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The Effectiveness of Rainwater Harvesting Infrastructure in a Mediterranean Island

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Abstract: Rainwater Harvesting system (RWHs) can be considered as an alternative water resource in the era of the climate crisis. This research aims to study the effectiveness of a RWHs for domestic non-potable use and the water demand of the community in a Mediterranean site (Chios island, Greece). A water balance model is applied to simulate the behavior of a rainwater tank and calculate the daily water savings. The analysis correlates rainwater tank capacity, catchment area and population. The operation of the rainwater collection system has been calculated for seven years. In order to assess the investment risk regarding the application of the RWHs, the financial ratio of PayBack (PB) period was determined. The multifaceted character of Rainwater Harvesting (RWH) practice in the three-dimensional concept of sustainability is discussed. This study concludes that RWH contributes to the greening of society, dealing with water scarcity in urban areas.

Keywords: water resources management; water scarcity; behavioral model; water-saving efficiency; sustainability; hydrosocial approach

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1. Introduction

Due to the climate crisis, the phenomenon of rapid urbanization and the insecurity regarding food and energy, the sustainable management of water resources remains a critical issue. The path towards adaptation and societies' resilience to overcome risks and threats to a more sustainable future entails attentiveness and place-tailored measures and actions [1]. The perceptivity that both nature and society are at risk drives scientific research to focus on adaptation strategies, to develop mitigation plans, to inspire sustainable solutions and to (re)invent practices how locals and communities, stakeholders and economies, can deal with changing settings and pressures [2]. The complexity and uncertain effectiveness of large-scale adaptation approaches, coupled with the appreciation that local decision-making on place-based vulnerability enables locals to develop community-led strategies and practices, avoid tragedies and confront challenges such as water scarcity, applying even traditional practices and patterns [2–8].

Rainwater Harvesting (RWH) has been identified as an alternative source of water supply for regions facing water scarcity [9–11]. However, until recently, it was not a widespread practice, and there was a debate about its efficiency, while installation costs were not fixed, and the knowledge about maintenance and probable risks was incomplete. Policy initiatives to introduce small-scale adoption were missing [10]. Damman et al. [12] highlight that RWH did not become widespread because the public is uninformed about this practice, knows little or nothing about the investment cost and doubts the water quality.

Nevertheless, RWH has been used since ancient years [13]. It is a technique that has provided water for domestic and agricultural use for millennia [14]. The practice of RWH in tanks (cisterns) was the only source of water supply in many cities of ancient Greece [15]. Over the centuries, the practice of RWH has been improved, and several types of tanks and hydraulic engineering have been advanced [16], highlighting a substantial nexus among culture, climate crisis and water stress [17].

Radonic [18] remarks that a relaunch of small-scale RWH practice for residential use in urban areas is observed globally, encouraged by water policies, water-pricing schemes, and climate change strategies [19–22]. Rainwater harvesting systems (RWHs) are currently implemented in Ethiopia [23], Australia [24], Bangladesh [25], Brazil [26], Germany [22], Greece [27], Zimbabwe [28], the United Kingdom [29], the USA [30], India [31], Indonesia [32], Jordan [33], Spain [20,34], Italy [35], Korea [36], Mexico [37], Namibia [38], South Africa [39], Portugal [40], Sweden [41] and Taiwan [42].

In the United States, the harvested rainwater is primarily used for irrigation. The collected water is used outdoors, and in this way, 60% of total water consumption is reduced, keeping the green spaces of the urban settings blooming [43]. On the other hand, the harvested rainwater in Asia, Europe and Australia is used for indoor non-potable end uses like toilet flushing and laundry [44], reducing potable water consumption levels.

Mediterranean countries, especially Spain and Greece, suffer from water scarcity. In Greece, water scarcity is noticed mainly in the islands which are characterized by insufficient water resources [45]. The Aegean islands have suffered from water scarcity for more than four decades [46], and it will become more severe due to climate change and growth in tourism. This study examines the sustainability of the RWH in the island of Chios, the fifth largest of the Greek islands. A poor water balance and declining water quality have become significant issues of concern in Chios island. Variation in rainfall and temperature related to the climate crisis and the scarcity of water resources have reduced the availability of water [47].

This study contributes to better knowledge of how small-scale practices like RWH can be introduced in regions sharing the same geomorphological and climatic characteristics as those in the Mediterranean region. Large infrastructures considering water-supply systems are incredibly costly. Furthermore, due to the climate crisis, many regions of the world have very limited water resources, or local communities are under conditions of water deterioration. This study sheds light on the efficiency of RWH as a source of water for uses other than drinking. It describes the technical feasibility and the costs involved in installation and ongoing maintenance for a house and a municipal building, a school. This work reveals that the economic barrier to implementing RWHs is not a barrier itself. The factors that define the technical feasibility, the economic effectiveness and the social acceptance of a RWHs are considered. Moreover, this survey contributes to the discussion about feasible solutions for greening the society, ensuring that everyone has access to water, no matter where they live. The authors of this study argue that the RWHs is safe, cheap and could be a widespread solution for safe water. It is proved by this work that the protection of the water and its sources, ensuring the quality of life of people, could be achieved by introducing low and straightforward budget solutions, using simple technology, based on local conditions and practices. An integrated approach of the RWHs in an urban context is developed.

2. The Social Condition of RWH

What is engaging with the term “rainwater harvesting” is that emphasis is given on the origin of the water. This is odd due to the widespread knowledge of the continuous movement of water within the Earth and atmosphere, the water cycle. Another trait of the term RWH is the lack of a unified definition as Yannopoulos et al. [48] note; while Haut et al. [49] support that the term describes the various methods of using, collecting and storing rain run-off water for domestic and agricultural purposes. Frazier and Myers [50] outline the term “water harvesting” as a process of collecting and storing water from an area suitable to accept the rainfall. The water harvesting is defined as a technology for collecting and storing rainwater from rooftops, land surfaces, road surfaces, or rock catchments using complex or straightforward techniques [51–54]. Antoniou et al. [16] consider RWH as the collection and storage of atmospheric precipitation in artificial reservoirs (tanks) for domestic purposes such as bathing and washing, in agriculture irrigation and introduce urban uses in offices, housing estates, industry, horticulture, and parks. According to Yannopoulos et al. [48], the RWH is the collection, conveyance, and storage of rainwater for future use (domestic, agricultural, environmental protection), applying a harvesting system suitable for collecting and storing precipitation run-off. It is an old practice widely used to provide urban dwellers with a potable water supply in many parts of the developing world [55].

