roofs (with a runoff coefficient of 0.95) and optimum tank sizes. Yet cost and long payback times for larger, more efficient tanks suggest the importance of compromising with environmentally sustainable and economic feasibility (Nasif et al., 2016).

RWH systems in hospitals represent great potential for substantial freshwater and operational cost savings. For example, the University College Hospital Ibadan found that a 12 m^3 tank could satisfy 78.1% of its water demand, resulting in savings of $51,072 over a period of 50 years, with a quick one-year payback period (Lade and Oloke, 2017).

In large hospitals located in semi-arid areas, RWH systems, when paired with demand-side measures like low-flow fixtures and xeriscaping, have demonstrated external water savings of around 25%. This decrease is largely a function of several crucial design variables such as rain catchment area, facility dimensions, and storage tank characteristics (Fulton, 2018).

All hospitals can benefit from water management goals through RWH systems, upon which they can rely: increase groundwater recharge, stormwater management (leads to less flooding), reduce potable water consumption. For example, a case study at AIIMS Hospital, Raipur, brought out the primary design factors and their associated costs and the twofold purposes of the urban water level management system serving both as a water system and a groundwater recharge system (Das, 2019).

RWH systems have shown a great promise to meet emergency water needs in health care facilities. For example, at Dilla University Referral Hospital in Ethiopia, RWH can provide

94.5–238.5% of emergency water demand, which suggests that RWH is a reliable alternative water source during public health emergencies like the pandemic of COVID-19 (Kanno et al., 2021).

Rainwater for drinking (RFD) systems in the hospital, especially in relatively rural regions, serves as a tool to increase the reliability of water supply by implementing a rigorous training and monitoring system. These systems have been used for increased confidence in operations and assurance in meeting drinking-water standards, addressing SDG 6 (Lee et al., 2021).

Assumptions and Limitations

This study is based on several key assumptions to facilitate the preliminary assessment of rainwater harvesting (RWH) potential. First, sloped roof surfaces were treated as flat to simplify calculations, which may underestimate the actual harvesting potential. Second, the runoff coefficients were derived from literature values for similar roofing materials, as on-site verification was not feasible. Third, the analysis relied on satellite imagery for roof area measurements, which may introduce minor inaccuracies compared to precise on-site measurements. Additionally, the study did not account for potential losses due to evaporation, leakage, or first-flush diversion. These assumptions and limitations highlight the need for future studies to incorporate detailed roof measurements, dynamic rainfall simulations, and on-site validation to refine the estimates further.

Material and Methods

Case study hospital

Yeşilköy Prof. Dr. Murat Dilmener Emergency Hospital, located in Istanbul, Turkey, was established to address critical healthcare needs during emergencies, including pandemics and natural disasters. Constructed in just 52 days on the grounds of Istanbul Atatürk Airport, the hospital spans 125,000 square meters, with a covered area of 75,000 square meters. It features 1,008 beds, including 432 intensive care units, 16 operating theaters, and around 100 dialysis units (Wikipedia, 2020). Named after Prof. Dr. Murat Dilmener, a prominent physician who passed away due to COVID-19, the facility symbolizes Turkey's commitment to enhancing healthcare infrastructure (Ministry of Health, 2020). In Figure 1, the geographical location of Yeşilköy Prof. Dr. Murat Dilmener Emergency Hospital is presented. In Figure 2, the satellite image of the hospital is given.

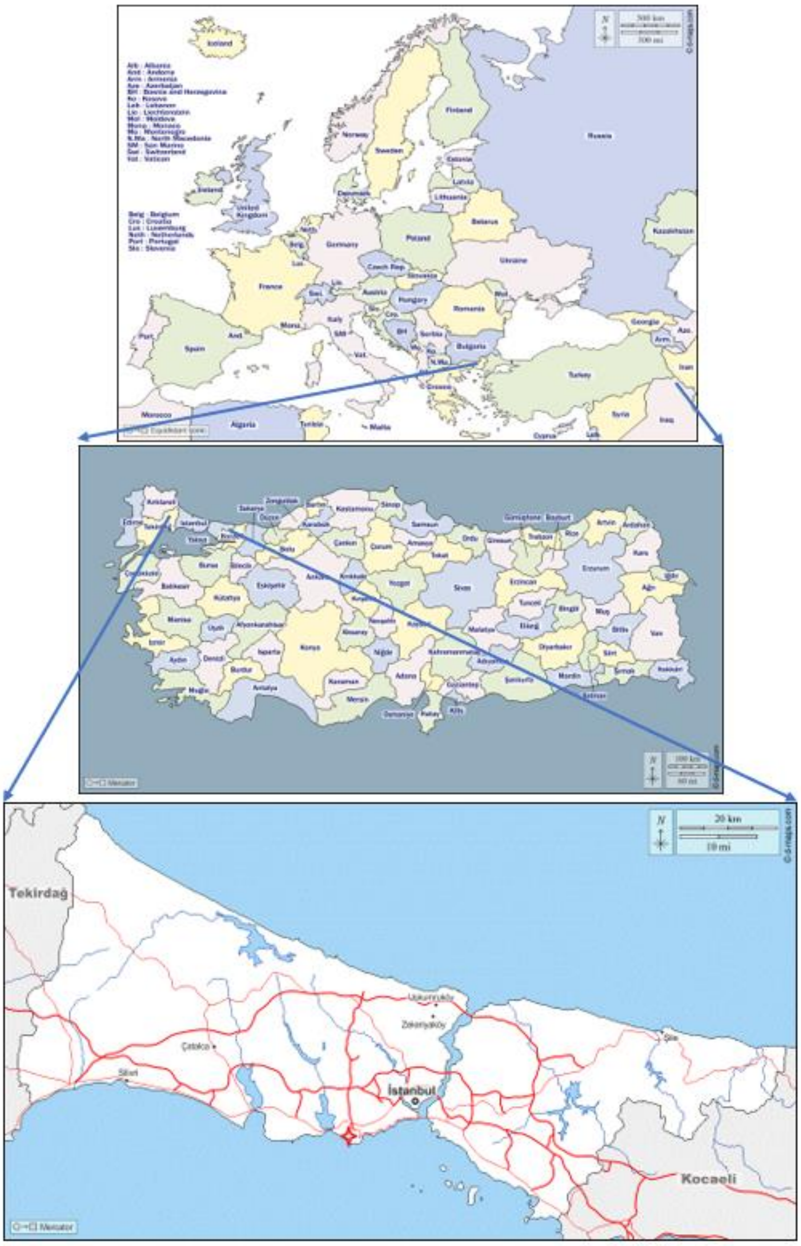

Figure 1. Location of the case study hospital

Figure 2. Satellite image of the case study hospital

Water consumption of the case study hospital

Accurate data on the water consumption of Yeşilköy Prof. Dr. Murat Dilmener Emergency Hospital is unavailable due to constraints in accessing detailed operational records. Comprehensive water consumption records often require formal requests and processing through administrative channels, which can be time-intensive and were not feasible within the timeline of this study. Therefore, an estimated consumption range is derived based on established benchmarks for hospitals in similar settings.

Studies and guidelines indicate that water consumption in healthcare facilities varies depending on factors such as geographical location, services provided, and facility size. For instance, the U.S. Environmental Protection Agency (EPA) reports that the median hospital uses approximately 315 gallons (about 1192 liters) of water per bed per day (U.S. Environmental Protection Agency, 2012). In a similar vein, the Central Public Health and Environmental Engineering Organisation in India prescribes 450 liters per bed per day for hospitals that have a bed count larger than a hundred. (Central Public Health and Environmental Engineering Organisation, 2016) A study conducted in Turkey on 118 public hospitals calculated the average water consumption per year to be about 192.26 m^3 per bed, which is approximately 526.74 L/bed/day (Teksoy and Altan, 2022). We have taken this value as a reference in this article because the assumptions would be specific for Turkey's water usage system and facilities in public hospitals, therefore the results could be localized.

