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Water conservation measures in buildings: a comparative study between rainwater harvesting and greywater use

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Portugal, a Mediterranean country in southwestern Europe, presents a worrying future concerning the availability of fresh water, essentially due to climate change. According to data from the Portuguese Institute of Meteorology (IPMA), the average annual temperature could rise by three degrees within two or three decades, and annual precipitation will reduce by between 20% and 25% in the territory. For the rational management of drinking water in urban areas, Portugal should adopt a fundamental principle called the "5R principle": Reduce consumption, reduce losses and inefficiencies, reuse water, recycle water, and resort to alternative sources. In order to achieve efficient use of drinking water in buildings and reduce consumption, installing efficient devices must always be the priority technical measure. Rainwater harvesting or using regenerated greywater is generally considered a complementary drinking water conservation measure. Typically, these non-potable waters have a potential for competitive uses (flush toilets, washing, etc.), so the simultaneous adoption of these two measures is generally not considered, although this is feasible. In this article, a comparative analysis is made between these two measures for a single-family house in the Central Region of Portugal, weighing technical, economic and sanitary aspects and considering the construction rules adopted in Portugal. For rainwater harvesting, a conventional system is considered, and for the use of treated (or regenerated) greywater, a building system for the use of treated greywater (or greywater recovery system) is considered. In either case, the uses considered for non-potable water will be the same: flush toilets, watering a small garden and washing clothes. The results show that the choice between these two drinking water conservation measures must be assessed in each specific situation, weighing the technical, sanitary and economic constraints.

KEYWORDS
rainwater harvesting, use of greywater, water efficiency, water conservation, sustainability

1 Introduction

"Global water crisis: the big issue of the 21st century." This phrase is a warning from the European Water Pollution Control Association (EWPCA), supported by many other entities, such as the World Water Council, which, in 1995, launched a serious warning about the global freshwater scarcity crisis (Saeijs and Van Berkel, 1995). A few years ago, the

UN also launched the International Decade for Action (2018–2028) under the theme "Water and Sustainable Development" (United Nations, 2016).

Portugal, a Mediterranean country in southwestern Europe, is an example of a country with a worrying future about the availability of freshwater due to climate change. According to data from the Portuguese Institute of Meteorology (IPMA), the average annual temperature could rise by three degrees within two or three decades, and annual precipitation will be reduced by 20% and 25%. Furthermore, this precipitation, although lower in total annual value, may occur more intensely and in shorter periods, causing an apparent contradiction: more significant periods of drought and more floods (Carvalho et al., 2013; Campos et al., 2017; European Environment Agency, 2021; European Commission, 2023; European Environment Agency, 2017; Trenberth, 2011; Wilby, 2007).

For rational drinking water management in urban areas, Portugal should adopt a fundamental principle called the "5R principle": Reduce consumption, Reduce losses and inefficiencies, Reuse water, Recycle water, and Resort to alternative sources (Silva-Afonso and Pimentel-Rodrigues, 2011; Silva-Afonso et al., 2011; Rodrigues et al., 2019; Pimentel-Rodrigues and Silva-Afonso, 2020; Pimentel-Rodrigues and Silva-Afonso, 2019; Silva-Afonso and Pimentel-Rodrigues, 2014). The order of these technical measures is not arbitrary. First, reducing consumption and losses must be considered, and then the reuse and recycling of water. These 3 "Rs" are generalizable for the management of other resources, but, in the case of water, a last measure is added (the resort to alternative sources), which essentially aims, in situations of scarcity, to avoid consumption of drinking water for uses that do not require this quality. Although it is the last of the five principles, it should not be the last one to be considered in a climate change scenario. On the contrary, the use of rainwater as an alternative source should become a priority in Portugal, due to its simultaneous benefits regarding water shortages resulting from drought and in controlling floods in urban areas.

In relation to rainwater harvesting systems in buildings (RWHS), conventional systems aimed at uses such as flush toilets, irrigating green areas, etc., are low-complexity solutions, although they must integrate several components (filters, cistern, etc.). For minor domestic uses, such as watering of small gardens, vegetable gardens or limited washing, the systems can be reduced to small, unburied reservoirs to collect limited volumes of rainwater, eliminating some components of conventional systems (Freni and Liuzzo, 2019; Akter et al., 2020; Pimentel-Rodrigues and Silva-Afonso, 2019). At the level of small settlements, condominiums or neighbourhoods, however, community solutions are beginning to be developed in several countries (such as Israel, China, etc.), aiming at integrated management of the reserve volumes installed in buildings to dampen extreme rainfall in the area, thus reducing possible urban flooding.

