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Evaluating Rainwater Harvesting Systems for Water Scarcity Mitigation in Small Greek Islands under Climate Change

Elissavet Feloni [1,2,*] and Panagiotis T. Nastos [2]

[1] Department of Surveying and Geoinformatics Engineering, Egaleo Park Campus, University of West Attica, Ag. Spyridonos Str., 12243 Athens, Greece
[2] Laboratory of Climatology and Atmospheric Environment, Department of Geology and Geoenvironment, University Campus, National and Kapodistrian University of Athens, 15784 Athens, Greece
* Correspondence: efeloni@geol.uoa.gr

Abstract: Rainfall variability, exacerbated by climate change, poses significant challenges to water resource management, particularly in regions prone to intense droughts and floods. The Greek islands, characterized by poor water potential, face interannual water supply issues dating back to their earliest habitation. Rainwater harvesting (RWH) systems emerge as a promising solution to address water scarcity in these regions. This study simulates RWH systems for two small Greek islands, Fourni and Nisyros, representing similar rainfall regimes. Multiple scenarios are explored, and system reliability is assessed in light of simulated daily rainfall time series incorporating climate change projections. Utilizing eight low/medium (RCP 4.5) and eight high (RCP 8.5) emission scenarios over a future 35-year period, the study evaluates system reliability based on model parameters (collection area: 40 to 140 m^2, rainwater tank volume: 5 to 30 m^3, number of household members: 2, 3), with 30% coverage of total daily water demand (180 L/d). Negligible evapotranspiration effects are assumed due to closed-type tanks. Results indicate that the RWH system demonstrates high efficiency in general. The investigation for the future period revealed that the system's performance varies, with instances where daily demand targets are not met, even with a 30 m^3 tank. This research underscores the potential of RWH systems as a cost-effective "green" solution, particularly in regions with deficient rainfall regimes. It highlights the importance of localized water management strategies, reducing reliance on mainland water transportation, and assisting desalination unit operations. In conclusion, this study contributes to the assessment of RWH systems, demonstrating their viability as a sustainable water management solution in regions facing water scarcity, contingent on local rainfall conditions and system design parameters.

Keywords: rainwater harvesting; dry islands; water resources management; water scarcity; Aegean Sea; Greece; climate change

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1. Introduction

Water scarcity is a pervasive issue in regions with limited available water resources, such as the Greek islands, posing challenges for local water management. Climate change will intensify this pressure in some parts of the world, including the Mediterranean basin, resulting in a predicted decrease in water resources in the coming decades [1]. Various techniques for water collection and storage are generally being explored to address this problem depending on local conditions, such as building dams, installing desalination units, groundwater recharge, and greywater recycling, among which rainwater harvesting (RWH) systems have gained prominence. RWH presents many benefits for urban sustainability, and it is emerging as a key strategy in order to cope with water scarcity in cities [2]. It has gained popularity in Greece and other various parts of the world due to its numerous benefits, including water conservation, self-sufficiency, and resilience to water scarcity. Many studies are available in the literature on the benefits, design, performance, and feasibility of RWH around the world, as evidenced by Shadmehri Toosi et al. [3]. RWH systems, typically implemented at the household level, offer a sustainable approach to supplementing water supply for multiple uses, including laundry, toilet flushing, and garden irrigation. Overall, incorporating rooftop RWH systems either as a complementary or primary water source in regions with sufficient rainfall holds significant potential for yielding both direct and indirect advantages. These benefits encompass alleviating strain on current water reserves and promoting the conservation of resources [3].

RWH systems typically comprise three key components: the catchment area, collection device, and conveyance system. Rainwater is commonly gathered from rooftops, courtyards, or treated surfaces, filtered, and stored for use. RWH offers several advantages. It relies on simple, affordable technologies that are easy to install and maintain, allowing for flexibility in adaptation to individual household needs. Economically, RWH reduces reliance on purchased water from public systems and alleviates pressure on aquifers and surface water sources. Integrating RWH into buildings minimizes treated water usage for non-potable tasks and addresses water scarcity concerns effectively. Despite its benefits, RWH has limitations due to supply constraints and rainfall variability, making households reliant on conventional water systems. Achieving water self-sufficiency may require a combination of technologies. Nevertheless, RWH can significantly supplement water resources, resulting in substantial cost savings for households [4]. The quantity of rainwater collected varies depending on geographic location, local climate attributes, and the capacity of storage tanks. Typically, runoff from rooftops is deemed unpolluted or of relatively good quality compared with runoff from surface catchments [5,6].

Determining the optimal size of rainwater harvesting (RWH) tanks is essential to ensure the efficiency and effectiveness of the system. Tank storage capacity cannot be standardized, as it greatly depends on factors such as local rainfall patterns, characteristics of the catchment surface, and household size. A range of methods have been utilized to assess the performance and design of RWH systems, including water balance simulation analyses, mass curve analyses [7–9], probabilistic methods [10], and economic optimization [11]. Sizing methodologies differ between countries, contingent upon adopted standards and regulations, with common methods including daily or monthly water balance models and dry period demand analysis [12–17]. While behavioral models offer the advantage of monitoring system variables over time, they may yield inconsistent results with varying rainfall datasets. In contrast, the water balance method directly utilizes local rainfall data as hydrological input, providing a practical approach for tank sizing [18].

In Greece, the pressing need arising from the unequal distribution of water resources and demand in both space and time exacerbates water management challenges [17]. However, there is a lack of standardized methodology for sizing RWH tanks, particularly when considering the effects of climate change. This study aims to address this gap by investigating the operation of RWH systems under different configurations of household size, collection area, and tank capacity on two Greek islands in the Aegean Sea: Fourni and Nisyros. The analysis employs a daily water balance model to assess system efficiency, quantified by the reliability coefficient (Re (%)), across various configurations. Historic daily precipitation time series for both islands and climate change scenarios are considered to evaluate system performance during historical and future periods. Results indicate that local precipitation regimes significantly influence system effectiveness, while future scenarios demonstrate satisfactory performance in most cases. The analysis of a single-family home's RWH system operation revealed that efficiency is primarily controlled by the collection area and household size. However, the tank volumes examined in this analysis proved inadequate to ensure satisfactory system performance in all scenarios. In conclusion, this study contributes valuable insights into RWH system performance in the Greek islands, facilitating informed decision-making for domestic water supply. By considering the local context and climate change projections, the findings underscore the importance of tailored RWH system design and management strategies for sustainable water resource management in water-stressed regions.

