



Impact of Recent Precipitation Trends on the Performance of Rooftop Rainwater Harvesting Systems: A Storage Yield Assessment for Mediterranean Urban Conditions [†]

Tuğçe Başar ^{1,*}  and Şahnaz Tiğrek ²

¹ Department of Civil Engineering, Başkent University, Ankara 06810, Türkiye

² Naval Architecture and Marine Engineering Department, Iskenderun Technical University, Hatay 31200, Türkiye; sahnaz.tigrek@iste.edu.tr

* Correspondence: tugcebasar@baskent.edu.tr; Tel.: +90-312-246-6666

[†] Presented at the 6th International Conference on Efficient Water Systems (EWaS6), Thessaloniki, Greece, 11–14 May 2026.

Abstract

Rooftop rainwater harvesting (RWH) offers a practical adaptation option for Mediterranean cities where water scarcity is amplified by seasonal rainfall and climate variability. This study reports early findings from a simplified monthly water balance screening model for a typical residential building, driven by ERA5-Land monthly precipitation for Antalya and İzmir (Türkiye). Scenarios cover roof areas of 250–3000 m² and practical tank capacities of 2–100 m³ under a fixed non-potable demand of 0.20 m³/day. The model tracks monthly storage dynamics and supply demand in order to compute demand coverage and monthly reliability (i.e., fraction of months in which full demand is met). Reliability-based storage thresholds (≥ 0.80) are derived for four evaluation windows (1996–2010, 2011–2025, 1996–2025, 1950–2025) to explore climate sensitivity. In parallel, a guideline-style sizing which is consistent with the Turkish rainwater harvesting guideline is implemented using a three-day storage rule based on the wettest month potential. To enable a like-for-like comparison, the collection losses are harmonized by setting loss to 0.10 in the simulation and efficiency to 0.90 in the guideline method. The results show stable thresholds for Antalya but stronger period sensitivity in İzmir. They also quantify cases where guideline sizing does not achieve the target reliability under dry season constraints. This approach supports the rapid, climate-aware pre-design of small- to medium-scale urban RWH systems.

Keywords: rainwater harvesting; monthly water balance; reliability; climate variability; ERA5-Land; Mediterranean climate; Antalya; İzmir



Academic Editors: Vasilis Kanakoudis, Evangelos Keramaris, Francesco De Paola, Habib Muhammetoglu and Theodora Papamitsou

Published: 24 June 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

1. Introduction

Rainwater harvesting can be traced back to ancient civilizations [1]. However, its importance diminished when technology made it possible to build large water storage systems and transport water over long distances. It is currently receiving attention again due to the depletion of fresh water resources. A significant percentage of rainwater is discharged through stormwater drainage systems without ever reaching the soil due to the impervious surfaces in cities [2]. Rainwater harvesting enables water to be stored locally, which helps to combat water shortages. Examples of rainwater harvesting can be seen all around the world, and extensive research has been conducted into the applicability, efficiency and cost of such systems [1,3–5].

Mediterranean climates exhibit pronounced intra-annual rainfall variability, typically characterized by wet winters and dry summers [6]. In urban areas, seasonality of rainfall limits the effectiveness of rooftop rainwater harvesting (RWH) unless the storage capacity is sized to bridge dry periods. At the same time, climate change can alter not only annual precipitation totals but also the seasonal distribution of rainfall, affecting system reliability and the storage–yield relationship. This study uses simplified screening models to provide a practical route to quantify design thresholds and to compare heuristic guideline sizing with performance-based targets.

This paper presents an early set of findings for Antalya and İzmir in Türkiye using ERA5-Land precipitation data and a monthly water balance model. A reliability target of 0.80 (80% of the months meeting full non-potable demand) was used to identify minimum tank capacities across roof areas and evaluation windows. In addition, three-day sizing is implemented according to the Turkish Rainwater Harvesting Guideline and compared directly under harmonized loss assumptions [7].

2. Data and Methods

2.1. Precipitation Data and Evaluation Windows

Monthly precipitation time series (1950–2025) were extracted from ERA5-Land monthly averaged data [8] at point locations representing Antalya (~36.89° N, 30.71° E) and İzmir (~38.42° N, 27.14° E). To explore climate sensitivity while keeping the analysis transparent, four evaluation windows were used: 1950–2025 (long window), 1996–2025 (modern baseline), and the two recent sub-periods of 1996–2010 and 2011–2025.