Infrastructure and environmental context, socio-cultural status and geographic factors influence the perception and the adaption of alternative systems or practices like RWH. If the RWH could be seen as a small-scale, decentralized green infrastructure, it depends, beyond climatic and physical conditions, on the awareness, experience and everydayness of the locals or communities. For example, Finewood [56], Meehan and Moore [21] highlight that two decades ago in the USA, in most states, the collection of rainfall in houses was achieved with some effort, and it was not a subject of interest for water policies, strategies and authorities. Recently, this form of green, informal infrastructure is regulated via municipal policy guidelines and financed by green programs, transforming it into formal policy. Taking a slightly different tack, an informal "no scientific" and traditional practice of collecting and using water is inaugurated as a standard, eco-friendly, scientific, and innovative small-scale, water-saving technology.

The citizens of Chios island are aware of the over-exploitation of groundwater that results in the salinization and the inflow of polluted waters into aquifers, making the water scarcity and the poor quality of their tap water one of the major problems of the island [57]. The way to address water scarcity and alter the water governance pattern requires trust, transparency and conceptual agreement between local government and residents [2,11]. In other words, if local governance would like to introduce the RWH as a sustainable system, it should also address social sustainability as a process and as a condition [58,59]. Successfully achieved transitions and shifts presuppose an integrated consideration of water supply and systems, alongside social, ecological and technical arrangements; segmentation fails to recognize interactions and complexities [60].

Cultural perceptions and social models regarding the use of water and its taste, smell, color, origin, quantity and quality are all critical and should be taken into consideration in order to improve dialogue between stakeholders, to avoid skepticism and to facilitate the smooth introduction of sustainable environmental technologies for water saving. Social structure, economic priorities and political context affect sustainability and consequently, the social performance is equally crucial as the technical and economic performances of the RWHs [51].

RWH could be characterized as a socio-technological system that involves pipes, distribution systems, pumps, tanks, individuals and communities that consume water. These shape economy, policy, cultural and social practices, norms, values, institutions and a network of relationships. The adoption and implementation of green infrastructure demand a transformation of behaviors, attitudes, values and priorities.

The RWH practice shares the same philosophy and goals as energy communities. Although water and energy are very different substances of life, policy, governance, technology, both are addressed in the 2030 Agenda for Sustainable Development, adopted by United Nations Member States [61]; both are essential components, thematic issues "*for peace and prosperity for people and the planet, now and into the future*". Nevertheless, both RWH and energy communities address questions regarding the tools that communities can use to advance sustainable development in a democratic way, enhancing social inclusiveness and individual integrity. For example, energy communities are developed in many municipalities for meeting social needs, covering the energy needs of a school, a safe home for women, or a shelter of migrants. In the same vein, RWHs could be constructed in municipal buildings, meeting fluid needs contributing to the greening of society.

3. Materials and Methods

3.1. Study Area

Chios island suffers from water scarcity, due to adverse hydrological and hydrogeological factors, alongside the lack of sustainable management and exploitation policy of water resources. The island of Chios belongs to the complex of northeast Aegean islands in Greece. Similar to the other Aegean islands, water resources in Chios island are limited because of the precipitation pattern and geological setting. Furthermore, topographic slopes control surface water flow into the sea. The low average annual rainfall, having insufficient surface run-off and infiltration, reinforced by the high average annual temperature and sunshine duration, cause a water shortage crisis. The aquifers in carbonate rocks outcropping in many islands present a high vulnerability to seawater intrusion [47]. A map showing the location of Chios island is presented in Figure 1.

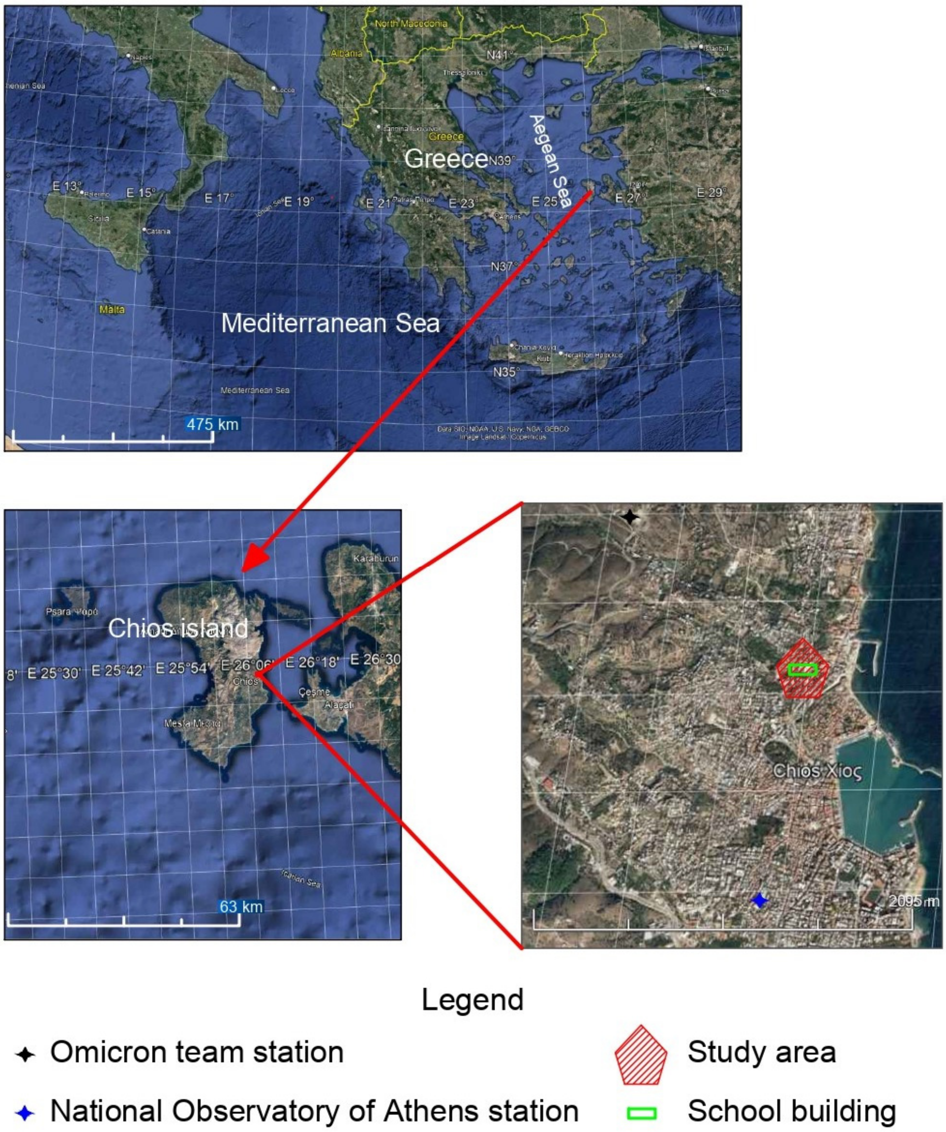


Figure 1. Map showing the area studied and locations of meteorological stations (modified from [62]).