2. Materials and Methods

2.1. Study Areas and Datasets

The analysis utilizes data from two small islands in the Eastern Aegean Sea, namely Fourni and Nisyros (Figure 1), selected as case studies to assess the reliability of rainwater harvesting systems. Fourni, the largest island in the Fourni Korseon complex, with a population of approximately 1300 inhabitants and a total area of approximately 31 km^2 within a municipal area of 45.247 km^2, is situated in the Aegean Sea between Ikaria, Samos, and Patmos islands. It features a Mediterranean climate, characterized by mild winters and hot, dry summers (Köppen climate classification: Csa), with an estimated total annual rainfall of around 500 mm/year [19]. According to the Corine Landcover 2018 dataset, artificial surfaces are estimated to make up around 4% of the total area, while the main use is sclerophyllous vegetation, followed by natural pastures, sparse vegetation, and agricultural land. Finally, as shown in Figure 2a, in Fourni, there are three main settlements, with no water supply. In the Fourni settlement with the highest population, residents use rainwater collection tanks and bottled water, and as the proper use of RWH technology will greatly help address this issue, the area has been selected for further investigation.

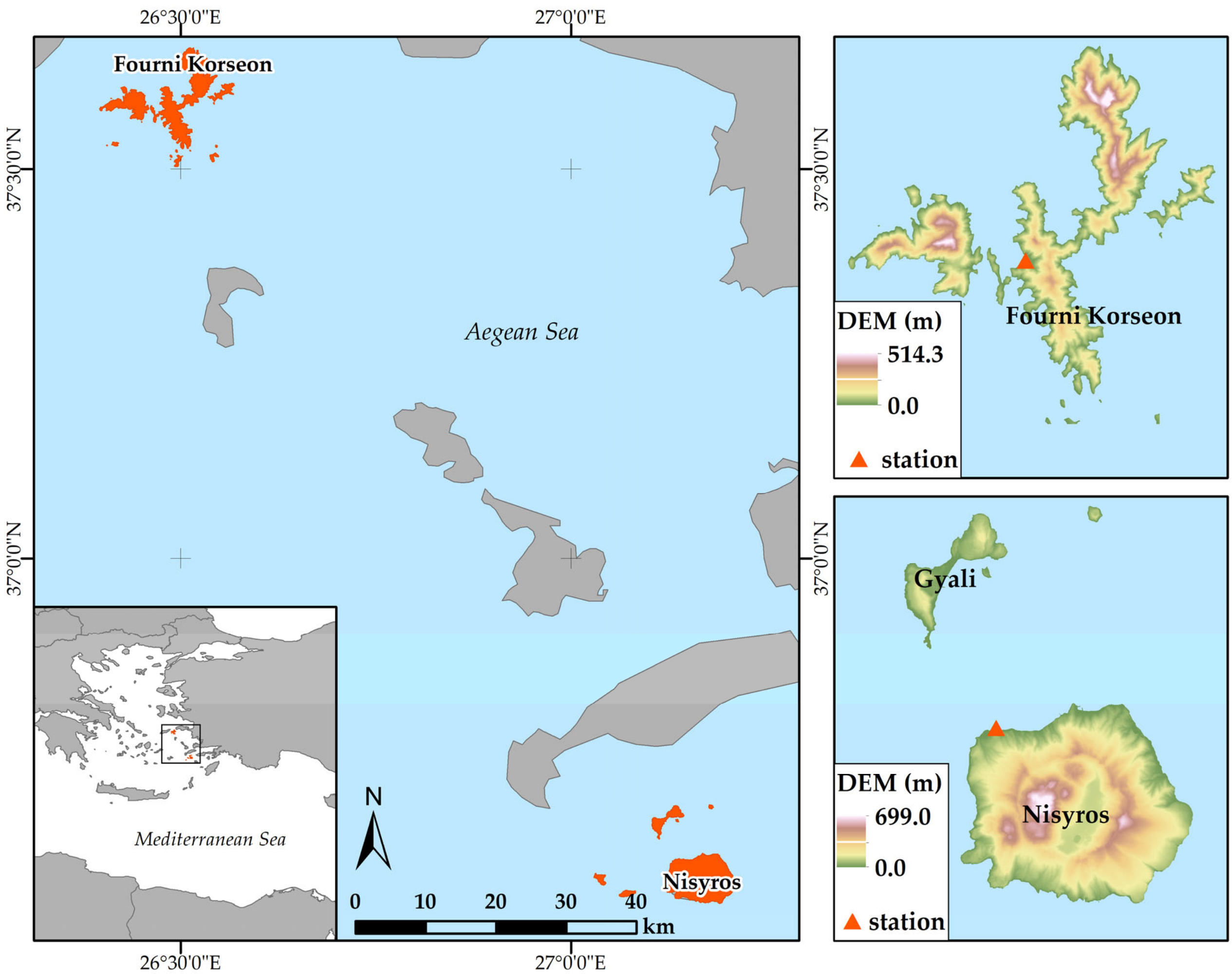


Figure 1. Fourni and Nisyros islands in the Aegean Sea.

Nisyros, a small volcanic island part of the Dodecanese group, lies in the Aegean Sea between the islands of Kos and Tilos. With an approximately round shape and an area of 41.6 km^2, Nisyros has a total of 1048 inhabitants. The island experiences mild winters and hot dry summers (Köppen climate classification: Csa), boasting an average annual temperature of around 20.0 °C and a slightly lower average annual precipitation, ranging between 350 mm and 600 mm [19,20] and presenting higher variability from year to year. There are four main settlements on the island, as shown in Figure 2b. Due to its geological structure, Nisyros experiences water degradation in both underground and surface water resources due to the presence of S-bearing minerals and volcanic rocks. The island primarily meets its water needs through three desalination plants in the Loutro area, with a capacity of 1020 m^3/day. Additionally, a reservoir located approximately 1.6 km northeast of the Emporio settlement supplements the water supply, with a useful volume of 78,000 m^3.