Across these windows, Antalya shows a reduction in mean annual precipitation from approximately 1213 mm (1996–2010) to 1065 mm (2011–2025), while İzmir decreases from about 767 mm to 714 mm. Notably, İzmir exhibits a modest increase in average dry season monthly precipitation (Apr–Sep) from 25.2 mm to 28.0 mm, which is relevant for storage reliability under a fixed demand.

2.2. Monthly Water Balance Model

A conceptual building-scale RWH system was evaluated using a simplified monthly mass balance. Monthly inflow is computed as [9]:

$$I_m = \frac{P_{mm,month}}{1000} \cdot A \cdot C_r \cdot (1 - L), \quad (1)$$

where $P_{mm,month}$ is monthly precipitation (mm/month), A is roof area (m^2), C_r is runoff coefficient (0.85), and L represents effective collection losses. Monthly storage volume, S_m , cannot exceed the tank capacity; therefore, it is calculated as:

$$S_m = \min\left(S_{max}, \max\left(0, S_{\{m-1\}} + I_m - D_m\right)\right), \quad (2)$$

where S_{max} is the tank capacity (m^3), S_{m-1} is the storage volume left from the previous month (m^3), I_m is the monthly inflow from rainfall (m^3), and D_m is the monthly water demand (m^3). The formulation ensures non-negative storage and prevents overflow beyond the tank capacity. Whether or not the monthly demand can be met according to accumulated water volume can be calculated as:

$$Q_m = \min\left(D_m, S_{\{m-1\}} + I_m\right), \quad (3)$$

A fixed non-potable demand of $0.20 \text{ m}^3/\text{day}$ is converted to monthly demand using the number of days in each month. Scenarios span roof areas of $A = 250, 500, 750, 1000$,

1500, 2000, and 3000 m² and practical storage capacities of $S_{max} = 2, 5, 10, 20, 30, 40, 60, 80$, and 100 m³. Losses were set to $L = 0.10$ (i.e., 90% effective capture) for all simulations.

2.3. Performance Metrics and Reliability Threshold

A reliability analysis [10] was carried out to check whether the minimum tank capacity met the required demand. Demand coverage is defined as the ratio of the total supply to demand (i.e., $\Sigma Q_m / \Sigma D_m$). Monthly reliability is defined as the fraction of months where supply equals to demand ($Q_m = D_m$), and, therefore, where full demand is met for each city, period and roof area, the minimum tank capacity meeting reliability ≥ 0.80 is reported as the screening threshold. The analysis includes all months within the defined evaluation windows for each city, period and roof area.

2.4. Guideline (Guideline-Style) Sizing and Harmonized Losses

To compare performance-based thresholds with common design heuristics, a guideline-style sizing was implemented using a three-day storage criterion anchored to the wettest month daily potential. The simplified guideline storage volume, $S_{guideline}$ (m³), was estimated as:

$$S_{guideline} = 3 \cdot \min(D_{day}, I_{day, max-month}) \quad (4)$$

where D_{day} is the average daily water demand (m³/day) and $I_{day, max-month}$ represents the average daily inflow (m³/day) derived from the wettest month within each evaluation window.

The daily inflow was calculated by dividing the maximum monthly precipitation $P_{max-month}$ (m³/month) by the number of days in the respective month n_{days} and multiplying by the catchment area A (m²), runoff coefficient C_r , and system efficiency E_f :

$$I_{day, max-month} = \frac{P_{max-month}}{n_{days}} \cdot A \cdot C_r \cdot E_f \quad (5)$$

To ensure a like-for-like comparison with the dynamic simulation framework, the guideline efficiency factor was set to $E_f = 0.90$, consistent with the assumed 10% system loss used in the simulations.

3. Results

Table 1 shows the minimum tank capacity (m³) required to achieve a monthly reliability threshold of 0.8 for each roof area and evaluation window, hereafter denoted as S_{Rel80} . It can be stated that despite the reduction in mean annual precipitation in 2011–2025, Antalya exhibits stable reliability thresholds across all evaluation windows. The minimum tank meeting reliability threshold value, 0.80, remains at 10 m³ for a roof area of 250 m², at 5 m³ for a roof area of 500 m², and at 2 m³ for a roof area 750 m² or more. This robustness reflects both Antalya's higher winter rainfall volumes and the fact that modest storage can satisfy fixed demand for moderate-to-large roofs.