The rainfall data series recorded during the 2013–2019 period in central Chios were used to evaluate the performance of the RWHs. The raw dataset of precipitation was derived from two metrological stations, namely, Omicron team station (elevation 32 m a.s.l.) and National Observatory of Athens station (elevation 23 m a.s.l.) (Figure 1). This period was selected because firstly, it meets the requirements for rainfall data for the dimensioning of a rainwater collection tank (5–10 years), following the German Regulation DIN 1989–1

(2002) of the German Institute Standardization. Secondly, it combines a period of drought that gives conservative estimates of precipitation and thus a higher safety factor in calculations. Figure 2 shows the height of the daily rainfall height of seven years. Daily rainfall ranges from 0 to 88 mm, and the mean annual height is H_{mean} 581.70 mm.

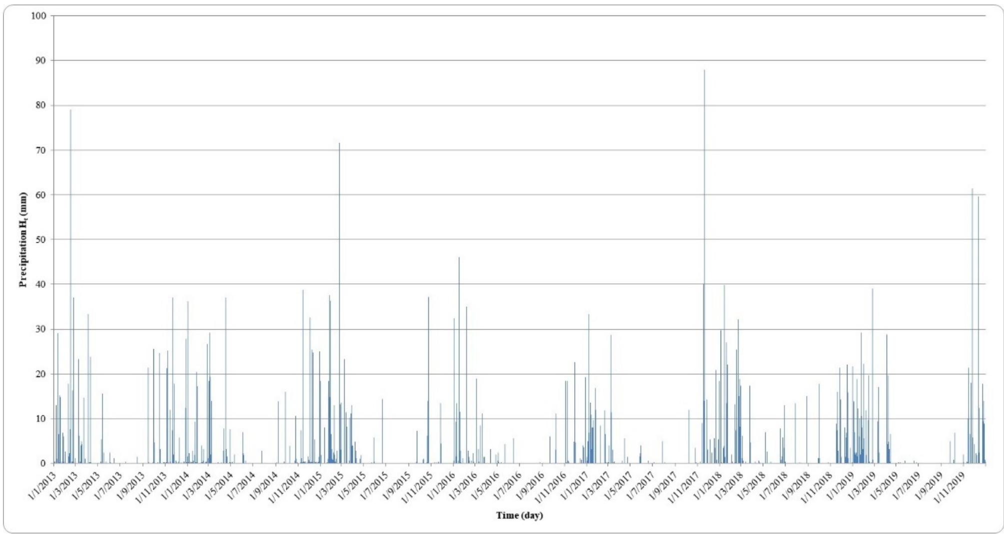


Figure 2. Historically daily precipitation data, based on the period 2013–2019.

A significant variation in rainfall is noticed between winters and summers. It was found that the average precipitation during winters reached a maximum of 145 mm in January, contrary to what is experienced in the summer period with almost no rainfall between May and September. Thus, the period between May and September can be fairly defined as dry months for this region. A cumulative total value of rainfall was calculated and found to be 384.6 mm for an entire year (Figure 3). Furthermore, in the year with the highest precipitation (2013), for the period between June and August the value is low (Figure 3). The low value of precipitation challenges the introduction of RWHs in the region, because RWHs is a potential option for water saving in regions with precipitation values between 1000 and 3000 mm [63,64].

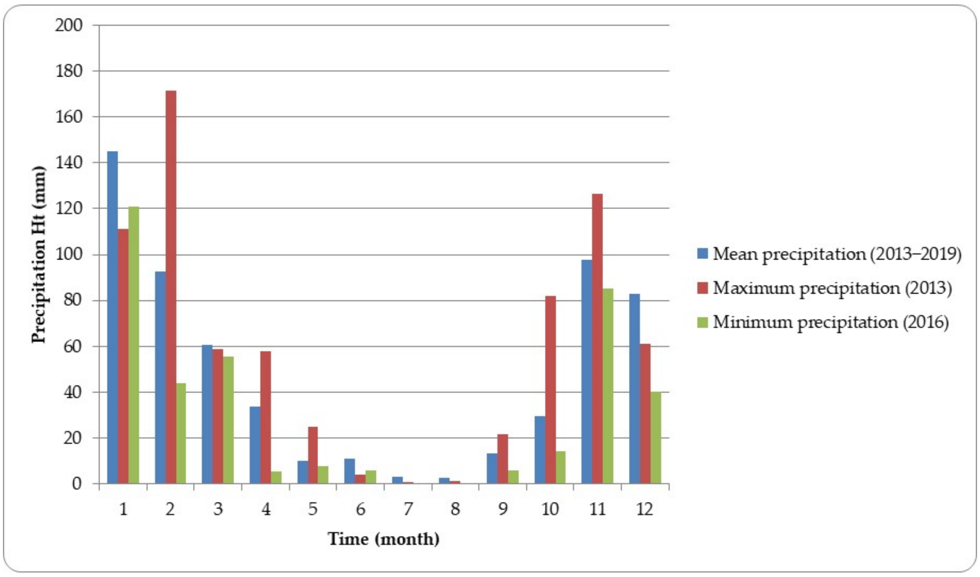


Figure 3. Maximum, minimum and mean monthly precipitation based on the precipitation record from 2013 to 2019.

3.2. Daily Water Balance Method

The simulation of the RWHs is determined based on the water balance method [65]:

$$V_t = V_{t-1} + Q_t - D_t - E_t - L_t \quad (1)$$

where: V_t is the volume stored at the end of time interval, t (m^3); V_{t-1} is the volume stored at the beginning of t day (m^3); Q_t is the inflow (harvested rainwater) during the time interval, t (m^3); D_t is the demand during the time, t (m^3); E_t is the evaporation (m^3) and L_t the losses (m^3).

The effects of evaporation and losses are disregarded since the storage tank is closed and underground. Therefore, the volume stored (V_t) is calculated using the following formula:

$$V_t = V_{t-1} + Q_t - D_t \text{ subject to } 0 \leq V_t \leq S \quad (2)$$

where: S is the capacity of the rainwater harvesting tank (m^3), provided that the computed volume in the store does not exceed the store's capacity. At the end of a prescribed time interval, the water in storage equals the volume of water remaining in the store from the previous interval, plus any inflow and less any demand during the period. The overflow on the storage tank is discharged to the sewage system.

Behavioral models, therefore, simulate the operation of the reservoir, concerning time, by routing simulated mass flows through the algorithm that describes the operation of the reservoir.

3.3. Inflow to the RWH Tank (Q_t)

The volume of run-off Q_t, (in m^3) from contributing catchments of a RWHs during a computational time step, can be determined as follows:

$$\begin{gathered} Q_t = 0, H_t \leq \delta \\ Q_t = c \cdot (H_t - \delta) \cdot A \cdot 10^{-3}, H_t > \delta \end{gathered} \quad (3)$$

where: c is the run-off coefficient of the contributing catchments; H_t is the measured rainfall depth in mm at period t; δ is the depth of the first flush over the catchment area, mm; A is the catchment area, (in m^2).