At Yeşilköy Prof. Dr. Murat Dilmener Emergency Hospital, a scenario-based method was employed to analyze water use and water impact for calculating RWH potential. When examining three different situations:

Base Scenario: Based on the national statistic average for Turkish public hospitals of 526.74 liters per bed per day.

Moderate Demand Scenario: We calculate this amount to be 600 liters per bed per day to allow for higher water consumption like what is expected in emergency medical treatment units.

High Demand scenario: assuming 800 liters/bed/day, which is peak water demand in any of the world's comparable facility.

A moderate load case of 600 L/b/d was used as the main basis for the calculations. This estimate represents a compromise between the amount of water required to operate an emergency healthcare facility and the capacity to realize its RWH potential. The study highlights the realistic role of RWH in satisfying water demand with this value by showing that it is neither overestimating nor requiring strictly institutional-type data. Future studies with full hospital records input could potentially minimize these estimates to determine the best method of contributing to sustainable water management.

Climatic conditions of the case study hospital location

Istanbul's distinctive climate, shaped by its strategic position at the crossroads of Europe and Asia and its proximity to the Black Sea and the Mediterranean, exhibits considerable variability. Table 1 provides meteorological data for Istanbul spanning from 1950 to 2022, emphasizing the importance of precipitation patterns in evaluating the potential for rainwater harvesting.

Table 1. Rainfall records for Istanbul from 1950 to 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

Assessment of rainwater harvesting potential for the case study hospital

The RWH potential of the hospital's roof is calculated using the equation 1 provided by Gould and Nissen-Petersen (1999):

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

Here, S represents the RWH potential in cubic meters, R denotes the monthly rainfall in meters, A is the roof area in square meters, and Cr is the runoff coefficient. Mothly rainfall data are already obtained from Table 1.

The sloped roof surfaces of Yeşilköy Prof. Dr. Murat Dilmener Emergency Hospital have been treated as flat in this study due to the absence of precise measurements for ridge height and slope angles. While sloped roofs typically offer a larger effective harvesting area and thus higher RWH potential, assuming flat surfaces provides a conservative estimate. This approach ensures straightforward calculations while still showcasing the significant RWH potential of the hospital. By demonstrating considerable harvesting possibilities under these simplified conditions, the results emphasize the importance of integrating RWH strategies. Future studies, incorporating slope measurements and ridge heights, would likely reveal even greater potential, further validating the need for sustainable water management practices.

The roof area was determined using satellite imagery and the polygon measurement tool in Google Earth Pro, a practical method given the infeasibility of on-site measurements. High-resolution images were utilized to accurately identify roof boundaries, with sloped surfaces assumed flat for simplicity. This conservative assumption simplifies calculations while delivering a reliable preliminary estimate of RWH potential.

Using the polygon tool, roof perimeters were traced directly on satellite images, allowing the tool to automatically compute enclosed areas in square meters. To streamline the process, roofs were grouped based on geometry, size, and connectivity. Identical or similar sections were aggregated into single measurements, simplifying the overall calculation without compromising accuracy. The total roof area was then obtained by summing the measurements and applied as the A parameter in the RWH potential equation.

The hospital roof is assumed to consist of metal sandwich panels, as indicated by Teknopanel, the supplier for both Yeşilköy Prof. Dr. Murat Dilmener and Sancaktepe Emergency Hospitals. According to Teknopanel, these panels are composed of stone wool insulation and metal cladding, likely made of galvanized steel or aluminum. While the exact type of metal is unspecified, the difference in runoff coefficients between galvanized steel and aluminum is negligible compared to materials such as wood or concrete. Both metals generally have runoff coefficients exceeding 0.90, making them highly efficient for RWH applications.

This durable and impermeable roofing material further highlights the suitability of the hospital's roof for rainwater collection. The runoff coefficient values were applied as the Cr parameter in the RWH potential equation, alongside the total roof area.

To facilitate the analysis, the hospital's main buildings were grouped into eight categories based on geometry, size, and material composition. Buildings with identical shapes and dimensions were grouped together for simplicity, and materials were classified into sandwich panels (likely metal or aluminum) and concrete. This grouping enables a streamlined yet accurate evaluation of the RWH potential.

Assuming these roof materials enables the study to proceed without requiring on-site verification, delivering practical and reliable insights into the hospital's RWH potential. Future investigations incorporating detailed material analyses and slope measurements could refine these estimates and further enhance the accuracy of RWH potential assessments.

Figure 3 presents an overview of the grouped roof sections, while Figures 4–11 illustrate each roof section in detail. Table 2 summarizes the roof numbers along with their respective areas and material types, and Table 3 provides the runoff coefficients for various roofing materials.