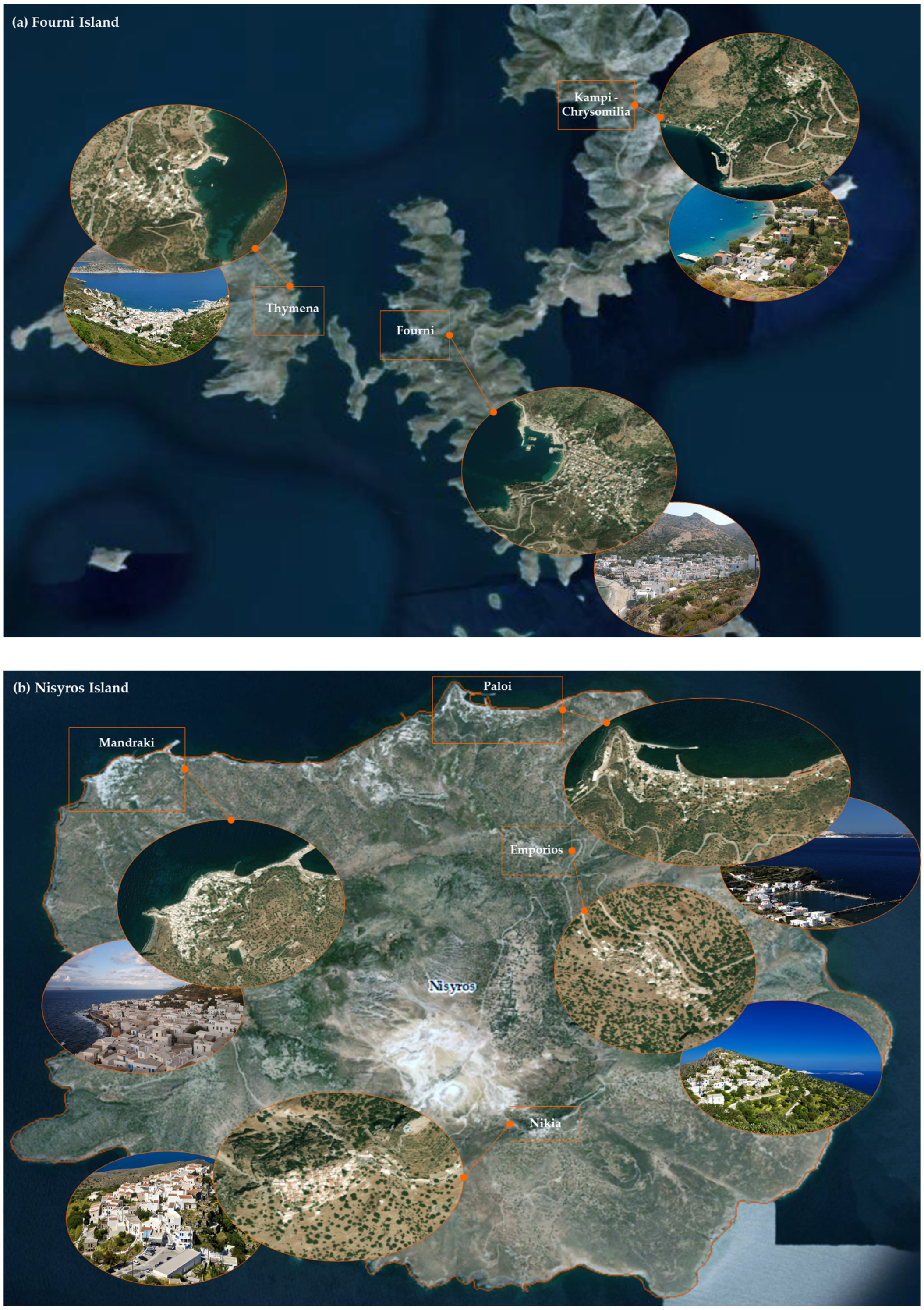


Figure 2. Settlements in (**a**) Fourni and (**b**) Nisyros islands (Basemap source: Google Earth).

In both islands, water scarcity issues intensify during the tourist season, with increasing demand due to rising visitor numbers. Both islands exhibit a similar pattern regarding residential distribution (Figure 2). Each island features a primary settlement (Fourni and Mandraki, for Fourni and Nisyros Islands, respectively), along with several smaller villages, each comprising a modest number of residences with rooftop areas varying between 30 m^2 and 100 m^2, totaling only several dozen. According to the Hellenic Statistical Authority [21], household sizes on both islands range from 1 to 3 members, with only 19% of residences accommodating families of 4–6 members. Figure 1 depicts the geographical locations of these two islands.

The implementation of an RWH system involves assessing the water balance, where rainfall serves as the inflow and targeted water demand (e.g., for toilet flushing, garden irrigation, etc.) represents the outflow. In this study, rainfall volumes were calculated using daily rainfall data collected from rain gauges operating on the islands. The data span from 2012 to 2023 for Fourni and from 2017 to 2023 for Nisyros. These data were obtained from local municipal authorities and are part of the NOA Automatic Network, which supplements the Hellenic National Meteorological Service network [22]. The quality control of the NOAAN high-frequency meteorological data is performed in two steps, as described in detail by Lagouvardos et al. [22].

Stations' locations are shown in Figure 1, and, on both islands, they are located to the settlement of the highest population (i.e., the primary settlements Fourni and Mandraki). Due to their small size and moderate elevation, the islands experience relatively uniform climatic conditions, resulting in consistent rainfall patterns across the entire area. Finally, the analysis considers the entire operational period of the stations, with records reflecting the regional climate through both annual and monthly mean values for both cases.

Future climate projections for both areas were obtained using the Data Extraction Application for Regional Climate (DEAR-Clima) web application tool [23]. This user-friendly web application provides time series of essential climate variables and indices at different temporal resolutions (daily, monthly, and annual), utilizing high-resolution regional climate model (RCM) simulations from the Coordinated Regional Downscaling Experiment (CORDEX) research program with a spatial resolution of 0.11°. Using DEAR-Clima, several meteorological data from the EURO-CORDEX for specific grid points can be acquired [24], while in this study, we utilized daily precipitation data under two representative concentration pathways (RCPs 4.5 and 8.5) for the future period from 2025 to 2060 and for each station location. These simulations are derived from various RCMs driven by multiple global climate models (GCMs); Table 1 outlines the eight products utilized in our analysis.