The first flush is the initial run-off of a rainfall event. During the initial phase, the pollutant concentration of run-off is usually higher than the remainder of the rainfall event. Therefore, a first flush depth of 0.33 mm (i.e., δ = 0.33 mm) or 5% of the total rainfall depth, was usually diverted away from the rainwater storage units in order to avoid collecting pollutants, including particulate matter, tree leaves and bird droppings to improve the quality of the harvested rainwater [66]. A 10% deduction was applied to account for rainwater losses of a rooftop. Thus, in this case, the runoff coefficient was set as 0.9 (i.e., c = 0.9) [67]. It is worth noting that both δ and c vary according to catchments, storage units, and local climate conditions.

Therefore, the volume of water that will withdraw from a surface (e.g., building roof) daily, Q_t, is calculated as follows:

$$Q_t = c \cdot 0.95 \cdot (H_t \cdot 10^{-3}) \cdot A \quad (4)$$

The annual volume of run-off (Q) can be expressed as:

$$Q = c \cdot 0.95 \cdot (H_{mean} \cdot 10^{-3}) \cdot A \quad (5)$$

3.4. Demand (D_t)

The annual demand can be expressed as:

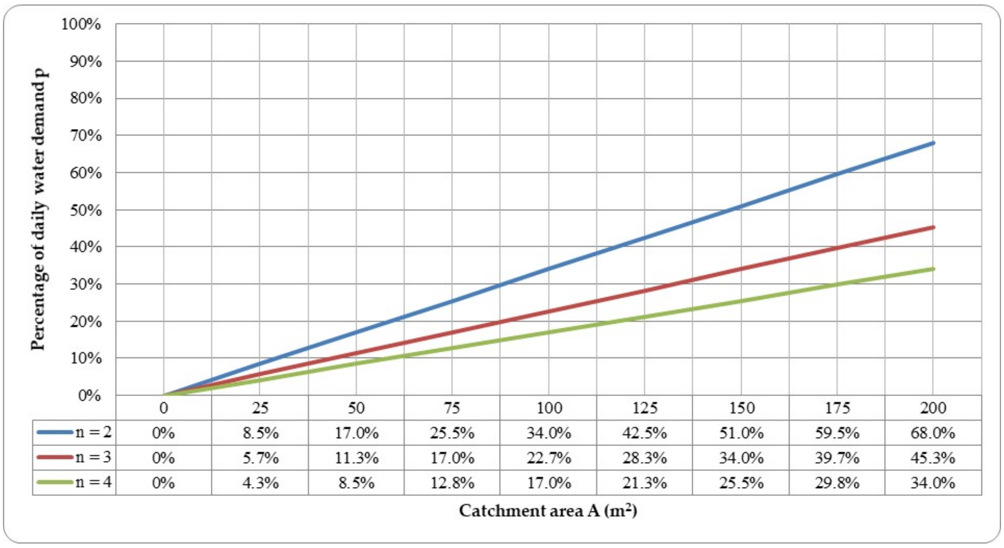
$$D_t = p \cdot (q \cdot 10^{-3})\, n \cdot 365 \quad (6)$$

where: p is the percentage of total water use satisfied from harvested rainwater; q is the daily water use in L/day/inhabitant; n is the number of residents.

Assuming that the mean annual harvested rainwater volume can satisfy the mean annual demand, the relation between the minimum required rainwater collection areas A, and the percentage p of total water daily demand is calculated as:

$$p = c \cdot 0.95 \cdot (H_{mean} \cdot 10^{-3}) \cdot A / (q \cdot 10^{-3})\, n \cdot 365 \quad (7)$$

Figure 4 presents the required minimum rainwater catchment area as a function of the percentage of water demand, satisfied by harvested rainwater for domestic use, and the number of inhabitants served, for average annual rainfall H_{mean} = 581.70 mm, with a run-off coefficient c = 0.9 and total daily water demand q = 200 L/inhabitant/day (in Greece daily water demand ranges from 100 to 200 L/inhabitant/day).



	0	25	50	75	100	125	150	175	200
n = 2	0%	8.5%	17.0%	25.5%	34.0%	42.5%	51.0%	59.5%	68.0%
n = 3	0%	5.7%	11.3%	17.0%	22.7%	28.3%	34.0%	39.7%	45.3%
n = 4	0%	4.3%	8.5%	12.8%	17.0%	21.3%	25.5%	29.8%	34.0%

Figure 4. Required catchment area as a function of the percentage of daily water demand satisfied by harvested rainwater for the number of inhabitants 2–4.

The maximum values of the percentage of total water daily demand satisfied by harvested rainwater as a function of the catchment area are estimated and presented in Figure 4). For example, using a catchment area of 100 m^2, 34% of the total daily demand is achieved for the number of inhabitants n = 2 and 22.7% of total daily demand for the number of inhabitants n = 3. Equation (7) shows an increase in the maximum percentage of daily water demand satisfied by harvested rainwater is achieved by reducing the total daily demand, q.

Figure 5 shows that for a household with two inhabitants and using a catchment area of 100 m^2, a 25% reduction in daily water use (i.e., from q = 200 to q = 150) causes a 33% increase in the maximum percentage of daily water demand that can be satisfied by rainwater demand.

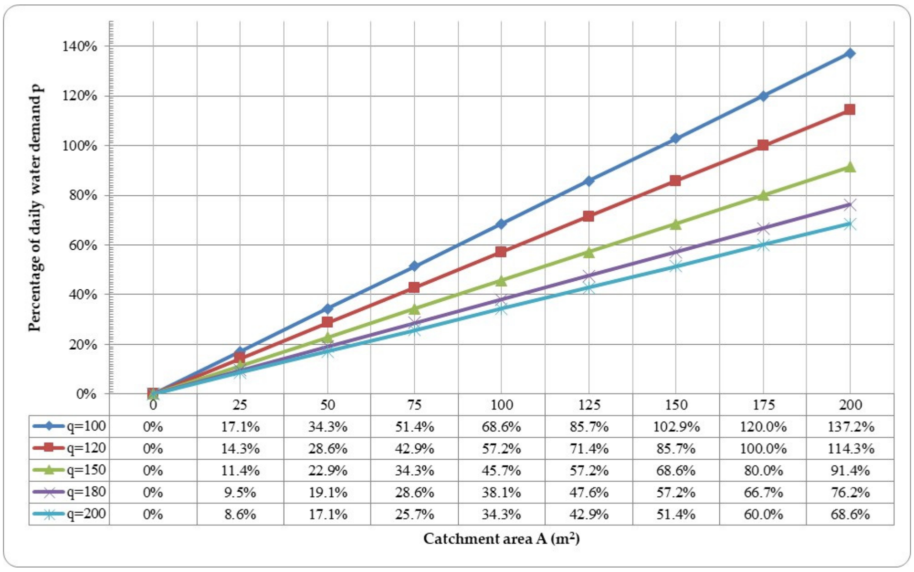


Figure 5. Required catchment area as a function of the percentage of daily water demand satisfied by harvested rainwater for two inhabitants and different values of daily demand.