Figure 3. Overview of the grouped sections

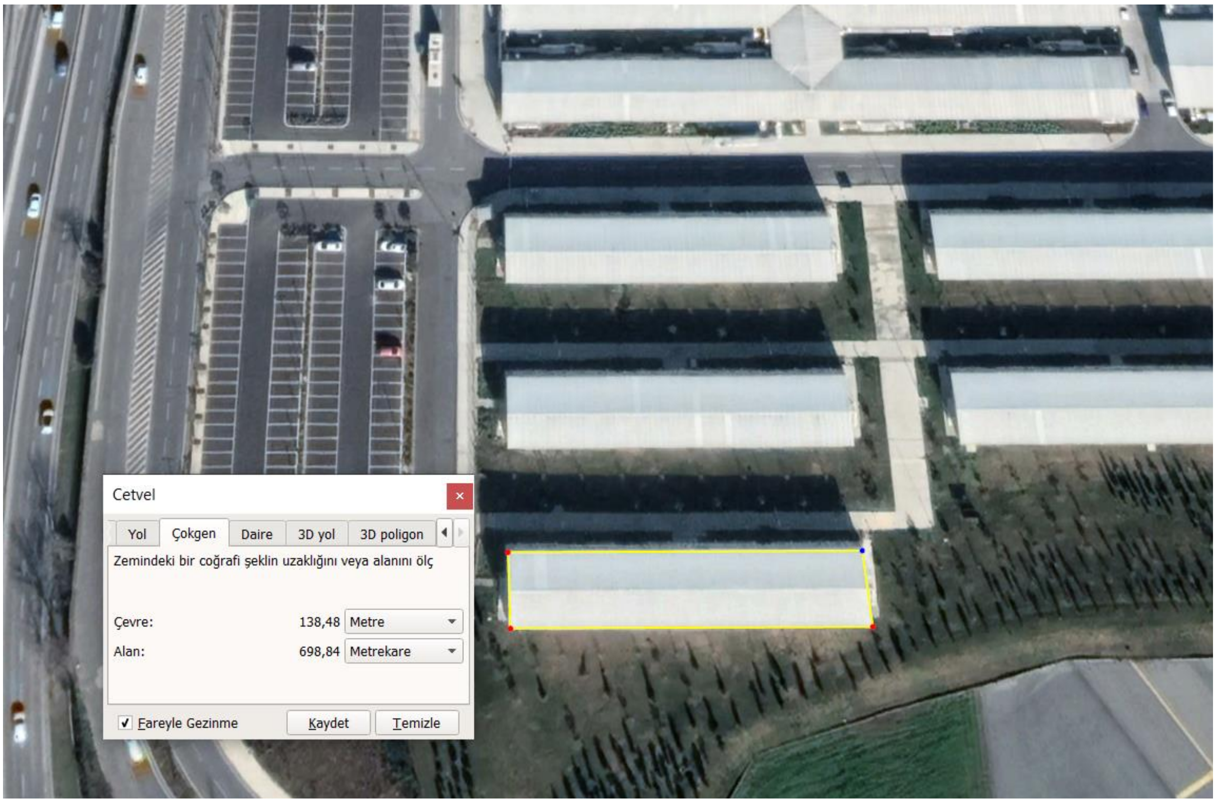

Figure 4. Roof group 1 and its polygon area measurement

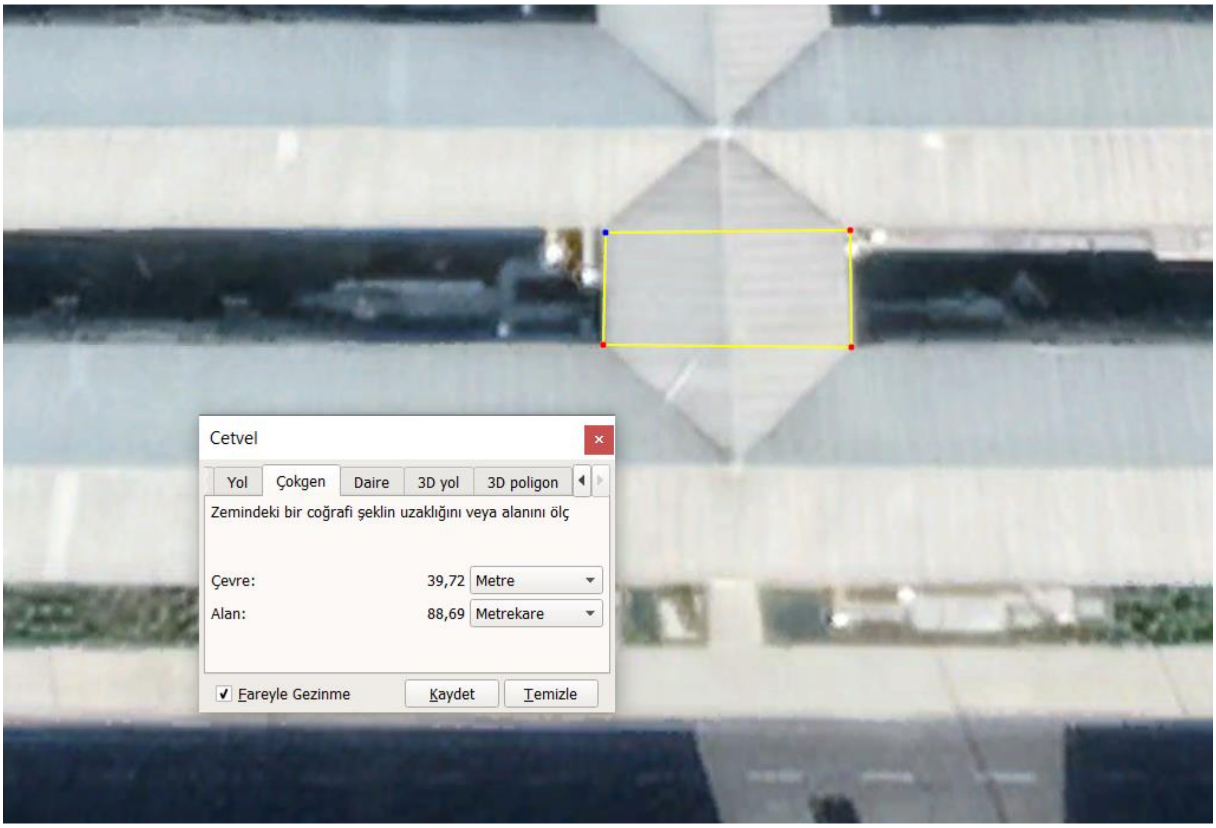

Figure 5. Roof group 2 and its polygon area measurement

Figure 6. Roof group 3 and its polygon area measurement

Figure 7. Roof group 4 and its polygon area measurement

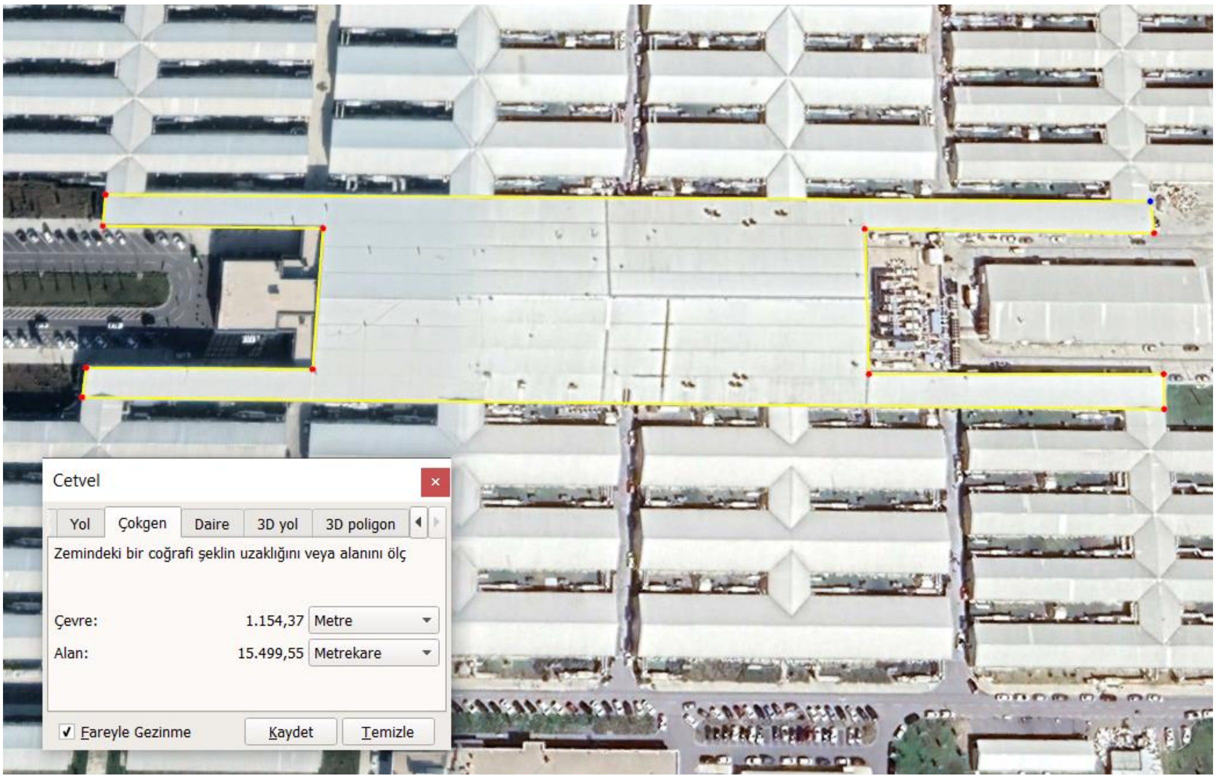

Figure 8. Roof group 5 and its polygon area measurement

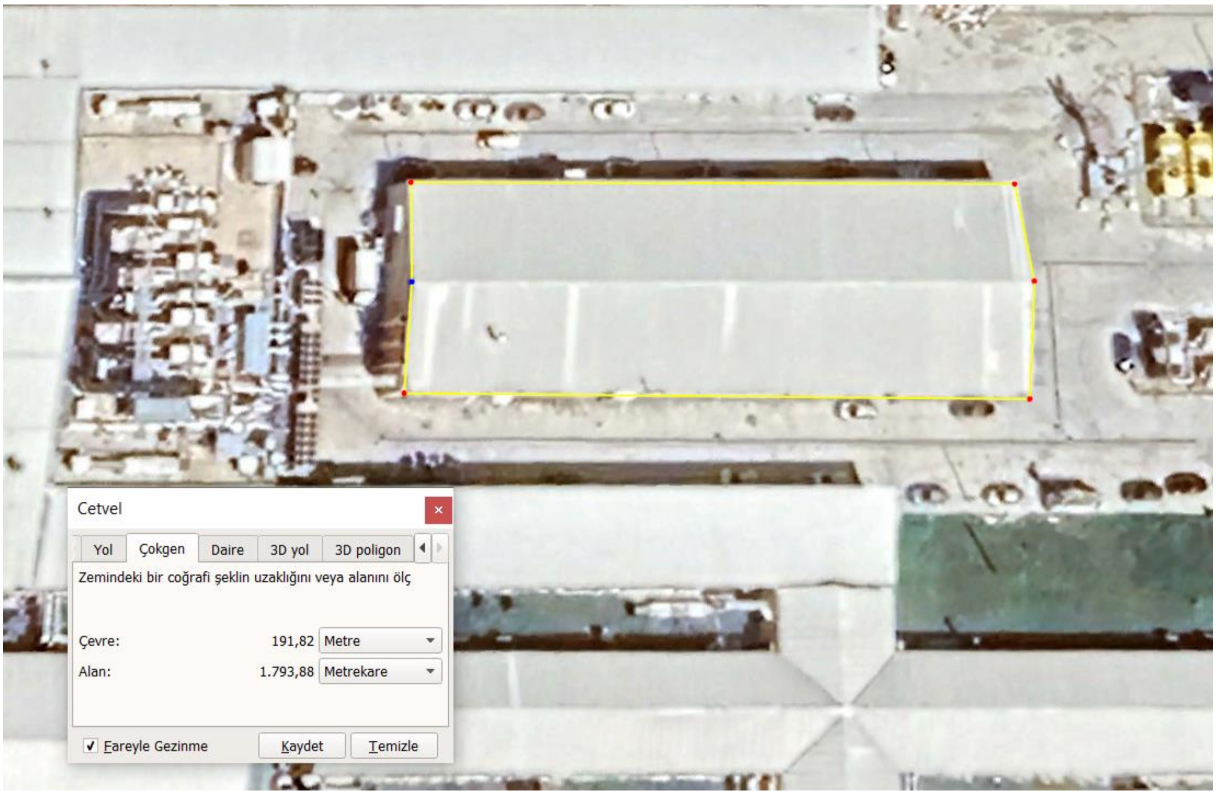

Figure 9. Roof group 6 and its polygon area measurement

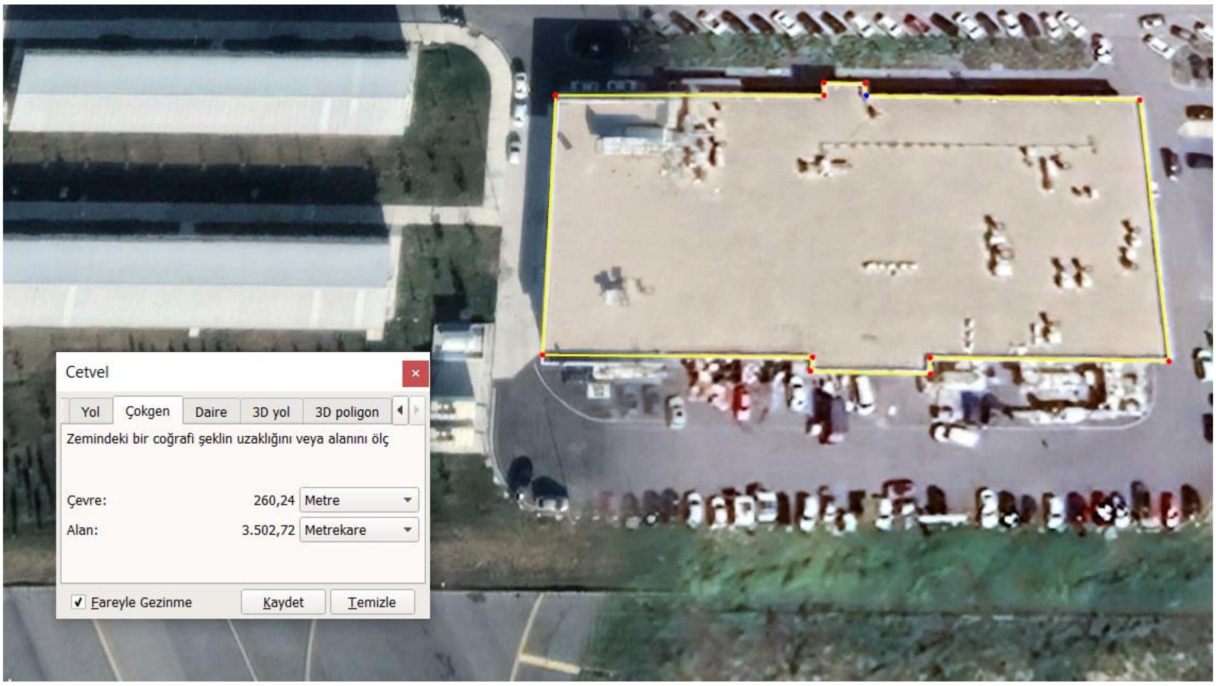

Figure 10. Roof group 7 and its polygon area measurement

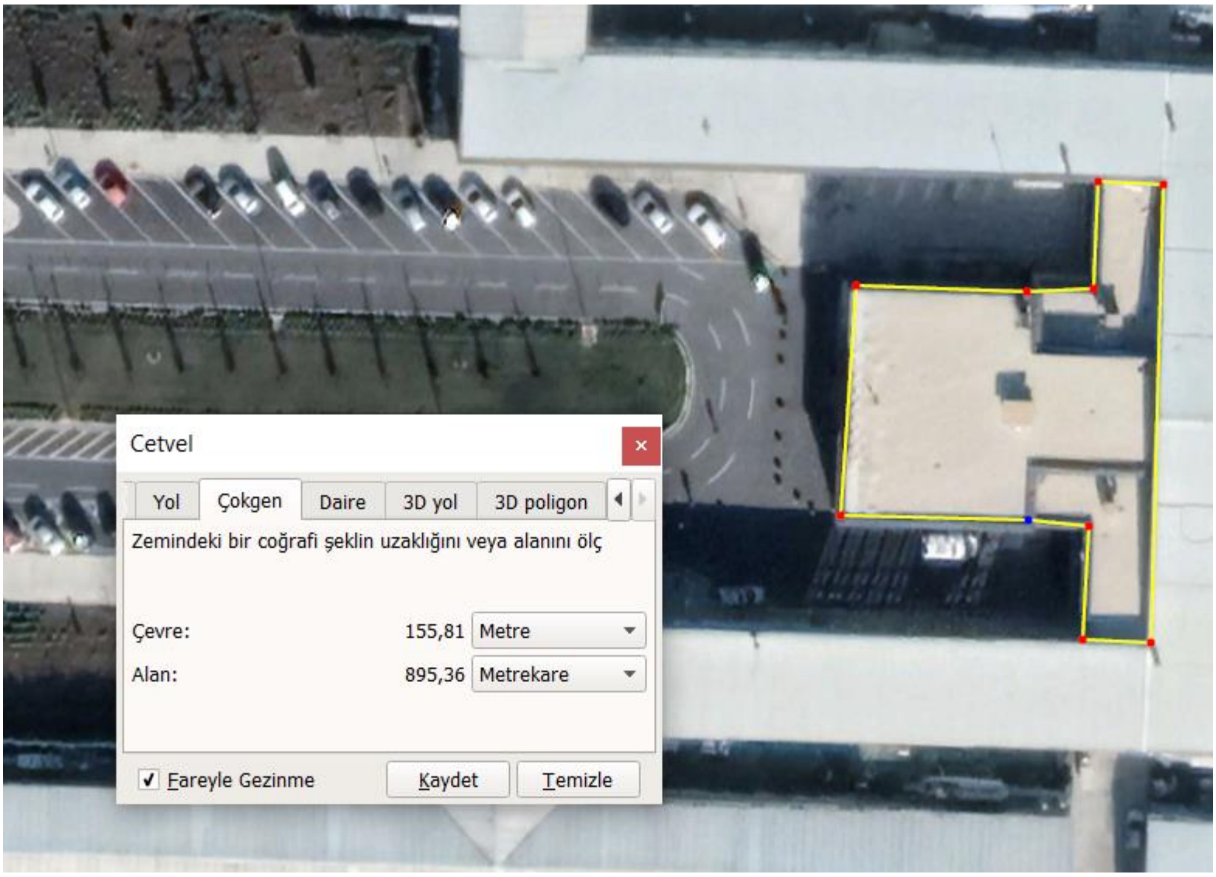

Figure 11. Roof group 8 and its polygon area measurement

Table 2. Categorization of hospital roofs by shape, size, and material type

Roof Number	Roof Material	Roof Area (m^2)
1	Sandwich panel (galvanized steel / iron or aluminum)	≈ 700
2	Sandwich panel (galvanized steel / iron or aluminum)	≈ 90
3	Sandwich panel (galvanized steel / iron or aluminum)	≈ 1450
4	Sandwich panel (galvanized steel / iron or aluminum)	≈ 1700
5	Sandwich panel (galvanized steel / iron or aluminum)	≈ 15500
6	Sandwich panel (galvanized steel / iron or aluminum)	≈ 1800
7	Sandwich panel (galvanized steel / iron or aluminum)	≈ 3500
	7 SECTIONS TOTAL	≈ 24740
8	Concrete	≈ 900
	1 SECTION TOTAL	≈ 900
	8 SECTIONS GRAND TOTAL	≈ 25640

Table 3. 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