Table 1. An overview of the climate simulations used in this study, along with the regional climate model and the global climate model.

ID	RCM	GCM
1	CLMcom-CCLM4-8-17	CNRM-CERFACS-CNRM-CM5
2	CLMcom-CCLM4-8-17	MPI-M-MPI-ESM-LR
3	IPSL-INERIS-WRF331F	IPSL-IPSL-CM5A-MR
4	KNMI-RACMO22E	ICHEC-EC-EARTH
5	SMHI-RCA4	CNRM-CERFACS-CNRM-CM5
6	SMHI-RCA4	IPSL-IPSL-CM5A-MR
7	SMHI-RCA4	MOHC-HadGEM2-ES
8	CLMcom-CCLM4-8-17	MOHC-HadGEM2-ES

2.2. Daily Water Balance Simulation and Scenarios

Different models are available for predicting the performance of RWH systems. In this study, we utilized a daily water balance model to determine the optimal sizing of rainwater harvesting tanks. Behavioral models, commonly used for their detailed design capabilities and relative simplicity, calculate changes in storage content of a finite reservoir using the water balance equation. This equation accounts for water fluxes, including runoff into the tank (inflow), overflow from the tank, and the extracted yield, with demand being met as long as storage is available. The water balance equation, employed on a daily scale, is expressed as follows:

$$S_t = S_{t-1} + R_t - D_t, \quad 0 \leq S_{t-1} \leq V_{tank} \tag{1}$$

where S_t is the stored volume at the end of the day (m^3); S_{t-1}, the stored volume at the beginning of the day (m^3); R_t, the harvested rainwater volume at the end of the day (m^3); D_t, the daily water demand (m^3); and V_{tank}, the capacity of rainwater tank (m^3). Several tank capacities in the range 5–30 m^3 were considered.

The daily harvested rainwater volume (runoff) from a roof area is calculated as

$$R_t = C \times A \times P_{eff,t} \tag{2}$$

where C is the runoff coefficient depending on water loss (dimensionless); A, the rain total catchment area (m^2), which can be a rooftop, courtyard, and/or pedestrian areas; and $P_{eff,t}$, the daily effective rainfall depth at the end of the day (m). The runoff coefficient can take different values, depending on the material of the catchment surface. In the present study, the coefficient is set equal to 0.90 [15,25,26]. Several rooftop areas in the range of 40–140 m^2 were considered.

The daily effective rainfall is calculated by subtracting the first flush from the total daily rainfall. The first flush refers to the initial period of rainwater runoff characterized by a significantly higher pollutant concentration compared with later periods [27]. Depending on site-specific characteristics, contaminant type, and intended water use, the literature advocates for ensuring adequate water quality. Yaziz et al. [28] and Coombes [29] demonstrated that excluding the first 0.33 mm of rainfall from the total daily rainfall as the first flush markedly enhances roof water quality. Accordingly, all daily water balance simulations in this study deducted the first flush of 0.33 mm from the daily rainfall series.

$$P_{eff,t} = P_t - 0.33 \tag{3}$$

where P_t is the daily rainfall; and 0.33, the value for the first flash.

The daily water demand of a household is calculated as

$$D_t = N_{cap} \times q \times \left(\frac{p}{100}\right) \tag{4}$$

where N_{cap} is the number of residents (cap); q, the daily water use per day (m^3/cap/day); and p, the percentage of total non-potable uses satisfied by harvested rainwater. With reference to a single-family home, the RWH system's performance is investigated for dwellings of two and three members. In this work, the target for water demand met is set for toilet flushing. Different studies have highlighted the benefits of using harvested rainwater for toilet flushing [30,31]. Zhang et al. [32] observe that harvesting all roof runoff for use in toilet flushing can reduce water consumption in residential buildings by about 25%. In our study, we set the percentage at 30%, following Liuzzo et al.'s [33] experiments on water demand for flushing calculation, where they analyzed water consumption data from four-person single-family homes in Palermo (Northwestern Sicily) over a two-year measurement campaign. It was determined that the amount of water required for toilet flushing for a four-member family is approximately 80 m^3 per year, representing 30.11% of the total water usage. Additionally, an indicative analysis of the system's performance for 40% and 50% target is also provided, to include other non-potable uses such as garden irrigation; a use that varies depending on the type of grass, soil properties, and climatic conditions at the examined site and season.

Considering the equations of the water balance and the daily water demand, the daily rainwater stored volume is calculated as

$$S_t = S_{t-1} + C \times A \times P_{eff,t} - N_{cap} \times q \times (\frac{p}{100}), \text{where } 0 \leq S_{t-1} \leq V_{tank} \tag{5}$$

The daily difference between runoff (inflow) and demand (outflow) is calculated as follows:

$$\Delta S_t = C \times A \times P_{eff,t} - N_{cap} \times q \times \left(\frac{p}{100}\right) \quad (6)$$

The equation for the daily water stored volume can be written as

$$S_t = S_{t-1} + \Delta S_t \quad (7)$$

The iterative calculation of the daily storage volume commences with an initial value of $S_{t-1} = S_0$ for t = 0. The initial volume S_0 can represent an empty tank, denoted by zero volume. As the tank fills, its volume can vary, with a maximum capacity equivalent to the tank's total volume V_{tank}. In this study, a scenario of an initially filled rainwater tank at the outset was assumed. The following repeated process is

$$\begin{gathered} if(S_{t-1} + \Delta S_t) > V_{tank} \; then \; S_{t,tank} = V_{tank}, \\ if(S_{t-1} + \Delta S_t) \leq V_{tank}, \; then \; S_t = S_{t,tank} = S_{t-1} + \Delta S_t \end{gathered} \quad (8)$$

where $S_{t,tank}$ is the actual available stored water volume in the tank at t day. When the tank is full and rainfall is recorded during the t day, there is a volume that overflows (O_t) and is calculated as

$$if S_t \geq V_{tank} \; then \; O_t = S_t - V_{tank}, \; else \; O_t = 0 \quad (9)$$

In the case that the volume of rainwater collected and stored ($S_{t,tank}$) is not enough to meet the demand, then the demand will be satisfied, in parts or in whole, with an additional amount of water delivered from the local public water supply, the tap (T_t), which can be calculated as

$$if(S_t < D_t) \; then \; T_t = D_t - S_{t,tank}, \; else \; T_t = 0 \quad (10)$$

The assessment of RWH system performance, often termed as water-saving efficiency [34], quantifies the extent to which water conservation meets overall demand. Various metrics define this variable; for instance, it can be delineated by volumetric reliability, representing the actual rainwater supply against water demand. In this investigation, the reliability coefficient (Re) denotes the proportion of days where water stored exclusively caters to individuals' needs over the total days of rain data recorded and utilized in the model simulation [35]:

$$Re(\%) = \frac{n_a}{N} \cdot 100\% \quad (11)$$

where n_a is the total number of days that fully meet the water demand target, and N, the number of days for which the simulation is performed.