Regarding reuse and recycling, it should be noted that on a global scale, nature already recycles and reuses all water. However, recycling is not common in urban areas in residential buildings, although it can have a wide range of applications in industrial buildings. In relation to the reuse of water in urban areas, it can be considered at four levels: the "direct level" in bathrooms (using specific sanitary equipment, combining, for example, a washbasin with a flush toilet), the "building level" (in the building as a whole, implying longer retention periods), the "local urban" or "community level" (in condominiums, neighborhoods, etc.) and the "global urban level," within the scope of global public systems (reuse of effluents from Wastewater Treatment Stations for irrigating green areas or golf courses, for example) (Pimentel-Rodrigues and Silva-Afonso, 2022; Silva-Afonso and Pimentel-Rodrigues, 2023).

The reuse at the building level of effluents without *faecal* contamination after treatment or regeneration (water from bathtubs, showers, washbasins, etc., which are generically called light greywater or simply greywater) is currently experiencing some generalization. However, this development may comprise health risks, especially in buildings for collective use, such as student residences, hotels, etc. In fact, the lack of specific official regulations in many countries has led to some applications that have revealed potential risks to public health due to deficiencies in design, operation or maintenance. To face this problem, the European Commission recommended, in the so-called "Blueprint Water," creating a technical-sanitary certification for these systems, guaranteeing the existence of mechanisms for periodic control of the quality of reused water, safety plans and adequate maintenance. The European Standard EN 16941-2 (On-site non-potable water systems–Part 2: Systems for the use of treated greywater) points in the same direction (European Committee of Standardization, 2020a).

As previously mentioned, aiming for efficient use of drinking water in buildings and reducing consumption through installing efficient devices must always be the priority technical measure. This measure responds, in general, to a very significant potential for reducing consumption in most situations with very short investment payback periods. Studies carried out in Portugal point to an average potential for reducing consumption in existing buildings of around 30% just by replacing devices with more efficient ones or by adjusting flow rates or volumes through simple measures (installation of reducers or replacement with more efficient ones, etc.). The possibility of reducing losses (which, in buildings, can be significant in the case of flush toilets or buried irrigation systems) must also be the subject of analysis (Silva-Afonso and Pimentel-Rodrigues, 2011; Silva-Afonso et al., 2011).

As a complementary drinking water conservation measure, rainwater harvesting or the use of regenerated greywater is generally considered after reducing consumption, as mentioned previously. Typically, these two types of non-potable water have potential for competitive uses (flush toilets, washing, etc.), so the simultaneous adoption of these two measures is generally not considered, although this is technically feasible.

In this article, a comparative analysis is made between these two measures for a single-family house in the Central Region of Portugal, weighing technical, economic and sanitary aspects and considering the construction rules adopted in Portugal. For rainwater harvesting, a conventional system with a cistern is considered, and for the use of treated (or regenerated) greywater, a building system for the use of treated greywater (or greywater recovery system - GWRS) is considered. In either case, the uses considered for non-potable water will be the same, namely flush toilets, watering a small garden and washing clothes.

2 Materials and methods

2.1 Design of rainwater harvesting systems (RWHS)

In Portugal, the technical requirements for the design, sizing, installation, certification and maintenance of Rainwater Harvesting Systems are defined in the Technical Specification ETA 0701 (ANQIP, 2022), under the responsibility of the Portuguese association for the building sanitary sector (ANQIP–Portuguese Association for Quality in Building Installations). It should be noted that there is also a European Standard for RWHS, the European Standard EN 16941-1: 2024 (European Committee for Standardization, 2018), which is generally not followed in Portugal, as it is not particularly suitable for Mediterranean climates. This Technical Specification is complemented by another (ETA 0702), which establishes a technical-sanitary certification scheme for these systems, following the recommendations of the so-called "Blueprint Water" from the European Commission.