In contrast, Izmir exhibits greater sensitivity to small roofs, where limitations during the dry season are more significant. For an area of 250 m², the required tank size decreases from 20 m³ between 1996 and 2010 to 10 m³ between 2011 and 2025, while the long-term (1950–2025) and modern (1996–2025) figures converge at 20 m³. For an area of 500 m², the threshold is 10 m³ across all windows. For an area greater than 1500 m², a tank capacity of 2 m³ is sufficient. These patterns suggest that the last few decades in Izmir have seen marginally higher dry season rainfall (see Figure 1), which improves month-to-month reliability for small roofs, even though annual totals have declined.

Table 1. Minimum tank capacity (m^3) required to achieve ≥ 0.80 monthly reliability for each roof area and evaluation window (demand = $0.20 \text{ m}^3/\text{day}$, $C_r = 0.85$, $L = 0.10$).

City	Period	Roof Areas (m^2)						
		250	500	750	1000	1500	2000	3000
Antalya	1950–2025	10	5	2	2	2	2	2
	1996–2010	10	5	2	2	2	2	2
	1996–2025	10	5	2	2	2	2	2
	2011–2025	10	5	2	2	2	2	2
İzmir	1950–2025	20	10	5	5	2	2	2
	1996–2010	20	10	10	5	2	2	2
	1996–2025	20	10	5	5	2	2	2
	2011–2025	10	10	5	5	2	2	2

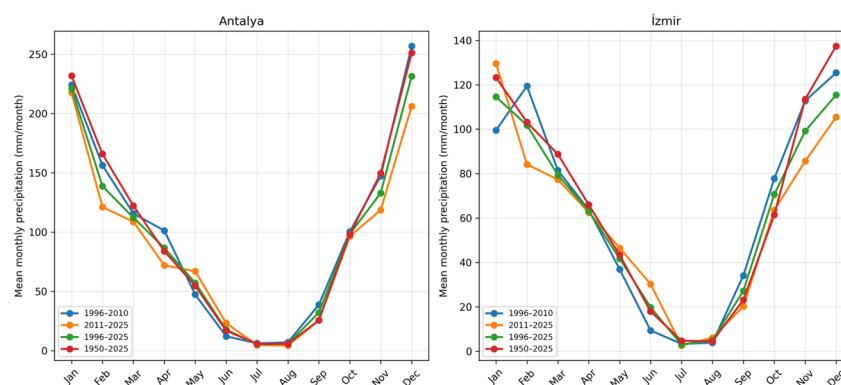


Figure 1. Monthly precipitation climatology for Antalya and İzmir across the evaluation windows (ERA5-Land monthly series).

The reliability curves in Figure 2a,b further illustrate the roof-area effect: larger catchment areas reach the target reliability with smaller tank capacities, whereas small roofs remain more sensitive to storage volume and seasonal rainfall variability.

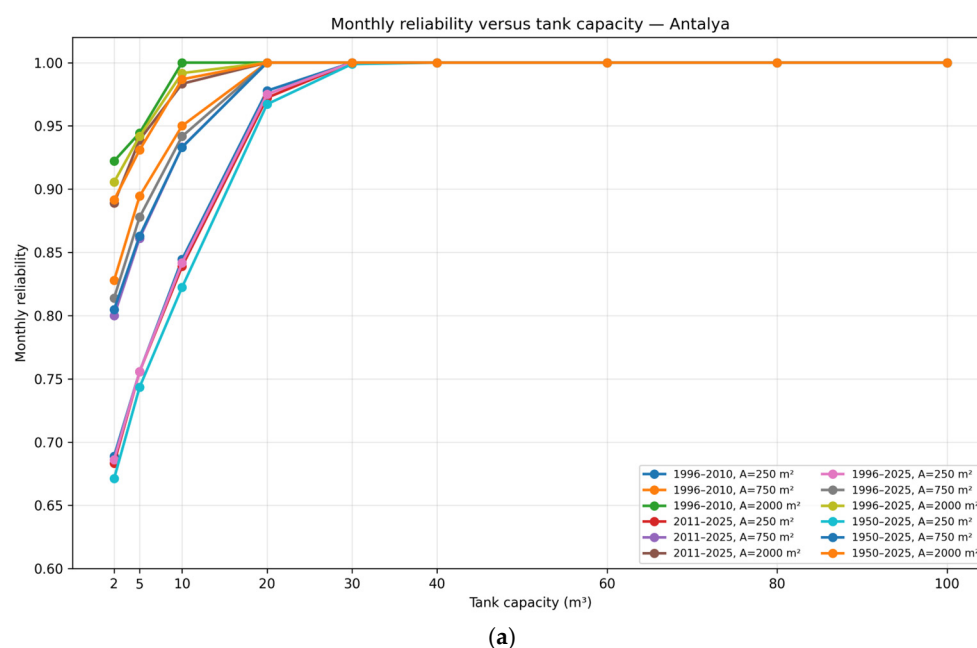


Figure 2. Cont.