3. Results and Discussion

3.1. Initial Simulation

The analysis began by leveraging historical rainfall data collected from local rain gauges to assess the performance of the rainwater harvesting (RWH) system deployed on both islands, as depicted in Figure 3 and Figure 4 for Fourni and Nisyros, respectively.

Based on the analysis conducted, several key findings emerge regarding the performance of rainwater harvesting (RWH) systems in the studied areas. Firstly, it was anticipated that the reliability of RWH systems would be diminished as the number of household members increased, a trend that was confirmed through the investigation of variable p, representing the percentage of the total demand, q, targeted by the system. Furthermore, across all examined combinations, the RWH system on Fourni island consistently exhibited superior performance compared with Nisyros island. Specifically, for a two-member household in Fourni, a collection area of 80 m^2 or greater could fulfill the 30% daily demand target for toilet flushing, irrespective of the tank size. However, limitations in meeting this target were observed for Nisyros, even with a tank capacity of 30 m^3 and a rooftop area of 140 m^2, attributed to the island's rainfall regime. While the system's performance generally improved with increasing rooftop area in Fourni, a slight decline was noted when the area exceeded 120 m^2. Conversely, results for Nisyros displayed a more linear trend, with reliability surpassing 90% only for tank volumes exceeding 20 m^3 and the largest rooftop areas in the three-member household case. In the case of a two-member household on Nisyros, the targeted percentage was met with rooftop areas of 100 m^2 or larger and tank volumes exceeding 10 m^3. Finally, investigating the system's performance under varying targeted percentages of total demand (for a two-member household in Nisyros) it was revealed that only systems with substantial collection areas could meet higher demands. The tank volume demonstrated minimal impact on performance, as evidenced by subtle trends observed in Figure 5, and this is in agreement with previous research for the Aegean region [36] and the Mediterranean area [14,33,37]. These findings underscore the importance of considering both household size and local climatic conditions when designing and implementing RWH systems for optimal performance and reliability.

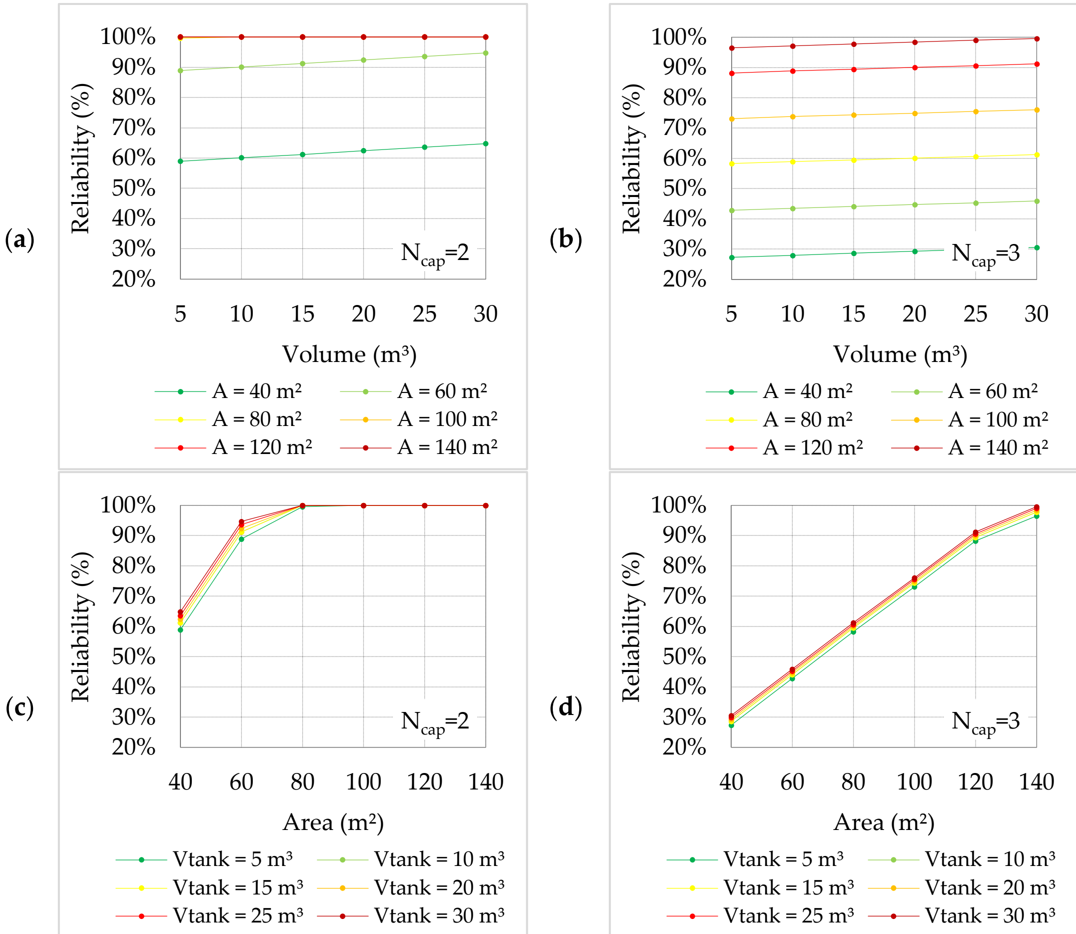


Figure 3. RWH system performance assessment for (**a**,**c**) two and (**b**,**d**) three household members on Fourni Island: reliability vs tank volume (**upper graphs**) and rooftop area (**lower graphs**).