Precipitation studies must use data from official sources, and it is desirable that they use historical precipitation series corresponding to periods of no less than 10 years. On the official website of SNIRH (Portuguese Water Resources Information System) (Instituto Português do Mar e da Atmosfera, 2025), precipitation records are accessible in numerous locations throughout the territory for the different months of the year. Given the characteristics of the climate and the significant variability of daily precipitation values, it is considered appropriate to size the cisterns based on the available values of the average monthly precipitation in the installation area.

Given the prolonged summer droughts that characterize the climate in mainland Portugal, ETA 0701 recommends that the first waters (first flush) not be used for some uses or that a device be installed to divert the initial flow, preferably with automatic operation. According to ETA 0701, the volume of the first waters to be diverted can be determined based on the catchment area and a pre-established rainfall height, which can vary between 0 and 8 mm, depending on local conditions, uses and intervals between rains (in the absence of data or studies of local conditions, it is recommended to divert a minimum volume corresponding to 2 mm of precipitation, with a lower value being adopted in justified cases). When the deviation from the initial flow is done automatically, through control units, a time criterion may be adopted alternatively. When choosing the temporal criterion, after periods of prolonged drought, a minimum volume to be diverted corresponding to the first 5 min of precipitation must be considered, with lower values being able to be adopted depending on the interval between precipitations. In small systems, ETA 0701 allows a simplified procedure for accounting for first flush losses, which will be adopted in this study and explained later, consisting simply of considering a reduction in the percentage of roof water use that is considered viable.

Rainwater can be used for flush toilets, washing machines, washing floors or cars, watering green areas and other uses that do not require potable water (cooling towers, fire networks, etc.). For watering green areas, washing floors and flush toilets, rainwater may not need any additional treatment. It is recommended, however, that the water respects, at a minimum, the quality standards applicable to bathing water. The use of rainwater to wash clothes, without specific treatment, must be done in appropriate washing machines, available on the market, with an automatic system for managing the supply source (potable water or rainwater) throughout the washing process. It is also recommended to place a microfilter with a minimum mesh size of 100 μm in the rainwater supply (ANQIP, 2022).

ETA 0701 recommends that RHWS be equipped with a supplementary water supply system to ensure their continuous operation for the intended uses, even with a lack of precipitation. If the supply is carried out in the cistern, the device must consist of an intermediate reservoir fed directly from an alternative supply, with discharge into the cistern (Type AB protection device, following European Standard EN 1717, in the case of drinking water supply) (European Committee for Standardization, 2020b).

2.2 Design of greywater recovery systems (GWRS)

As in the case of RWHS, there has also been a Technical Specification (ETA 0905) for GWRS in Portugal since 2009, under the responsibility of ANQIP (ANQIP, 2024a). It should be noted that there is also a recent European Standard for these systems (the European Standard EN 16941-2:2021), which is not usually followed in Portugal, as it is more generalist than ETA 0905. ETA 0905 is complemented by another Specification (ETA 0906) (ANQIP, 2024b), which establishes a technical-sanitary certification scheme for these systems, as concerning RWHS, following the recommendations of the European Commission "Blueprint Water" (European Commission, 2012).

ETA 0905 establishes technical criteria for carrying out GWRS with a long retention period, but it can also be applied, by user decision, to systems with a short retention period in the applicable parts. According to ETA 0905, GWRSs with a short retention period correspond to compact sanitary appliances (combination of washbasin and flushing cistern, for example) and may also include simplified systems in compartments of single-family homes, generally with just one user or users of the same family. The other systems, in buildings for collective use and/or with commercized treatment equipment, are classified as GWRS with long retention times.

ETA 0905 focuses on health security concerns. It requires the preparation of a Security Plan, with the initial version being the installer's responsibility, but periodically updated by the user. This Safety Plan must include, at a minimum, the characterization of the installation, a risk assessment, the criteria for assessing the conformity of the quality of the regenerated water (justifying any differences to what is prescribed in the ETA) and the procedures in case of failure or serious problem (Action Plan).

The ETA presents several tables with the quality requirements of regenerated water for flush toilets, garden watering and washing, including maximum allowable values and tolerances. There is also a table with the periodicity of analyses in the different phases of the GWRS (start-up phase, current exploration phase and after prolonged stoppage or detection of serious problems).

2.3 The basis for the sizing of RWHS and GWRS

The house considered for the present study has four flush toilets, a 6 kg washing machine and a small lawn measuring 30 m^2. It is

TABLE 1 Sizing parameters for rainwater harvesting systems (ETA 0701) and total values.