To validate the results, the RWH potential estimates were compared with findings from Nasif et al. (2016) and Kanno et al. (2021), both of which examined RWH potential in hospital settings. The comparison showed that the estimated percentage of water demand met by RWH closely aligns with their reported ranges, supporting the credibility of the results within a healthcare facility context.

Future research is recommended to incorporate dynamic rainfall simulations and scenario-based modeling to enhance the analysis of RWH potential under various climatic conditions. Such simulations could capture temporal rainfall variability and provide insights into the system's performance during extreme weather events.

The fundamental rwh system components

A RWH system tailored for the roof groups of Yeşilköy Prof. Dr. Murat Dilmener Emergency Hospital utilizes practical and effective components. The process begins on the roof, where the selection of roofing material is pivotal for ensuring water quality.

The hospital's roofs are assumed to consist of metal sandwich panels, likely composed of galvanized steel or aluminum, based on supplier information. These materials are advantageous for RWH as they resist corrosion and minimize debris accumulation, unlike materials such as asphalt shingles, which can release contaminants over time and compromise water quality.

Figure 12 illustrates the fundamental components of the proposed RWH system, showcasing the flow of harvested rainwater from the roof surface to the storage system and emphasizing its efficient and straightforward design.

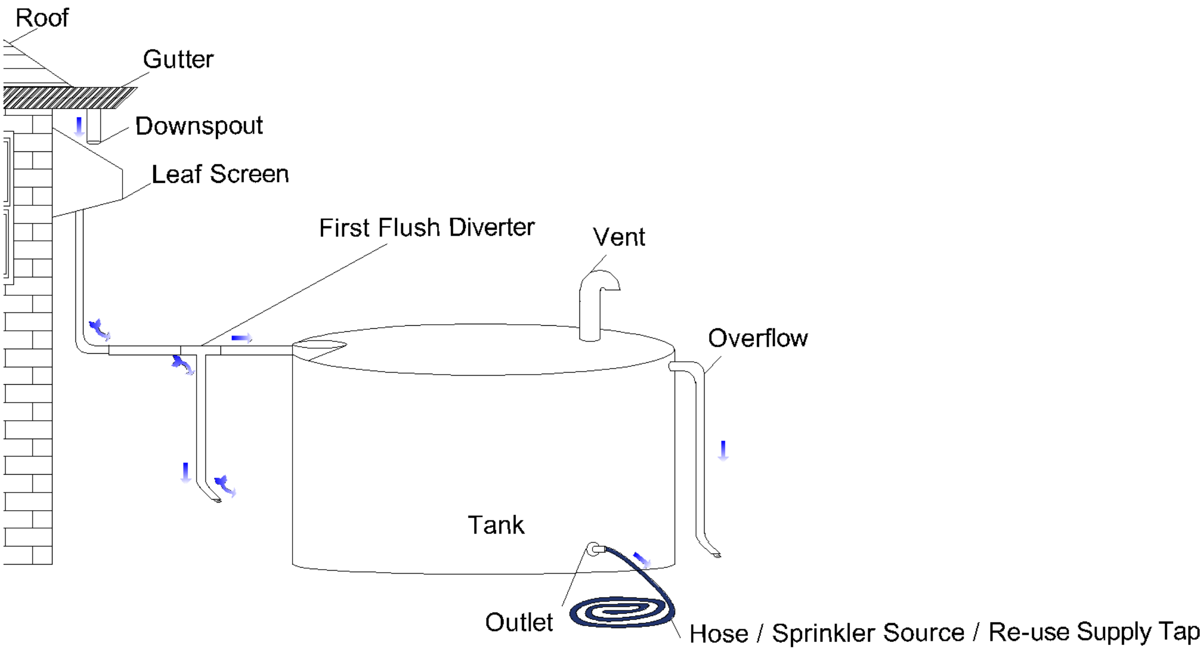

Figure 12. Fundamental RWH components (Muftuoglu and Oral, 2024)

Rainwater from the roof is directed into gutters specifically designed to accommodate heavy rainfall, as illustrated in Figure 13. To prevent blockages, a mesh leaf screen is installed to filter out larger debris such as leaves and twigs. While the screen effectively captures most contaminants, finer particles may still pass through. Featuring a mesh size capable of filtering particles larger than 1–2 mm, the screen ensures that cleaner water enters the storage system while minimizing the risk of downspout blockages. The flow capacity of this design depends on the dimensions and specifications of the mesh and screen, allowing for adaptability to varying rainfall intensities.

Figure 13. The leaf screen

The water passes through a first flush diverter on its way to the storage tank, effectively removing heavier pollutants that may have bypassed the leaf screen. Figure 14 provides an illustration of this diverter.

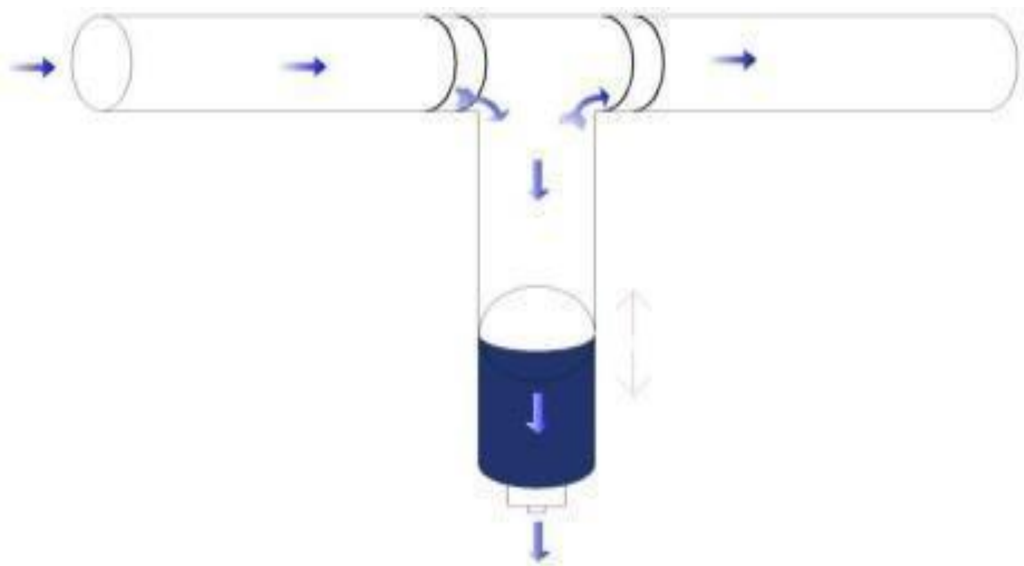

Figure 14. The first flush diverter system (Müftüoğlu, 2024)

The first flush diverter, incorporating a ball valve within a vertical pipe, plays a crucial role in separating contaminated water from the clean flow directed to the storage tank. When the ball valve reaches its capacity, it seals the pipe, effectively capturing dirt and impurities.