3.2. Climate Change Scenarios Investigation

In this section, we interpret the implications of climate change on the performance of rainwater harvesting (RWH) systems. This analysis focuses on the utilization of the eight climate simulations outlined in Table 1, which represent two distinct climate scenarios: RCP 4.5 and RCP 8.5, denoting medium and high emissions scenarios, respectively. For the sake of brevity, we focus on the most reliable values of collection area and tank volume, considering that the majority of local rooftop areas fall within the range of 60 to 100 m^2, and the installation of water tanks of up to 10,000 L is feasible in the existing infrastructure.

Consequently, our investigation considers these specific combinations, which are elucidated in Figures 6 and 7 for Fourni and Nisyros, respectively. This figure encapsulates the outcomes of all examined climate simulations under the two climate-change scenarios for both two- and three-member households across the two islands, offering a comprehensive overview of the system's response to evolving climatic conditions.

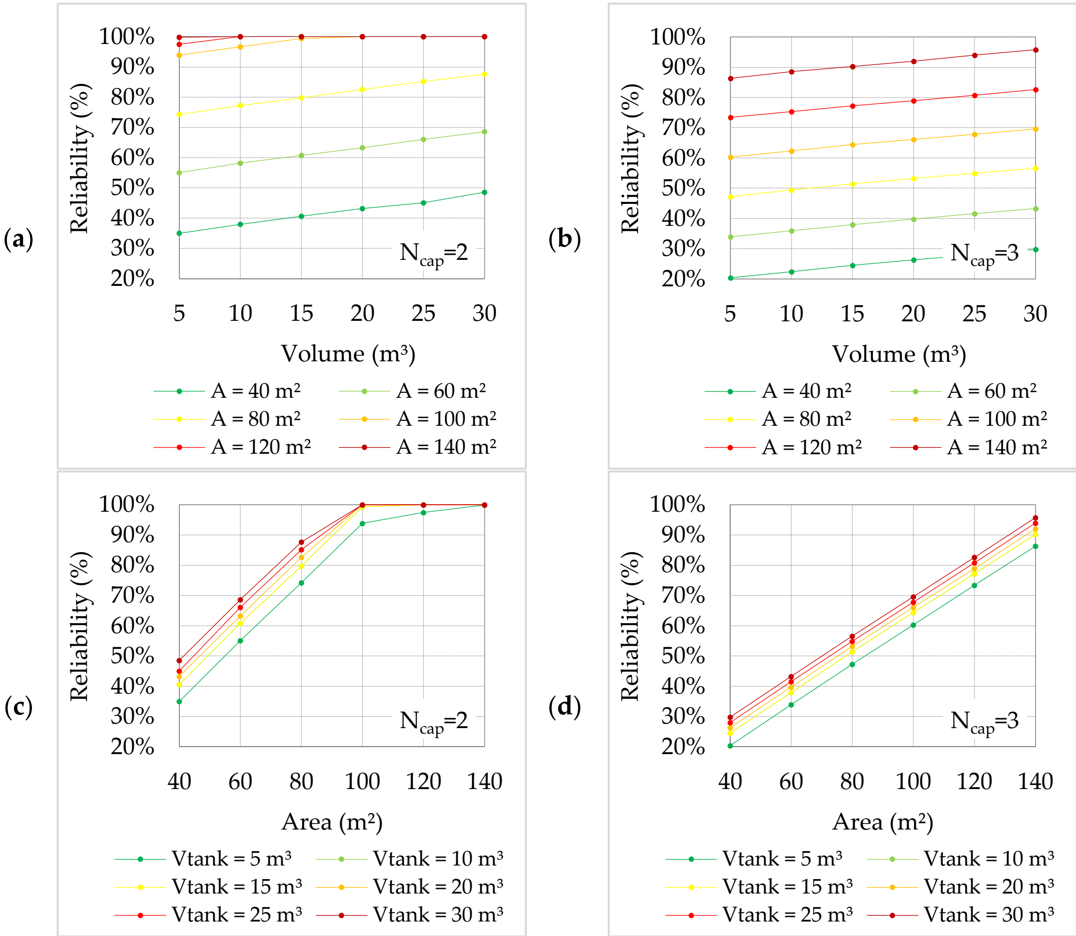
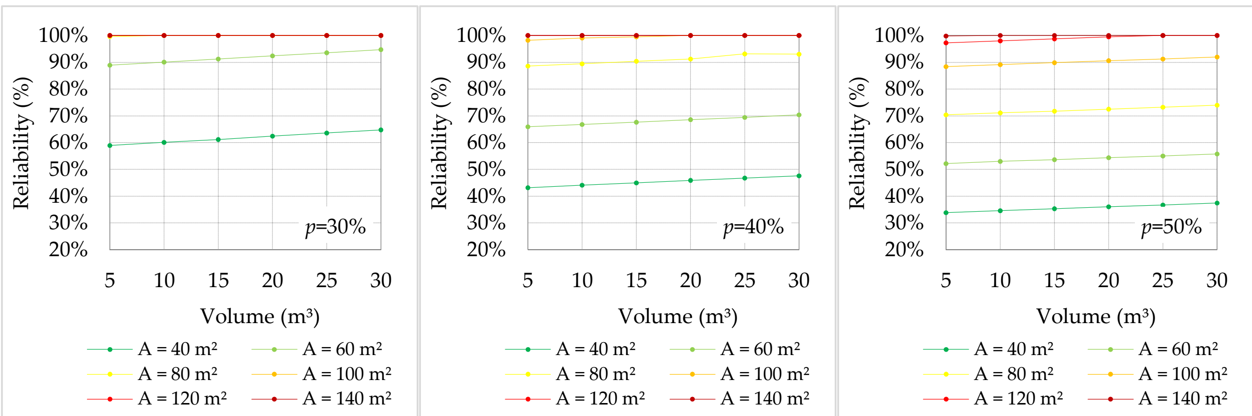


Figure 4. RWH system performance assessment for (**a**,**c**) two and (**b**,**d**) three household members on Nisyros island: reliability vs tank volume (**upper graphs**) and rooftop area (**lower graphs**).