Device or use	Unit consumption	Estimated monthly consumption	Total values
Flush toilets in homes	24 L/(person.day)	720 L/(person.month)	4 × 720 = 2,880 L/month
Washing machine (label "A")	10 L/(person.day)	300 L/(person.month)	4 × 300 = 1,200 L/month
Garden watering	450–800 L/m^2	(total from April to September)	450 × 30 = 13,500 L/year

TABLE 2 Average monthly precipitation and usable volumes of rainwater.

Month	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Average monthly precipitation (mm)	173	217	247	249	233	185	142	143	68	26	33	83
Usable volume of rainwater (m^3)	33.63	42.18	48.02	48.41	45,30	35.96	27,60	27.80	13.22	5.05	6.42	16.14

inhabited by a family of four people. It is considered that the dwelling is usually occupied for 11 and a half months (during August, the family generally takes a 15-day vacation away from the dwelling. The total area of roofs (impervious) is 270 m^2.

The sizing parameters for the RWHS were taken from the ANQIP Technical Specifications ETA 0701 and are summarized in Table 1. According to this Table, monthly values of 2,880 L (1,440 L in August) and 1,200 L (600 L in August) will be adopted respectively for flushing toilets and washing machines. For garden watering, ETA 0701 reports a minimum total consumption in lawns of 450 L per m^2 from April to September (months that generally require watering in Mediterranean climates). The total value of 13,500 L was divided differently over the 6 months, considering 3,000 L in the summer months (June, July, and August) and 1,500 L in the remaining 3 months of irrigation.

The volume of usable rainwater in a given period can be determined by the equation:

$$Va = C \times P \times A \times \eta f \quad (1)$$

where Va is the volume of usable rainwater (litres) in the period of time considered, C is the runoff coefficient (relationship between the volume collected and the total volume of precipitation in a given period of time), P is the height of the useful precipitation accumulated in the period considered (mm), A is the catchment area (m^2), and ηf is the hydraulic efficiency of the filter, i.e., the relationship between the useful volume that enters the cistern and the total volume collected (the difference between these volumes corresponds to the volume diverted by the filter, together with solids such as leaves, bird debris, etc.)

The average monthly precipitation in the area was taken from the official SNIRH website, as mentioned previously, and is presented in Table 2. These average values were calculated for the Castelo Burgães station (40.853°N; −8.379°W), the closest to the housing location, which currently presents data from 1937/38 to 1922/23 (Instituto Português do Mar e da Atmosfera, 2025), with 12 years of missing values, that is, with a total of 73 years of records. As is evident, there is a variability in monthly precipitation values from year to year, but the approximate criterion based on the average monthly value, considered in ETA 0701 and other international standards, has proven to be adequate. It should be noted that the European Standard EN 16941-1 allows for the possibility of carrying out these studies based on annual, monthly or daily values, but in Portugal, the SNIRH does not provide daily values for most stations.

Table 2 also indicates the usable volumes of rainwater, calculated according to Equation 1, considering a hydraulic efficiency (ηf) of 0.9 for the filter, a total collection area (A) of 270 m^2, and a coefficient of runoff (C) of 0.8 for the roof. Although the roof is made of impervious material, a value lower than 1.0 was adopted for C to consider, in a simplified way, the losses caused by the first flush deviation.

For greywater recovery systems, ETA 0905 establishes that domestic wastewater with a lower concentration of pollutants (called light greywater) must be considered as a priority for use. In residential buildings, these waters generally come from discharges from bathtubs, showers and sinks, but under certain conditions, discharges from washing machines or even wastewater from kitchens can also be considered (dark greywater). In the present case, only light greywater was considered. Regarding the availability of light greywater, ETA 0905 provides some indications. A production of 40 L per day and per person is referred to for buildings equipped with efficient devices. This value corresponds to around 4,800 L per month in the present case [40 L/(day and person) × 4 persons × 30 days/month = 4,800 L/month]. In the holiday month (August), only the value of 2,400 L/month will be considered.

3 Results and discussion

3.1 Technical aspects. availability vs. demand

In addition to the specific engineering aspects associated with each of these water efficiency measures for drinking water conservation, which will later be analyzed from an economic perspective, the most relevant technical considerations concern, in each measure, the balance between availability and demand. Based on the basic data mentioned in the previous chapter, it was possible to build Table 3, which compares the demand for non-potable water with the respective availability in each solution.