The trapped water can then be repurposed for irrigation using a slow-release valve or nozzle. While this method does not ensure complete purification, it significantly improves water quality. Additional filtration, desalination, or purification processes can further enhance the water's usability.

Water storage tanks, commonly constructed from materials such as plastic, concrete, or metal, share several essential features. The first critical component is the access port, which enables regular maintenance, cleaning, and repairs. The second is the ventilation opening, designed based on fluid mechanics principles to prevent vacuum formation and potential implosion when water flows in or out. The third vital element is the overflow opening, fitted with a pipe equal to or larger than the inflow, ensuring excess water is safely discharged during heavy rainfall. This overflow can also be linked to adjacent tanks for additional storage and to prevent spillage.

The fourth essential feature is the outlet, which facilitates water distribution for various applications. For instance, a hose can be attached for irrigation, or the system can be connected to sprinklers through pumping equipment. The tank material must endure environmental conditions such as humidity and sunlight, resist chemicals, and prevent biological growth, including mold and algae, which could compromise water quality. Sludge accumulation at the tank base can reduce efficiency; positioning the outlet above the sludge or at the tank's base can help mitigate clogging. Additionally, extending the inlet pipe beyond the first flush diverter and maintaining a gap minimizes sludge buildup.

The key components of the storage tank are depicted in Figure 15.

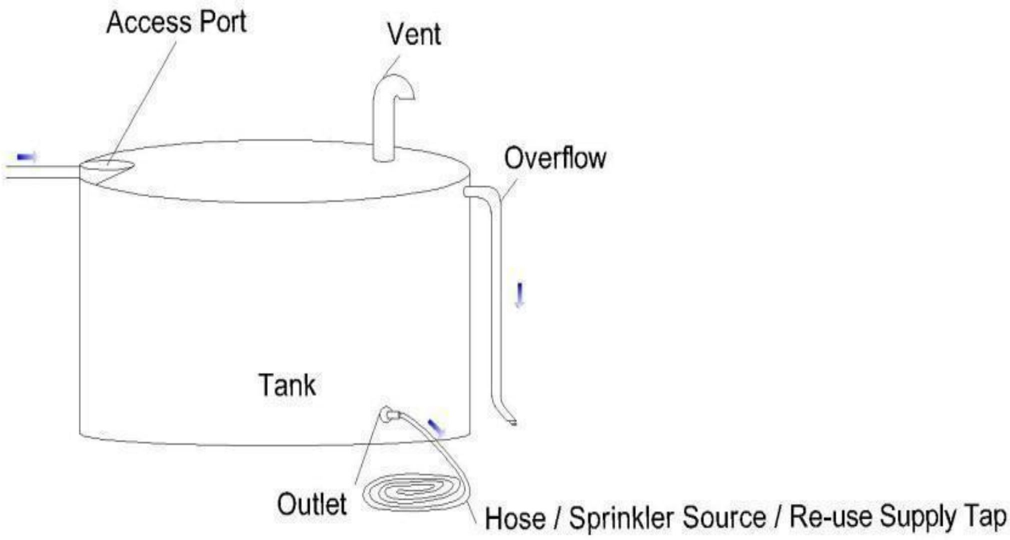

Figure 15. The tank and its associated components (Müftüoğlu, 2024)

Results

The rainwater harvesting potential for the roof sections of the case study hospital is calculated using Eq. (1) and presented in Table 4.

Table 4. Rainwater Harvesting Potential of the Hospital Roof (7 metal sections and 1 concrete section)

Months	RWH Potential (m^3)
January	2053.77
February	1614.16
March	1444.73
April	1087.56
May	746.40
June	638.79
July	515.16
August	563.24
September	927.28
October	1527.16
November	1740.09
December	2273.57

Statistical analysis offers meaningful information about possible trends, patterns, and variation in RWH potential during various months. Descriptive statistics specifically are essential for summarizing and understanding important features of a dataset. Common measures included mean, medians, standard deviation, range, variance, coefficient of variation (CV), skewness, and kurtosis.

The mean, which provides an average for all the variables in a population, is a measure of central tendency. On RWH analysis, average monthly value is the average amount of rainwater harvesting potential received in one average month. It is essential for planning and resource criteria in RWH systems. Based on the values provided in Table 4, the mean monthly RWH potential for the hospital is calculated as approximately 1260.997 m³. This average reflects a reasonable baseline for understanding the overall water harvesting capacity throughout the year. However, deviations from this mean, such as the significantly higher potential in December and January, or lower potential in July, highlight the importance of flexible strategies to accommodate seasonal variations in rainwater availability. The simple expression for obtaining the mean is presented in eq. (2).

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

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 in a dataset when all data points are arranged in ascending order. In this study, the monthly rainwater harvesting (RWH) potential values provided in Table 4 were sorted, yielding the following sequence (in m^3): 515.16, 563.24, 638.79, 746.40, 927.28, 1087.56, 1444.73, 1527.16, 1614.16, 1740.09, 2053.77, 2273.57. As there are 12 data points, an even number, the median is calculated as the average of the sixth and seventh values in the ordered dataset, 1087.56 m^3 and 1444.73 m^3. The resulting median value is 1266.15 m^3.

Unlike the mean, which is 1260.997 m^3, the median is less influenced by months with extremely high or low rainwater harvesting potential. This makes the median a more robust indicator of a "typical" month's potential, particularly when extreme values are present. The similarity between the median and mean values suggests a relatively balanced distribution of rainwater harvesting potential across the months. This balance is indicative of moderate variability in monthly rainfall, making it feasible to design rainwater harvesting systems that can accommodate the observed trends without extensive adjustments for extreme months.

The standard deviation quantifies the dispersion or variability of data points around the mean, providing insight into the degree of fluctuation in rainwater harvesting (RWH) potential across different months. Based on the data provided in Table 4, the standard deviation of monthly RWH potential is calculated as 573.62 m^3. This value indicates the average deviation of monthly RWH potential from the mean value, which is 1260.997 m^3.

A higher standard deviation, like the one observed here, suggests significant variability in monthly rainwater harvesting potential. For instance, while some months, such as July (515.16 m^3), exhibit low harvesting potential, others, such as December (2273.57 m^3), show considerably higher potential. This variability necessitates the implementation of flexible rainwater harvesting system designs that can accommodate fluctuations, such as storage tanks with sufficient capacity for high-rainfall months and contingency measures for low-rainfall periods.

Conversely, a lower standard deviation would indicate more consistent RWH potential, making system design and management simpler. However, in this case, the observed variability underscores the importance of incorporating robust planning strategies to ensure the system can handle periods of extreme deviations effectively, ensuring both efficiency and sustainability. Obtaining the standard deviation can easily be done by performing the Eq. (3).

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

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, calculated as the difference between the maximum and minimum values. This simple yet powerful metric highlights the total variation within a dataset. In the context of rainwater harvesting, the range indicates the disparity between the months with the highest and lowest rainfall. Such information is essential for determining the required storage capacity and developing effective usage strategies. In this study, the range spans from 515.16 m^3 in July, the driest month, to 2273.57 m^3 in December, the wettest month, as shown in Table 4. This significant variation emphasizes the need for adaptable storage solutions to accommodate fluctuations in rainwater harvesting potential throughout the year. Understanding the range allows for better anticipation and management of these fluctuations, ensuring the system's efficiency and reliability. Expression of the range is given in Eq. (4) below.