3.5. Behavioral Model

In order to simulate the behavior of a rainwater tank, rainfall data was used as an input with a preselected roof area, tank volume, and water consumption to obtain the reliability of the water supply from the tank for the selected parameters. For an exact representation of the rainwater tank, it is necessary to add water to the tank and simultaneously subtract the water demanded from it.

The algorithm for the model relies on a yield-before-spillage operating rule [42,68]:

$$Y_t = \min\{D_t; V_{t\text{-}1} + Q_t\} \ \& \ V_t = \min\{V_{t\text{-}1} + Q_t - Y_t; S\} \tag{8}$$

where: Y_t = yield from the tank during the time interval t; D_t is the demand during the time, t (in m^3); V_{t-1} is the volume stored at the beginning of t day (in m^3); Q_t is the inflow (harvested rainwater) during the time interval, t (in m^3) and the capacity (S) of the rainwater harvesting tank (in m^3).

The process is calculated day after day and starts from an initial stored water volume $V_{t-1} = V_0$ at time t = 0. The most conservative value is $V_0 = 0$ for an initially empty rainwater tank and the maximum value $V_0 = S$ for an initially full rainwater tank. The value $V_0 = 1$ is adopted for a partially full rainwater tank in this study.

The performance of RWHs is generally described in terms of water-saving efficiency, expressed as the total actual rainwater supply over water demand. It provides a measure of how much water has been conserved compared to the overall demand, and it is also referred to as volumetric reliability.

The performance of the system by its Water Saving Efficiency (WSE) can be described in the Equation (9):

$$\mathrm{WSE} = 100 \cdot \Sigma Y_t / \Sigma D_t \tag{9}$$

Moreover, the performance of the RWHs depends on several factors such as the number of inhabitants, water demand, roof catchment area, and time steps. That is why a reliability assessment should be generated considering these variables.

An Excel-based sheet hydrological model, which provides the operating algorithm, was developed to simulate the hydrological processes of RWHs. Water balance simulations were performed on a daily scale, thus accounting for the effect of extreme rainfall of 24 h duration and dry spell on the RWHs.

The feasibility of six different rainwater tank sizes (3, 5, 10, 15, 20 and 20 m^3) and three different catchment areas (75, 100 and 125 m^2) was examined. The different catchment area reflects the standard choices in the design of houses by residents. Additionally, the number of inhabitants per household in Chios generally varies between 2 and 4, reflecting small and large families. In this study, the water demand for non-potable uses of a household was determined, assuming q = 200 L/inhabitant/day and p = 33%. This percentage corresponds to water use for toilets 26%, and garden irrigation 7%.

RWH has been practiced through time, focusing on dry periods. The RWHs in school serves about 100 students and teachers. The Christmas holidays, the Easter break, summer and school holidays, and weekends were excluded from the calculations. The effectiveness of rainwater tanks of different volumes (10, 15, 20, 24, 30, and 40 m^3) with a catchment area of 600 m^2 was examined. The total demand for non-drinking water for residential uses such as toilet flushing, bathing and watering plants was determined as q = 20 L/day/inhabitant and p = 100%. The rainwater tank is located underground. Table 1 presents a summary of all cases simulated in this study.

Table 1. Summary of all cases simulated in this study (* house, ** school).

Number of Inhabitants *n*	Tank Capacity S (m^3)	Catchment Area A (m^2)	Runoff Coefficient c	Daily Consumption (L/Day/Inhabitant)
2 *	3, 5, 10, 15, 20, 25	75, 100, 125	0.9	200
3 *	3, 5, 10, 15, 20, 25	75, 100, 125	0.9	200
4 *	3, 5, 10, 15, 20, 25	75, 100, 125	0.9	200
100 **	10, 15, 20, 24, 30, 40	600	0.9	20

3.6. Economic Assessment of the RWH Infrastructure

To perform the economic analysis of the RWHs an estimation of the required investment and the benefits was undertaken and the PayBack (PB) period for each case was considered. The cost of installing and operating a RWHs can be divided into tank, installation, operation and maintenance costs. In this study, the costs related to the system maintenance were considered negligible compared to purchase and installation costs [69]. The energy cost for pumping rainwater was not considered. This assumption was made because Chios city does not have a constant supply of tap water—there is water just for a few hours per day and for a few days per week, especially during the summer season.

Because of water service interruption in the municipality distribution system, the residents of Chios have already installed a pumping station that ensures the provision of water for the days and hours that there is no running water in their taps. Therefore, the energy costs for water supply are the same, either using rainwater or stored water from other sources.

The cost of a domestic tank varies between EUR 500 and 5000 depending on the shape, size and material. In the current study, a typical underground tank made from high density polyethylene (HDPE) was selected. The cost of this kind of tank ranges from EUR 350 for a 3 m^3 tank to EUR 3100 for a 25 m^3 tank. Table 2 summarizes the costs of the RWH components for each tank capacity.

The estimated total cost of each simulated case of RWH in a school is presented in Table 3. The total cost for the examined tank capacities ranges from EUR 3700 to 7600 (Table 3).

Table 2. Total cost (EUR) of the RWHs in a house.

Tank Capacity (m^3)	3	5	10	15	20	25
Cost of purchasing and installing the tank	450	600	1300	2100	3000	4000
Cost of purchasing and installing pump and electric equipment	400	400	400	400	400	400
Cost of purchasing and installing drainage pipes in and out the tank	600	600	600	600	600	600
Cost of purchasing and installing rainwater filter	300	300	300	300	300	300
Total cost	1750	1900	2600	3400	4300	5300

Table 3. Total cost (EUR) of the RWHs in a school.

Tank Capacity (m^3)	10	15	20	24	30	40
Cost of purchasing and installing the tank	1300	2100	2600	3300	4200	5200
Cost of purchasing and installing pump and electric equipment	400	400	400	400	400	400
Cost of purchasing and installing drainage pipes in and out the tank	1600	1600	1600	1600	1600	1600
Cost of purchasing and installing rainwater filter	400	400	400	400	400	400
Total cost	3700	4500	5000	5700	6600	7600

The financial benefit comes from the reduction in the annual water bill. This annual revenue is calculated as the savings related to the substitution of main water for rainwater. Table 4 shows the current domestic water price of water supply in the region.

Table 4. Water tariff for domestic consumption in central Chios island.