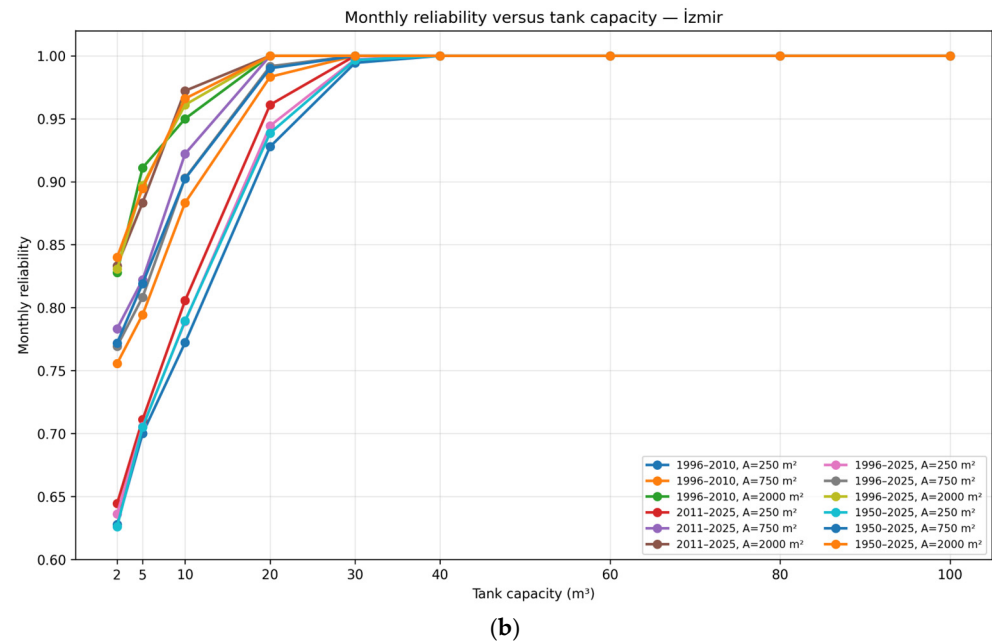


Figure 2. (a) Monthly reliability versus tank capacity for selected roof areas in Antalya (demand = $0.20 \text{ m}^3/\text{day}$, $C_r = 0.85$, $L = 0.10$). (b) Monthly reliability versus tank capacity for selected roof areas in İzmir (demand = $0.20 \text{ m}^3/\text{day}$, $C_r = 0.85$, $L = 0.10$).

4. Discussion

Table 2a,b compare the guideline-based sizing and reliability-based sizing (≥ 0.80) presented in Table 1 for Antalya and İzmir, respectively. Storage capacity according to the guideline is based on a three-day criterion and rounded up to the next practical tank size before achieving the reliability target.

Table 2a,b illustrate the divergence between heuristic sizing rules and performance-based reliability targets in seasonal climates. Under the harmonized loss assumption ($E_f = 0.90$, $L = 0.10$), the guideline-style three-day criterion yields a theoretical storage of approximately 0.6 m^3 ($3 \times 0.20 \text{ m}^3/\text{day}$) in many cases. However, when rounded to the smallest practical tank size (2 m^3), it often fails to achieve a reliability level of at least 0.80 for small roofs. For instance, for an area of 250 m^2 between 1950 and 2025, the reliability achieved with the rounded guideline tank is 0.671 in Antalya and 0.626 in İzmir, which is below the target due to deficits during the dry season.

An insight relevant to climate change is that changes in annual totals alone are insufficient for design screening; the seasonal distribution of rainfall determines how frequently the system can meet monthly demand without depletion. In İzmir, despite lower annual totals, recent decades have shown slightly higher dry season precipitation (Apr–Sep), which has reduced the required tank size for an area of 250 m^2 from 20 m^3 (1996–2010) to 10 m^3 (2011–2025). This demonstrates that climate change can modify seasonality in unexpected ways, shifting reliability thresholds, and highlights the importance of evaluating multiple time periods rather than relying on a single climatology.