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

Where:

x_{max} is the maximum value

x_{min} is the minimum value

Variance measures the average of the squared deviations from the mean, offering a numerical assessment of how far individual data points diverge from the mean value. Unlike standard deviation, which is expressed in the same units as the measured variable (e.g., m^3), variance represents this dispersion in squared terms. Although slightly more abstract in interpretation, variance is a fundamental metric for understanding overall variability within a dataset and serves as the basis for numerous statistical analyses.

In the context of rainwater harvesting, a calculated variance of 369479.3 m^6 (as derived from Table 4) reflects significant variability in potential across different months. This high variance indicates uneven rainfall distribution, with some months exhibiting harvesting potential far below or above the mean. Such variability underscores the need for flexible system designs capable of adapting to inconsistent rainfall patterns. Recognizing and accounting for variance is vital for optimizing resource allocation, ensuring storage adequacy, and maintaining efficient water management throughout the year. The calculation of the variance is given by Eq. (5) below.

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

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 another statistical measure, which is the ratio of the standard deviation to the mean, expressed as a percentage. It allows for a comparison of datasets with different means or scales by giving a relative measure of variability in terms of the mean. The CV for the rainwater harvesting potential data shown in Table 4 is about 45.52%, which is the standard deviation (573.58 m^3) divided by the mean (1260.997 m^3) expressed as a percentage. This is a relatively high CV and, hence, shows lots of variation in the potential for rainwater harvesting from month to month; therefore, it will be important to plan accordingly. Strategic techniques must be employed to manage the collection and use of the water in order to ensure continuous availability of the resource over the course of the year, given that the rainfall experienced during any given month can be a significant percentage of the total received within a particular year. In relation to rainwater harvesting, CV demonstrates the degree of variation in harvesting potential against the mean monthly potential. Meaning there is a large variation from month to month of rainwater harvesting potential (high CV), when indicated that there must be a systematic planning of balancing of water harvested and water consumed. By scheduling it that way, optimal management of resources is guaranteed all year long, regardless of rain levels fluctuating. The simple calculation of CV is given in Eq. (6) below.

$$CV = \frac{\sigma}{\mu}\, x\ 100 \qquad (6)$$

Where:

σ is the standard deviation

μ is the mean

Skewness is a statistical measure that describes the asymmetry of a data distribution. A skewness value close to zero indicates a symmetrical distribution, while positive or negative skewness reflects an imbalance. Understanding skewness is essential for interpreting the central tendency and distribution of a dataset.

In the context of rainwater harvesting potential, a positive skewness value of 0.55, as calculated from Table 4, indicates a slightly right-skewed distribution. This suggests that certain months, such as December (2273.57 m^3) and January (2053.77 m^3), exhibit exceptionally high harvesting potential compared to the overall average. Conversely, months with lower-than-average potential, such as July (515.16 m^3) and August (563.24 m^3), contribute less to the distribution's tail.

Recognizing this positive skewness highlights the need for planning strategies that account for peak harvesting periods while managing resources effectively during lower-potential months. Such insights help optimize water storage and usage throughout the year, ensuring sustainable water management practices. Skewness parameter can be obtained by the Eq. (7) given below.

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

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 characterizes the "tailedness" of a data distribution, reflecting the extent to which extreme values occur compared to a normal distribution. A high kurtosis value indicates the presence of more outliers or data points that significantly deviate from the mean, while a low kurtosis suggests a distribution with lighter tails and fewer extremes.

For rainwater harvesting potential, the calculated kurtosis value of -0.69 from Table 4 reveals a slightly platykurtic distribution. This suggests that extreme values, such as the highest potential in December (2273.57 m^3) and the lowest in July (515.16 m^3), occur less frequently than expected in a typical distribution. The relatively low kurtosis value implies that most monthly harvesting potentials are closer to the mean, with fewer drastic deviations.

Understanding kurtosis helps in preparing for unexpected rainfall events by identifying the likelihood of extreme months. While this study shows limited occurrence of such extremes, planning for peak and trough periods remains essential to ensure resource availability and sustainable water management throughout the year. Kurtosis parameter can be obtained by following the Eq. (8) below.

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

Where:

n is the number of values

μ is the mean

σ is the standard deviation

x_i is the individual value

Table 5 presents the descriptive statistics for the rainwater harvesting potential data.

Table 5. Descriptive statistics for the rainwater harvesting potential of the hospital

Statistic	Value
Mean	1261.00 m^3
Median	1206.63 m^3
Standard Deviation	586.94 m^3
Variance	344509.43 m^6
Range	1758.41 m^3
Minimum	515.16 m^3
Max	2273.57 m^3
Coefficient of Variation	46.54 %
Skewness	0.76
Kurtosis	-1.14

Assuming a water consumption rate of 600 liters per bed per day as previously stated, the daily water demand for Yeşilköy Prof. Dr. Murat Dilmener Emergency Hospital, a 1,000-bed facility, is 600 cubic meters per day, calculated from a water consumption rate of 600 liters per bed per day. The percentage of water consumption compensated by the rainwater harvesting potential for each month is presented in Table 6.

Table 6. Compensation percentages

Months	RWH Potential (m^3)	Water Consumption (m^3)	Percentage (%)
January	2053.77	18600	11.04
February	1614.16	18600	9.61
March	1444.73	18600	7.77
April	1087.56	18600	6.04
May	746.4	18600	4.01
June	638.79	18600	3.55
July	515.16	18600	2.77
August	563.24	18600	3.03
September	927.28	18600	5.15
October	1527.16	18600	8.21
November	1740.09	18600	9.67
December	2273.57	18600	12.22

In Figure 16 below, the monthly rainwater harvesting (RWH) potential is presented using a line graph. The graph highlights the variability in RWH potential throughout the year, with the highest values observed in December (2273.57 m³) and January (2053.77 m³), and the lowest in July (515.16 m³). This seasonal fluctuation corresponds to regional rainfall patterns, emphasizing the importance of storage capacity for peak months to offset shortages during drier periods.

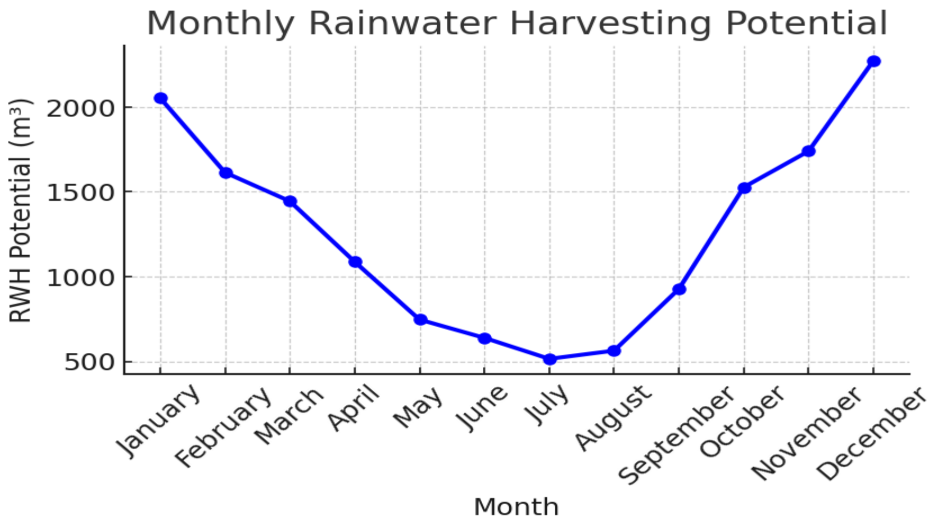

Figure 16. The monthly rwh potential

In Figure 17 below, the monthly RWH potential is compared to the hospital's total water consumption. A bar chart represents the consistent monthly water consumption (18600 m³), while the overlaid line graph depicts the RWH potential. The comparison highlights that RWH can meet a maximum of 12.22% of the hospital's water demand in December and a minimum of 2.77% in July. This visualization underscores the contribution of RWH to water savings and its limitations during dry months.