Classes (m^3)		Water Usage (EUR/m^3)	Sewage Usage System (EUR/m^3)	VAT on Water Price (EUR/m^3)	VAT on Sewage Price (EUR/m^3)	Sum (EUR/m^3)
1° Class	0–10	0.00	0.00	0.00	0.00	0.00
2° Class	11–20	0.00	0.00	0.00	0.00	0.00
3° Class	21–45	0.80	0.24	0.07	0.04	1.15
4° Class	46–70	1.20	0.36	0.11	0.06	1.73
5° Class	71–100	1.25	0.38	0.11	0.06	1.80
6° Class	>101	1.38	0.41	0.12	0.07	1.99

Table 4 is provided by the Water Supply and Sewerage Company of Chios. The cost is charged per m^3 of water used and remains constant for a certain quantity of consumption up to 20 m^3 (Class 1 and 2). For classes 1 and 2 there is a fixed tariff. As the water consumption escalates, the tariff shifts to the next class of price and so on for each class of consumption until the highest one. The current average cost of mains water as an indicator of savings is underestimated, given that the full cost of water is likely to be higher than currently priced, mainly because of water scarcity and increasing water costs related to more expensive water technology (i.e., desalination). This is mainly explained because water prices will have to move to full-price water recovery under European Union [70] Water Framework Directive, which mentioned that "*The Member States shall take account of the principle of recovery of the costs of water services, including environmental and resource costs*". Consequently, homogenization of prices throughout Europe is introduced [34]. In this study, it is estimated that water supply prices will rise at 2 EUR/m^3 in the next years. It is one of the most straightforward investment appraisal techniques. The PB period has the disadvantage of neglecting the time value of money, which is a serious drawback since it can lead to improper decisions. In order to assess the investment risk associated with the application of the RWHs, the financial ratio of the PB period was determined. In this study, PB was used to compare the simulated cases.

4. Results and Discussion

The method, process, technology, procedure, practice, or system—no matter how RWH is defined—has a long history in semi-arid areas, or in regions facing water scarcity, mimics nature. Nowadays, RWH is (re)introduced as a green infrastructure for water management and governance [43] towards sustainable development. Furthermore, with the increased demand for food, climate change and its impact on water, the mindset change regarding environmental sustainability, the increased value placed on local participation in organization and management of local resources, and the consciousness that local comminutes can create institutions and settings that affect the resilience and play a critical role in achieving sustainability [71] regenerate the interest in the RWHs [72]. RWH is a practice that can be implemented on a small scale, operates effortlessly, is highly adaptive to local conditions, uses low-cost technology and in the agricultural sector it improves water use efficiency, reduces soil erosion, improves soil fertility, and increases agricultural productivity [73].

The RWH strategy is rather opposite to modern water governance systems focused on large-scale centralized infrastructure. The dominant hydraulic paradigm—the symbol of the domination of human over nature, through science and technology—has overlooked the "other", the decentralized, informal and small-scale infrastructure. Nevertheless, the modern narrative about green infrastructure, along with the state reductions in funding for public works and services, the emergence of mega-cities all over the world, and their missing infrastructure, contribute to the discussion about different patterns of organization linked to local actors, social priorities and local context [43].

This case study discusses how an existing system of storing water in a Mediterranean island, facing water scarcity, can be transformed to a RWHs aiming for sustainability. The paper argues that green solutions such as RWHs can be smoothly introduced, as it requires low-cost investment, using technology which is already applied or is easily obtainable. The different scenarios regarding the efficiency of RWHs in Chios island concerning domestic use or communal needs are developed in Tables 5 and 6, respectively.

Table 5. Results for each strategy for domestic use applied in this research.

Tank Capacity S (m^3)	Average WSE	ΣYield (m^3)	Average Yield (m^3)	Annual Savings (EUR)	RWHs Cost (EUR)	PB Period (Year)
Input data: n = 2, A = 75 m^2, q = 200 L/day/inhabitant, p = 33%						
3	50.39%	170.03	24.29	48.58	1750	36
5	55.04%	185.69	26.53	53.05	1900	36
10	63.44%	214.03	30.58	61.15	2600	43
15	69.67%	235.07	33.58	67.16	3400	51
20	72.84%	245.76	35.11	70.22	4300	61
25	74.77%	252.28	36.04	72.08	5300	74
Input data: n = 2, A = 100 m^2, q = 200 L/day/inhabitant, p = 33%						
3	54.38%	183.48	26.21	52.42	1750	33
5	59.36%	200.27	28.61	57.22	1900	33
10	69.40%	234.14	33.45	66.90	2600	39
15	77.87%	262.74	37.53	75.07	3400	45
20	84.84%	286.24	40.89	81.78	4300	53
25	89.27%	301.19	43.03	86.05	5300	62

Table 5. *Cont.*

Tank Capacity S (m^3)	Average WSE	ΣYield (m^3)	Average Yield (m^3)	Annual Savings (EUR)	RWHs Cost (EUR)	PB Period (Year)
Input data: $n = 2$, A = 125 m^2, q = 200 L/day/inhabitant, p = 33%						
3	57.04%	192.46	27.49	54.99	1750	32
5	62.31%	210.24	30.03	60.07	1900	32
10	72.99%	246.25	35.18	70.36	2600	37
15	82.84%	279.49	39.93	79.85	3400	43
20	90.77%	306.25	43.75	87.50	4300	49
25	94.33%	318.27	45.47	90.94	5300	58
Input data: $n = 3$, A = 75 m^2, q = 200 L/day/inhabitant, p = 33%						
3	40.80%	206.47	29.50	58.99	1750	30
5	44.58%	225.61	32.23	64.46	1900	29
10	48.18%	243.81	34.83	69.66	2600	37
15	50.15%	253.81	36.26	72.52	3400	47
20	50.49%	255.51	36.50	73.00	4300	59
25	50.49%	255.51	36.50	73.00	5300	73
Input data: $n = 3$, A = 100 m^2, q = 200 L/day/inhabitant, p = 33%						
3	44.97%	227.58	32.51	65.02	1750	27
5	49.69%	251.46	35.92	71.84	1900	26
10	56.03%	283.55	40.51	81.01	2600	32
15	60.63%	306.84	43.83	87.67	3400	39
20	63.29%	320.33	45.76	91.52	4300	47
25	65.27%	330.33	47.19	94.38	5300	56
Input data: $n = 3$, A = 125 m^2, q = 200 L/day/inhabitant, p = 33%						
3	47.81%	241.98	34.57	69.14	1750	25
5	53.01%	268.30	38.33	76.66	1900	25
10	60.06%	303.93	43.42	86.84	2600	30
15	65.81%	333.05	47.58	95.16	3400	36
20	70.75%	358.05	51.15	102.30	4300	42
25	75.37%	381.44	54.49	108.98	5300	49
Input data: $n = 4$, A = 75 m^2, q = 200 L/day/inhabitant, p = 33%						
3	33.72%	227.53	32.50	65.01	1750	26.92
5	36.63%	247.20	35.31	70.63	1900	26.90
10	38.35%	258.75	36.96	73.93	2600	35.17
15	38.35%	258.75	36.96	73.93	3400	45.99
20	38.35%	258.75	36.96	73.93	4300	58.16
25	38.35%	258.75	36.96	73.93	5300	71.69
Input data: $n = 4$, A = 100 m^2, q = 200 L/day/inhabitant, p = 33%						
3	38.11%	257.16	36.74	73.48	1750	24
5	42.68%	288.00	41.14	82.29	1900	23
10	46.75%	315.46	45.07	90.13	2600	29