For Antalya, the thresholds remain unchanged across the different time periods, suggesting that, given the assumed level of demand and the sizes of the roofs tested, the system is less sensitive to the recent reduction in annual precipitation. This robustness is consistent with higher winter rainfall volumes, which enable storage to recover after dry months. However, the reliability of the smallest roofs during the dry season remains substantially lower than during the wet season. This implies that climate-driven lengthening of the dry season or reductions in spring rainfall would increase the required storage, a factor that should be considered in future work through the use of perturbed seasonal scenarios.

Table 2. (a) Guideline-based sizing versus reliability-based sizing for Antalya. (b) Guideline-based sizing versus reliability-based sizing for İzmir.

Period	Roof Area (m ²)	$S_{\text{guideline}}$ (m ³)	$S_{\text{guideline}}$ Rounded (m ³)	Reliability (Guideline)	S_{Rel80} (m ³)	$S_{\text{guideline}} - S_{\text{Rel80}}$ (m ³)
(a)						
1950–2025	250	0.6	2	0.671	10	−9.400
	500	0.6	2	0.759	5	−4.400
	750	0.6	2	0.805	2	−1.400
	1000	0.6	2	0.832	2	−1.400
	1500	0.6	2	0.861	2	−1.400
	2000	0.6	2	0.891	2	−1.400
	3000	0.6	2	0.928	2	−1.400
1996–2010	250	0.6	2	0.689	10	−9.400
	500	0.6	2	0.772	5	−4.400
	750	0.6	2	0.828	2	−1.400
	1000	0.6	2	0.856	2	−1.400
	1500	0.6	2	0.894	2	−1.400
	2000	0.6	2	0.922	2	−1.400
	3000	0.6	2	0.950	2	−1.400
1996–2025	250	0.6	2	0.686	10	−9.400
	500	0.6	2	0.764	5	−4.400
	750	0.6	2	0.814	2	−1.400
	1000	0.6	2	0.842	2	−1.400
	1500	0.6	2	0.872	2	−1.400
	2000	0.6	2	0.906	2	−1.400
	3000	0.6	2	0.942	2	−1.400
2011–2025	250	0.6	2	0.683	10	−9.400
	500	0.6	2	0.756	5	−4.400
	750	0.6	2	0.800	2	−1.400
	1000	0.6	2	0.828	2	−1.400
	1500	0.6	2	0.850	2	−1.400
	2000	0.6	2	0.889	2	−1.400
	3000	0.6	2	0.933	2	−1.400
(b)						
1950–2025	250	0.6	2	0.626	20	−19.400
	500	0.6	2	0.732	10	−9.400
	750	0.6	2	0.772	5	−4.400
	1000	0.6	2	0.786	5	−4.400
	1500	0.6	2	0.814	2	−1.400
	2000	0.6	2	0.840	2	−1.400
	3000	0.6	2	0.884	2	−1.400
1996–2010	250	0.6	2	0.628	20	−19.400
	500	0.6	2	0.706	10	−9.400
	750	0.6	2	0.756	10	−9.400
	1000	0.6	2	0.767	5	−4.400
	1500	0.6	2	0.817	2	−1.400
	2000	0.6	2	0.828	2	−1.400
	3000	0.6	2	0.889	2	−1.400
1996–2025	250	0.6	2	0.636	20	−19.400
	500	0.6	2	0.725	10	−9.400
	750	0.6	2	0.769	5	−4.400
	1000	0.6	2	0.781	5	−4.400
	1500	0.6	2	0.817	2	−1.400
	2000	0.6	2	0.831	2	−1.400
	3000	0.6	2	0.881	2	−1.400
2011–2025	250	0.6	2	0.644	10	−9.400
	500	0.6	2	0.744	10	−9.400
	750	0.6	2	0.783	5	−4.400
	1000	0.6	2	0.794	5	−4.400
	1500	0.6	2	0.817	2	−1.400
	2000	0.6	2	0.833	2	−1.400
	3000	0.6	2	0.872	2	−1.400

5. Conclusions

A simplified monthly water balance screening framework was used to derive reliability-based storage thresholds for rooftop rainwater harvesting (RWH) in two Mediterranean cities in Turkey: Antalya and Izmir. ERA5-Land precipitation data was used for this analysis. With a fixed demand of 0.20 m³/day and a loss of 0.10, Antalya exhibits stable reliability thresholds of ≥ 0.80 across all evaluation windows (10 m³ for 250 m², 5 m³ for 500 m² and 2 m³ for ≥ 750 m²). Izmir requires larger storage for small roofs and exhibits sensitivity to periods linked to changes in dry season rainfall, which highlights the importance of climate-aware evaluation windows. Even when harmonized via efficiency ($E_f = 0.90$), a guideline-style three-day sizing can under-size storage with respect to a reliability target for small roofs, highlighting the importance of performance checks during the early design stage.