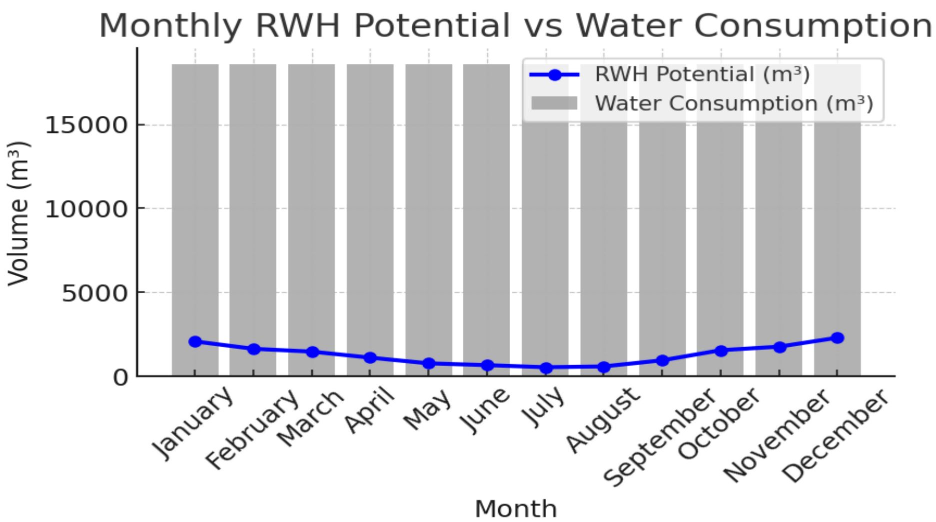

Figure 17. The comparison of monthly rwh potential and water consumption

In Figure 18 below, a bar chart displays the percentage of the hospital's water consumption covered by RWH each month. The highest coverage occurs in December (12.22%) and January (11.04%), while the lowest is in July (2.77%). This chart effectively illustrates the seasonal dependence of RWH and reinforces the importance of integrating storage and supplementary water sources to maintain supply continuity throughout the year.

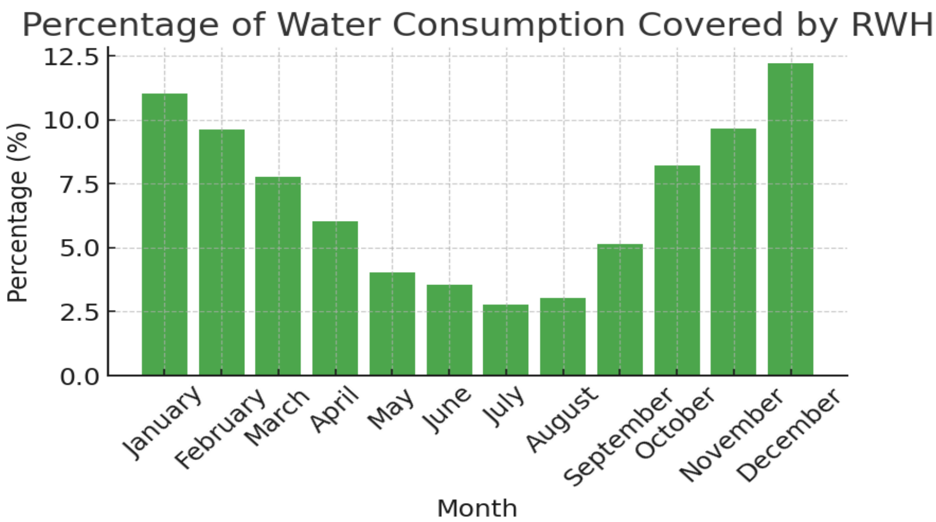

Figure 18. The percentage of water consumption covered by rwh

A cost-benefit analysis was conducted using insights from Lade and Oloke (2017), who reported that a 12 m³ tank system covered 78.1% of the water demand at the University College Hospital, Ibadan, resulting in $51.072 in savings over 50 years with a one-year payback period. Applying this context to the RWH potential at Yeşilköy Prof. Dr. Murat Dilmener Hospital, the projected water savings, particularly in peak months such as December (2273.57 m³) and January (2053.77 m³), demonstrate the potential for significant cost savings. While site-specific installation costs and operational expenses may differ, this case highlights the economic viability of RWH systems in healthcare facilities. A detailed cost analysis based on local construction and maintenance costs is recommended for future research to refine the payback period and return on investment.

Currently, this study focuses on RWH potential based on satellite-derived roof area and average monthly water consumption. Although no direct comparison with other healthcare facilities was performed, future research should validate these results by comparing them with findings from similar studies. Such comparisons will help contextualize the estimated RWH potential and its contribution to water savings in healthcare settings.

Conclusion

This study assessed the RWH potential of Yeşilköy Prof. Dr. Murat Dilmener Emergency Hospital using a simplified analytical framework that incorporated satellite imagery, regional precipitation data, and assumptions regarding roof material and geometry. Although conservative assumptions, like considering slanted rooftops as flat planes, were used, the results demonstrate the large utility of RWH in emergency medical centers.

The analysis showed that the mean monthly RWH potential was 1261.00 m^3, and the month of December had the greatest harvesting potential at 2273.57 m^3, followed by January at 2053.77 m^3. July, on the other hand, had a minimum potential of 515.16 m^3, highlighting great seasonal changes. This discrepancy of 1758.41 meters cubed between the top and bottom months reveals the necessity for flexible storage and water distribution systems to distribute water throughout the year uniformly. The statistical analyses also confirmed these results. The standard deviation is 586.94 m^3 and the CV is 46.54%, again showing marked variability from month to month in rainfall patterns. A positive skewness of 0.50 means that although some months receive moderate rain, there are some that receive very high amounts of precipitation, and every excess drop can be saved as rainwater. On the other hand, with a kurtosis of -1.36, this result shows that it is a rather flat distribution without major extreme cases, which means that RWH systems will be able to work well year-round.

RWH comprises as little as 2.77% to as much as 12.22% of the monthly water usage of the hospital, yet the importance of RWH exceeds these values. I was looking at sustainable water management terms, they are only four little dollars, but they are also thousands of cubic meters of water every year. These savings help lessen the burdens placed on municipal water systems, especially in areas with water shortages.

RWH systems are particularly important in critical times, like in case of droughts or silences of municipal water supply, where each liter of harvested water plays a vital role in maintaining hospital operations. For places such as emergency healthcare facilities, where constant water supply is essential, RWH offers a higher level of reliability.

Furthermore, RWH drives the promulgation of other sustainable practices in healthcare. Awareness is brought up, reliance on water from other areas is decreased, and more water management is incorporated. And then as infrastructure matures, as your system multiplies and other systems grow around it, the role of RWH increases with time, especially with the inclusion of other supplicant facets (such as gray water reuse or simple water-economizing technology).

Overall, this study emphasizes that the benefit of RWH is not only in the direct water savings realized immediately, but also in the potential long-term benefits of decreasing the dependence on outside supplies, increasing water security, and increasing sustainability in vital healthcare facilities. Future studies should perfect this by revealing the roof measurements, the type of materials present, and more mobile forms of rainfall. The study seeks to promote the implementation of RWH systems in healthcare infrastructure by illustrating their feasibility and advantages, contributing to sustainable water resource management.

Conflict of Interest Statement

The author of the article declares that there is no conflict of interest.

Contribution Statement Summary

The author declares sole responsibility for the entirety of the article.

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