In either measure, availability does not meet demand in the warmer months. This situation essentially arises from the existence of watering in these months. In either case, by suppressing watering, availability would always exceed demand.

TABLE 3 Balance between availability and demand with RWHS or GWRS.

Month	Monthly demand				(RWHS) available volume of monthly rainfall	(RWHS) available volume - demand difference	(GWRS) volume available monthly	(GWRS) available volume - demand difference
	Flushes in toilets	Washing machine	Garden watering	Total monthly demand				
	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)
October	2.88	1.20	0.00	4.08	33.63	29.55	4.80	0.72
November	2.88	1.20	0.00	4.08	42.18	38.10	4.80	0.72
December	2.88	1.20	0.00	4.08	48.02	43.94	4.80	0.72
January	2.88	1.20	0.00	4.08	48.41	44.33	4.80	0.72
February	2.88	1.20	0.00	4.08	45.30	41.22	4.80	0.72
March	2.88	1.20	0.00	4.08	35.96	31.88	4.80	0.72
April	2.88	1.20	1.50	5.58	27.60	22.02	4.80	−0.78
May	2.88	1.20	1.50	5.58	27.80	22.22	4.80	−0,78
June	2.88	1.20	3.00	7.08	13.22	6.14	4.80	−2.28
July	2.88	1.20	3.00	7.08	5.05	−2.03	4.80	−2.28
August	1.44	0.60	3.00	5.04	6.42	1.38	2.40	−2.64
September	2.88	1.20	1.50	5.58	16.14	10.56	4.80	−0.78
Total	33.12	13.80	13.50	60.42	349.73		55.20	

Maintaining watering, however, the way to solve the problem of the deficit is different in both solutions. In the case of RHWS, a cistern with a volume close to 5 m^3 (a current commercial volume), as recommended by ETA 0701 for the values in question, easily allows the problem of the deficit in July to be resolved, at least in years with average precipitation, since storing part of the June surplus (6.14 m^3) will allow the July deficit to be covered.

In the case of GWRS, the problem of deficit in the warmer months can be solved by using effluents from the kitchen and dishwasher (dark greywater) and/or by supplying a regenerated greywater system with water from a resource source (such as the public network). In the first case, greywater treatment demands are higher than when only light greywater is treated, while in the second case, there are additional costs to be considered related to supply from another source. In these systems, the tank's volume must remain close to the volume used daily, as recommended by ETA 0905, which translates into a reduced value (200–250 L).

It is considered important to note the following:

a) In the case of RHWS, the Mediterranean climate generally causes critical situations in the summer months, mainly when watering occurs. In the present case study, this situation is not serious given the low occupancy of the building in August, the small green area and the relatively large roof area. In any case, it is important to note that the study is based on monthly rainfall averages, which present significant variability in terms of value and diagram of precipitation throughout the days of the month, meaning that the result does not guarantee that there will not be occasional shortages on some days of the month. In the event of exceptional and prolonged droughts (increasingly frequent in the Mediterranean climate), there may be a need to rely on a supply from the mains (or other alternative source) for several months;
b) In the case of GWRS, the system can work flawlessly in current situations, as long as there is a daily production of greywater (baths, sinks) and uses limited to the house's interior (flush toilets and washing machines) by the same users.
c) In the case of GWRS, there is a significant reduction in the volume of sewage in buildings, which does not occur with RHWS. This situation is apparently advantageous, but it can cause problems in the drainage and treatment of wastewater in receivers' public systems.
d) GWRS generally imply greater energy consumption (the energy consumption in the greywater treatment process is around 1.8 kWh/m^3). The treatment is not required in the case of rainwater. The additional energy consumption to pressurize the water is the same in both solutions.

3.2 Sanitary aspects

For RHWS, the ETA 0701 recommends the installation of an upstream filter with a mesh size of less than 1 mm and a device that reduces turbulence and reduces the speed of water entering the cistern, which should preferably be upward. Pumping suction must also be carried out at low speed and, when possible, between 10 and 15 cm below the water level in the cistern, using a floating inlet or through an equivalent system that does not allow the suction of floating waste or waste deposited at the bottom of the cistern. The Technical Specification states that RWHS, as carried out following

TABLE 4 Parameters to be analyzed and frequency of tests in the current operation in GWRS.