(a) (b) (c)

Figure 5. Analysis of rainwater harvesting (RWH) system performance under increased water demand. An example of a two-member household on Fourni island. Targets at (**a**) 30%, (**b**) 40%, and (**c**) 50% of the total daily demand. Reliability vs rooftop area.

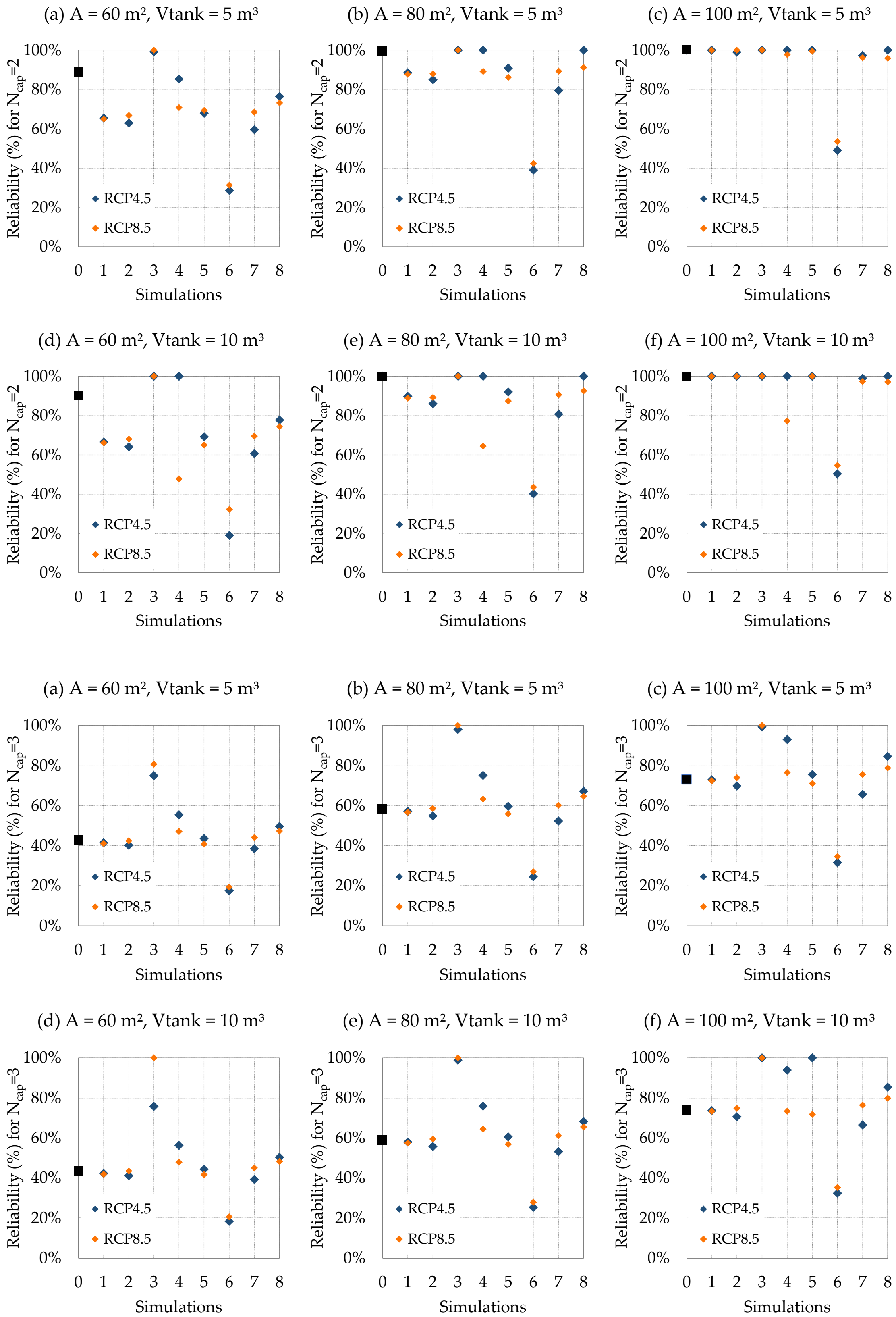


Figure 6. Rainwater harvesting system reliability based on historical period (0 simulation; black square symbol) and future period (1–8 simulations) under RCP 4.5 (blue diamonds) and RCP 8.5 (orange diamonds), for various combinations of rooftop area (A= 60 m^2 (**a**,**d**); A= 80 m^2 (**b**,**e**); and A = 1000 m^2 (**c**,**f**) and tank size (V= 5 m^3 (**a**–**c**); V= 10 m^3 (**d**–**f**)), considering a two- (**upper graphs**) and three-member household (**lower graphs**) on Fourni island.