Future work will extend the screening to additional Mediterranean cities and test climate-perturbed precipitation regimes (e.g., seasonal scaling factors) to quantify robustness margins for both guideline-based and reliability-based designs.

Author Contributions: Conceptualization, T.B. and Ş.T.; methodology, T.B.; software, T.B.; validation, T.B.; formal analysis, T.B.; investigation, T.B. and Ş.T.; resources, T.B. and Ş.T.; data curation, T.B.; writing—original draft preparation, T.B.; writing—review and editing, Ş.T.; visualization, T.B. and Ş.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Publicly available datasets were analyzed in this study. The ERA5-Land monthly averaged data from 1950 to present are available from the Copernicus Climate Change Service (C3S) Climate Data Store (CDS) (<https://cds.climate.copernicus.eu/datasets/reanalysis-era5-land-monthly-means?tab=overview>), accessed on 1 February 2026. The processed datasets and calculations generated during the current study are available from the corresponding author upon reasonable request.

Acknowledgments: Generated using Copernicus Climate Change Service information 2026. Neither the European Commission nor ECMWF is responsible for any use that may be made of the Copernicus information or data it contains.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Albayrak, D. A Study on Rainwater Collection in Built Environment. Master's Thesis, Middle East Technical University, Ankara, Turkey, January 2024.
2. Tiğrek, Ş.; Sipahi, S.Ö. Rehabilitation of storm water collection systems of urban environment using the small roads as conveyance channels. *Int. J. Environ. Sci. Technol.* **2012**, *9*, 95–103.
3. Bañas, K.; Robles, M.E.; Maniquiz-Redillas, M. Stormwater Harvesting from Roof Catchments: A Review of Design, Efficiency, and Sustainability. *Water* **2023**, *15*, 1774. [CrossRef]
4. Teston, A.; Piccinini Sclaro, T.; Kuntz Maykot, J.; Ghisi, E. Comprehensive Environmental Assessment of Rainwater Harvesting Systems: A Literature Review. *Water* **2022**, *14*, 2716. [CrossRef]
5. Çolak, M.; Esringü, A. Üniversite Yerleşkelerinde Sürdürülebilir Su Kaynakları Yönetimi: Yağmur Suyu Hasadı Uygulamaları. *PEYZAJ-Eğitim Bilim Kültür Ve Sanat Derg.* **2025**, *7*, 200–219. [CrossRef]
6. Lionello, P.; Malanotte-Rizzoli, P.; Boscolo, R.; Alpert, P.; Artale, V.; Li, L.; Luterbacher, J.; May, W.; Trigo, L.; Tsimplis, M.; et al. The Mediterranean climate: An overview of the main characteristics and issues. *Dev. Earth Environ. Sci.* **2006**, *4*, 1–26. [CrossRef]
7. Turkish Ministry of Agriculture and Forestry, General Directorate of Water Management. *Yağmur Suyu Hasadı Rehber Dökümanı (Rainwater Harvesting Guideline)*; Turkish Ministry of Agriculture and Forestry, General Directorate of Water Management: Ankara, Türkiye, 2022.

8. Copernicus Climate Change Service. ERA5-Land Monthly Averaged Data from 1950 to Present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). 2022. Available online: <https://cds.climate.copernicus.eu/datasets/reanalysis-era5-land-monthly-means?tab=overview> (accessed on 1 February 2025).
9. Khan, A.; Park, Y.; Park, J.; Kim, R. Assessment of Rainwater Harvesting Facilities Tank Size Based on a Daily Water Balance Model: The Case of Korea. *Sustainability* **2022**, *14*, 15556. [[CrossRef](#)]
10. Modarres, M.; Kaminskiy, M.; Krivtsov, V. *Reliability Engineering and Risk Analysis: A Practical Guide*; Marcel Dekker, Inc.: New York, NY, USA, 1999; ISBN 0-8247-2000-8.

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.