Parameters to be analyzed	Frequency of tests (in operation phase)
Legionella spp. (a sample mandatory in summer)	Biannual
Faecal streptococci (*Enterococci*)	Monthly
Faecal coliforms (*Escherichia coli*)	Monthly
Pseudomonas aeruginosa	Biannual
pH	Monthly
BOD_5	Monthly
Suspended solids	Monthly
Turbidity	Monthly
Ammonia nitrogen	Monthly
Total nitrogen	Biannual
Total phosphorus	Biannual
Residual chlorine (if chlorine is used in the greywater regeneration process)	Monthly

these recommendations, provides essential filtration, sedimentation and flotation treatments.

For watering green areas, washing floors, and flush toilets, rainwater may not require any additional treatment under these conditions. In any case, it is recommended that the water respects, at a minimum, the quality standards applicable to bathing water. In the case of toilet flushing, it is also recommended that a notice be placed advising that the lid must be closed before flushing.

About GWRS, the substances present in greywater generally result from personal hygiene products, detergents, hair, skin, dandruff particles and, eventually, dirt from clothes, and are easily biodegradable. Due to this biodegradability, treatment cannot be delayed too much, as decomposition processes involving sulphates and unpleasant smells can be triggered. As mentioned previously, water from showers and bathtubs is generally not very polluted, but washing machines tend to have a higher pollutant load, and kitchen water (sink and dishwasher) is even higher.

In GWRS, a risk assessment must be carried out to determine whether the system is safe and fit for purpose. The risk assessment must consider the effects of exposure and the potential impacts of the system on people, the environment and physical assets. The European Standard EN 16941-2 states that it is essential that greywater systems are designed to ensure that the non-potable water produced is fit for purpose and does not present undue health risks. The EN presents guidelines for bacteriological and physicochemical parameters in various uses, stating that each country can impose stricter values. In this sense, ETA 0906 indicates the requirements to be observed in Portugal regarding the use of regenerated greywater in buildings.

The parameters to be controlled vary according to their use. ETA 0905 indicates, for all possible uses in buildings, the parameters that must be controlled, the respective guidelines (maximum recommended values and maximum permitted values) and the frequency of tests during the start-up period, in regular operation and after a prolonged stop or detection of a severe failure. For the various uses considered in this case study, Table 4 indicates the set of parameters that must be controlled in regenerated greywater, as well as the frequency with which control analyses must be carried out in the operation phase. Table 4 shows that, to prevent risks to public health, analytical control must have a significant impact on the functioning of the GWRS, both in economic terms and in terms of interventions during the system's operation. It should be noted, however, that ETA 0905 allows the frequency of tests or the list of parameters to be analyzed to be less demanding, depending on the risk assessment. In any case, the need and importance of analytical control are often ignored or undervalued when opting to reuse water in buildings.

3.3 Economic aspects

The price of water in Portugal is relatively low in some regions. In the house considered for this case study, the annual cost of mains water does not exceed €500. On the other hand, the set of necessary tests indicated in Table 4 has an annual cost in Portugal of no less than €1,200. Even assuming that risk assessment in tiny single-family homes can significantly reduce the necessary analytical controls (changing, for example, the frequency of some analyses from monthly to biannual), it is difficult to predict a cost of less than €200/year.

Given that a GWRS can reduce network water consumption by around 40%, these figures show that GWRS may be of little interest from an economic point of view in regions where water from the mains has a low price. From the outset, its use will only be engaging in areas with high-priced water or shortages in public supply.

Regarding the initial investment costs for the two systems, some studies indicate additional costs in relation to traditional solutions (considering installing systems in the construction phase and not renovating an existing installation). The values indicated in Table 5 were provided by suppliers for the present case, after a market consultation by the owner.

Apparently, GWRS is more advantageous, but given that the main components of this system have a useful life of 15–20 years,

TABLE 5 Initial installation costs for the two systems.

System	Total costs, including equipment, cistern, additional pipework, etc. (€)
Rainwater harvesting system (RWHS)	9.10000
Greywater recovery system (GWRS)	7.60000

TABLE 6 Comparison of advantages and disadvantages between RWHS and GWRS in Mediterranean climates.