Table 5. *Cont.*

Tank Capacity S (m^3)	Average WSE	ΣYield (m^3)	Average Yield (m^3)	Annual Savings (EUR)	RWHs Cost (EUR)	PB Period (Year)
15	48.62%	328.08	46.87	93.74	3400	36
20	50.10%	338.08	48.30	96.60	4300	45
25	50.44%	340.35	48.62	97.24	5300	55
Input data: n = 4, A = 125 m^2, q = 200 L/day/inhabitant, p = 33%						
3	40.85%	275.62	39.37	78.75	1750	22
5	46.20%	311.78	44.54	89.08	1900	21
10	51.87%	350.03	50.00	100.01	2600	26
15	55.76%	376.25	53.75	107.50	3400	32
20	58.44%	394.34	56.33	112.67	4300	38
25	59.96%	404.61	57.80	115.60	5300	46

Table 6. Results for each strategy for a school applied in this study.

Tank Capacity S (m^3)	Average WSE	ΣYield (m^3)	Average Yield (m^3)	Annual Savings (EUR)	RWHs Cost (EUR)	PB Period (Year)
Input data: n = 100 inhabitants, A = 600 m^2, q = 20 L/day/inhabitant						
10	46.45%	1122.35	160.34	320.67	3700	12
15	52.83%	1276.45	182.35	364.7	4500	12
20	57.37%	1386.10	198.01	396.03	5000	13
24	59.97%	1448.88	206.98	413.97	5700	14
30	63.08%	1523.93	217.7	435.41	6600	15
40	66.64%	1610.00	230	460	7600	17

This RWH is proposed for non-potable uses, i.e., flushing toilets and irrigation. A general aspect of Table 5 is that even with a 25 m^3 rainwater tank, the full WSE cannot be achieved even for non-potable uses. For example, while for a catchment area of 100 m^2, with two users, the maximum percentage of water demand that can be satisfied from harvested rainwater is 34% (Figure 4) and 100% for non-potable uses, the analysis shows that the water demand varies between 54 and 89%. Figure 6 shows the average WSE for non-potable uses with n = 2, A = 100 m^2.

The efficiency of the RWHs depends on the rainfall and roof catchment area. Maybe a catchment area greater than 150 m^3 with a tank greater than 30 m^3 could meet 100% of the water demand. However, this system may not be economically acceptable.

This research showed that an increase in the number of users for the same tank capacity, i.e., the increase in demand, reduces system performance. This is because there is no harvested water to be yielded due to low precipitation. It is also recorded that the performance of the system is improved as the tank capacity is increased. However, this increase tends to become stable if the capacity of the tank is greater than 15 m^3. Especially in the case of n = 4, A = 75 m^2, q = 200 L/day/inhabitant, p = 33%, the system performance is stabilized using tanks greater than 10 m^3, which can be explained by the low precipitation and small catchment areas. It is indicative that by increasing the capacity by 500%, from 5 to 25 m^3, the water saving increased from 4.7 to 51.41% or 1.65 (case of n = 4, A = 75 m^2, q = 200 L/day/inhabitant, p = 33%) to 15.44 m^3 (n = 2, A = 125 m^2, q = 200 L/day/inhabitant, p = 33%), respectively. These water savings increase the PB periods by approximately 45–75 years. Evaluating these results, it is clear that the large rainwater tank sizes may not be the solution due to space and cost limitations, while there is an increased risk of quality degradation of harvested rainwater.

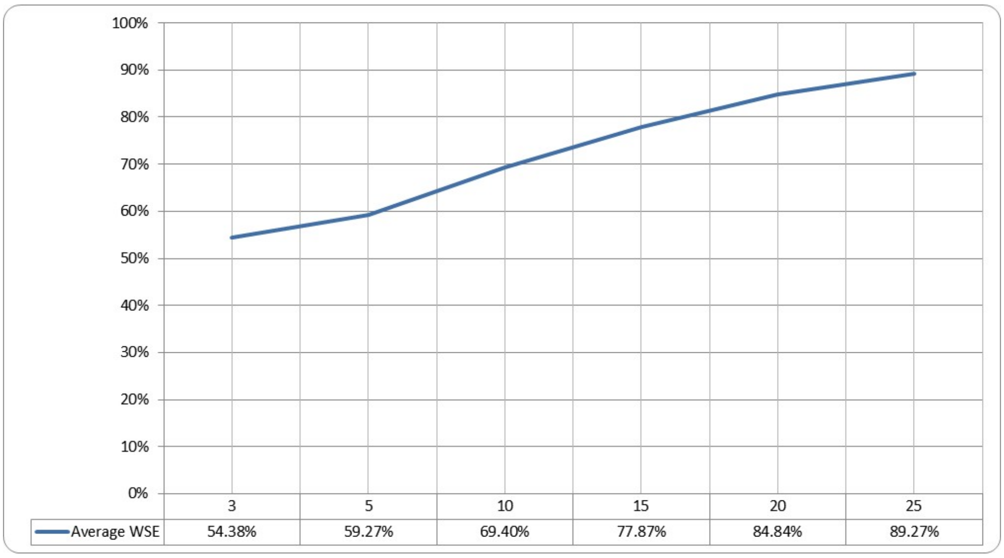


Figure 6. Average WSE for non-potable uses with n = 2, A = 100 m^2.

The optimum tank size in terms of PB period was found equal to 5 m^3 for all cases. The PB ranges from 21 to 35 years, with a mean value of 28 years depending on the input data. In any case, installing a RWHs with a 5 m^3 tank, with an investment cost of EUR 1,900 and a PB period of 28 years, is financially acceptable.

In Germany, a study concluded that water saving ranges from 30 to 60% and depends on the precipitation depth and the catchment area [74]. In Australia, using RWHs in 27 residential units, a total water saving of around 60% is feasible [75]. Ghisi et al. [76], who performed analysis over 62 cities in Southern Brazil mentioned that the water savings for potable use vary between 34 and 94%. In China, the Nanyang Technological University investigated the use of rainwater for toilets throughout the campus [52]. They reduced potable water consumption by 12.4% [52]. The performance of a rainwater collector installed in a house in Nottingham (UK) was monitored and a mean water-saving efficiency of 57% was obtained [77].

Regarding the school building, it is observed that the efficiency of the RWH varies between 46 and 66% (Table 6). Interestingly, the repayment period ranges from 12 to 17 years, suggesting that it is an investment with a good return. The near-zero water demand for schools during the weekends, public (Christmas, Easter) and school (summer) holidays contributes to the better performance of the RWHs.