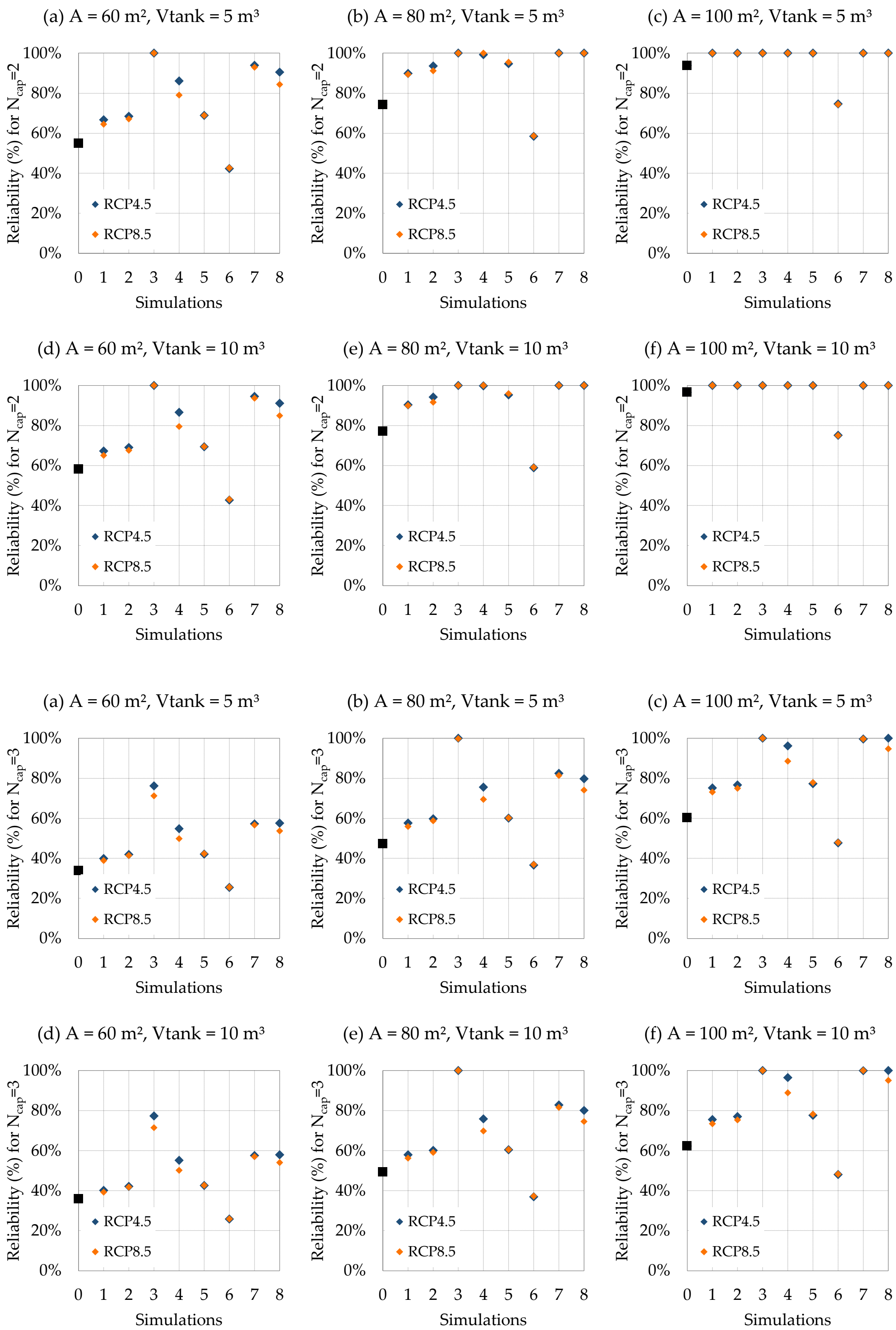


Figure 7. Rainwater harvesting system reliability based on historical period (0 simulation; black square symbol) and future period (1–8 simulations) under RCP 4.5 (blue diamonds) and RCP 8.5 (orange diamonds), for various combinations of rooftop area (A = 60 m^2 (**a**,**d**); A = 80 m^2 (**b**,**e**); and A = 1000 m^2 (**c**,**f**) and tank size (V = 5 m^3 (**a**–**c**); V = 10 m^3 (**d**–**f**)), considering a two- (**upper graphs**) and three-member (**lower graphs**) household on Nisyros island.

Investigating the reliability of RWH systems under various climate change scenarios generally aligns with the findings derived from historical daily rainfall data. Consistently, simulations conducted up to 2060 indicate a satisfactory performance of systems deployed in Fourni island, echoing the outcomes of the initial simulations. However, distinct trends emerge from the diverse simulations, characterized by different combinations of global climate models (GCMs) and regional climate models (RCMs), as outlined in Table 1. Notably, in most cases, the reliability of the systems improves under the RCP 8.5 scenario compared with RCP 4.5, likely due to the positive trends observed in daily rainfall across the majority of the simulated time series. Figures 6 and 7 depict the resulting reliability for all future projections and historical periods, facilitating comparative analysis and highlighting the significant variability among future estimates. With the exception of the sixth simulation (SMHI-RCA4, IPSL-IPSL-CM5A-MR), the results demonstrate satisfactory future performance, with some scenarios even exhibiting further improvement. Moreover, it becomes evident that, similar to the historical period, rooftop area predominantly influences system reliability. Consequently, among all the examined simulations, variability in system reliability diminishes as the collection area increases for both islands. Thus, confirming the findings based on the historical period, the RWH system under study demonstrates superior performance on Fourni island.

4. Conclusions

Urban design and planning have traditionally prioritized conventional water supply systems, overlooking the potential of rainwater harvesting (RWH) as a sustainable solution. However, amidst escalating concerns regarding water scarcity and environmental sustainability, there has been a notable paradigm shift. Increasingly, urban planners and policymakers are acknowledging the significance of RWH systems in alleviating water stress and bolstering resilience against the impact of climate change. As cities grapple with more frequent and severe droughts, floods, and other extreme weather events, the imperative to diversify water sources and embrace nature-based solutions such as RWH becomes increasingly evident. Furthermore, RWH systems offer not only water security but also myriad co-benefits, including mitigating stormwater runoff, relieving strain on aging infrastructure, and fostering green urban spaces. Thus, investigating the performance of RWH systems under climate change scenarios is imperative for informed decision-making and the formulation of sustainable urban development strategies.

In this study, a daily water balance model was employed to evaluate the reliability of an RWH system under evolving climatic conditions on two small islands in the Aegean Sea, Greece. The analysis of the variability in the RWH system's reliability underscored the significant impact of spatiotemporal rainfall variability on system performance. Notably, Fourni island necessitates a smaller storage volume compared with Nisyros, with results indicating superior performance when the collection area exceeds 100 m^2 for both islands, especially for two-member households. This highlights the environmental and economic advantages of RWH systems over traditional water supply methods. Further analysis, incorporating the influence of climate change on precipitation patterns and subsequent system performance, revealed considerable variability among estimates for smaller systems. Conversely, larger systems exhibited greater resilience, with consistently high performance across examined simulations.

In conclusion, the identification of discernible trends could profoundly affect the efficacy of an RWH system, albeit contingent upon the system's scale. Hence, the design of RWH tanks should integrate an assessment of future climate scenarios, particularly in regions such as islands, where rainfall patterns significantly diverge and impact RWH system performance. Additionally, while there is potential to meet higher water demand, demand patterns characterized by significant daily variations may necessitate more precise modeling. Ultimately, RWH systems can play a pivotal role in complementing conventional water supply systems. Therefore, incentives and governmental support may be pivotal in incentivizing householders to adopt RWH water systems in residential urban areas.

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