System	Greywater recovery systems (GWRS)	Rainwater harvesting systems (RWHS))s
Technical advantages	• Can ensure availability of non-potable water at all times, as long as only internal uses in the building are considered; • Reduces the volume of effluents from the building to the outside (although it can raise problems in the drainage and treatment of wastewater in public systems).	• Promotes water retention in buildings, dampening flood peaks in urban spaces or stormwater networks; • Technically simple system, recovering an ancient technology.
Technical disadvantages	• Not recommended for watering unless considered as single-use. • Treatment technology is not generally accessible to regular consumers, requiring maintenance by a specialized third-party entity.	• Foreseeable insufficiency of rainwater in the summer months; • Not recommended for watering unless a supply is accepted from an alternative source in the summer months or a cistern of suitable volume is considered.
Economic advantages	• Lower initial investment cost.	• Costs lower than GWRS considering the useful life of the installation; • Lower energy consumption compared to RWHS.
Economic disadvantages	• Costs higher than RWHS considering the useful life of the installation; • High analytical control costs; • Energy costs in treatment are similar to the total energy consumed in the public system per m^3 supplied.	• Higher initial investment costs compared to GWRS.
Sanitary advantages	• The demanding analytical control required has, as a counterpart, the minimization of health risks.	• Lower health risks compared to GWRS; • There is no need for analytical control requirements in current situations.
Sanitary disadvantages	• Relatively high analytical control requirements; • Higher health risks compared to RWHS; • Risk of cross-connections between potable and non-potable networks in systems without adequate execution control or certification.	• Risk of cross-connections between potable and non-potable networks in systems without adequate execution control or certification.

compared to 40–50 in RWHS (Santosh et al., 2019), it can be concluded that, in economic terms, RWHS is preferable. In general, current maintenance requirements (not including analytical control) do not differ significantly between the two solutions. Table 6 summarizes the main advantages and disadvantages of each system.

The joint installation of an RWHS and a GWRS is possible, but, as mentioned previously, it has no apparent advantages, given that the uses are competing and the cost is not very different from the sum of the investments in the two systems individually. Only the guarantee of permanent availability of non-potable water in a climate with prolonged droughts could, in some situations, justify this hypothesis.

4 Conclusion

Considering technical, sanitary and economic aspects, there is no obvious choice between installing a GWRS and a RWHS. The choice may depend on local precipitation patterns, sanitary requirements in the building, supply reliability from the mains, etc.

Generally, when permanent availability of non-potable water (or water not supplied by the public system) is desired, a GWRS may be the option. However, RHWS can also operate continuously if they have an alternative supply from the public network in months without rainfall or an adequate size cistern.

The use of GWRS or RWHS for watering green spaces in the Mediterranean climate must be carefully considered and is unlikely to be feasible. In the case of GWRS, where there is generally a balance between the production of light greywater and the use of regenerated water, irrigation must be provided mainly through additional supply to the system from the public network (which may not be very rational), unless the use of dark gray water is also considered. In the case of RHWS, watering in the warmer months, generally without precipitation, also significantly harms the system's viability.

In buildings that present significant health risks, such as healthcare buildings (hospitals, nursing homes, etc.), GWRS may not be a good economic option, due to the costs inherent in the analytical control requirements, which must necessarily be very demanding. In the case of RWHS in Mediterranean climates, the technical-economic optimization of the systems usually leads to the consideration of a supplementary supply from another source in the summer months, even without watering.

The widespread use of systems that use non-potable water inside buildings, especially GWRS, can entail significant health risks, especially in buildings for collective use. In this context, a serious gap stands out in many countries, which is the absence of specific legislation for these systems (only standards or specifications that are generally voluntary), which may imply potential risks to public health resulting from deficiencies in design, operation or maintenance.

Another gap that must be filled with the generalization of GWRS is the assessment of their impact on public sewage systems, since there are still few studies in this area. This negative impact can be seen in drainage networks, due to the reduction in flow rates, impairing the drainage of solids, or in waste water treatment plants (WWTP), since the flow to be treated is lower than the base flow considered for the sizing of the WWTP.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

CP-R: Conceptualization, Formal Analysis, Investigation, Methodology, Visualization, Writing – review and editing. AS-A: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft.

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Conflict of interest

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