The behavior of the rainwater collection system with tank volume of 24 m^3 in the school building correlated to the variation in the precipitation is shown in Figures 7 and 8. Figure 7 presents the daily precipitation rate for the year 2019. The annual precipitation is 685 mm, about 17% higher than the average of seven years (581.70 mm). From day 120 to 265, there is hardly recorded any rainfall event. It is observed that during May–September (dry season), the volume of the stored water is near to zero.

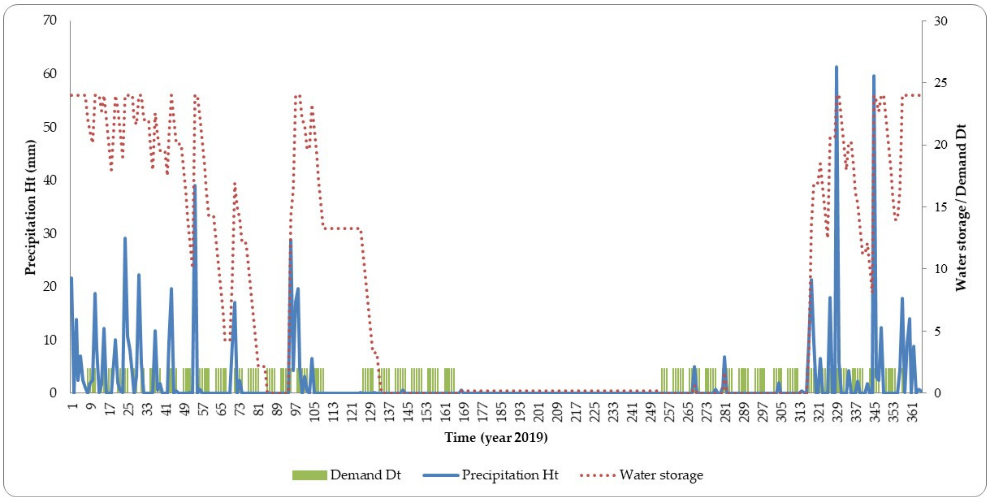


Figure 7. Water demand, precipitation and water storage in the RWHs for a school in 2019.

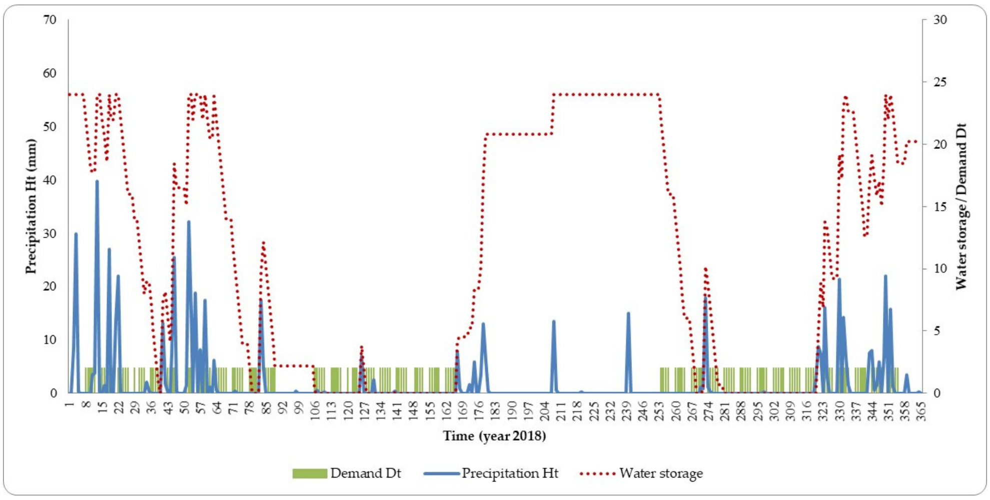


Figure 8. Water demand, precipitation and water storage in the RWHs for a school in 2018.

Figure 8 presents the daily precipitation for the year 2018. The annual precipitation is 579.20 mm, approximately equal to the seven-year average (581.70 mm) but less than 100 mm regarding the annual precipitation of the year 2019, for the days 120–265. During the dry season, i.e., from May to September, there is rainfall, which affects the stored volume of rainwater.

Preeti and Rahman [78] reported that water savings from a RWHs range widely across Australian capital cities. Using three different water uses and 10 different tank sizes, they concluded that a RWHs could be very efficient in meeting the water demand for laundries and toilets in all Australian cities [78]. Rahman et al. [79] concluded that water savings from a RWHs depend on climatic and demographic factors, often presenting considerable spatial variability. According to Xu et al. [80], local water policies and strategies should be adapted to local water resources, efficiently resolving the conflict between water inequality and water conservation.

The low-scale infrastructure such as RWH reduces the cost of water supply compared to conventional large-scale infrastructure such as dams. The Municipality of Chios has estimated that if the 25% of residents install a RWHs, the overall benefit is equivalent to the construction of a dam with effective capacity of 370,000 m^3 which costs about EUR 1,500,000 [81].

RWH highlights that the relationship between society and water is a complex concern with historical, social, and geographical dimensions. The societal ethic towards water reflects the conceptions and expectations for water and the environment, landscape, and society itself [82]. Hydrosocial practice connects the water with the technologies, the society with the landscape. In this vein, RWH practice facing water scarcity problems, coupled with low-quality water in its distribution system, allows the local community to adapt to physical and technical conditions by implying a simple, low-scale infrastructure, in contrast to an extensive one that seems to be ineffective.

5. Conclusions

In this survey, the correlation between the collected water from a RWHs, the catchment area and the number of users served was assessed. Water saving through integrated water management is put forward by the practice of RWH. Considering the specific geophysical characteristics of the Chios island, and everyday routines of its inhabitants, this work investigates the context that makes the RWHs a sustainable one and a reality for the islanders. The number of users and contributing surfaces define the water supply and inflow, and ultimately the optimal volume of the collection tank. Water harvesting could be applied for other uses except drinking in both houses and schools. Daily rainfall data in the Chios island is used as an input to the system simulation model for toilet flushing and garden irrigation for seven years. This study discussed the optimal size of the rainwater collection tank via the application of the daily water balance for specific collection surfaces and defined needs. In the case of a house where water is used daily, the installation of a rainwater collection system with a tank of 5 m^3, with an investment cost of EUR 1900, and an average price of a 28-year repayment period is economically acceptable. In the case of a school setting, with no water consumption in the summer season, it is estimated that a RWHs with a tank of 24 m^3 covers 60% of water needs, costs EUR 5700 and the repayment period is about 14 years. This study indicates that it is smooth enough to connect the society, beyond the economy, with the environment. Social analysis points out the community's attitude, norms and forms of knowledge regarding water perception and its day-to-day management affect the implementation of water practices and facilitate the dialogue among stakeholders and local authorities. Social practices such as RWH, which are already exercised in Chios island, could enhance the quality of urban life connected to environmental values. This study argues that social services, such as education and social safety, can be further supported by providing safe water in sustainable way, through RWH.

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