



Sustainable analysis of rainwater harvesting in the context of water management: Artvin Çoruh University

Sürdürülebilir su yönetimi kapsamında yağmur suyu hasadının analizi: Artvin Çoruh Üniversitesi

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Abstract

Water is the essential source of life, and its sustainable management is a global priority. While increasing population and climate change threaten freshwater resources, rainwater harvesting (RWH) offers a significant alternative. This study investigated the technical, environmental, and economic feasibility of RWH systems at the Main and Seyitler campuses of Artvin Çoruh University (AÇÜ). Analyses were based on 2023 data for roof area, roof material, and water consumption obtained from the university's relevant departments, along with Artvin's annual rainfall amount (691.6 mm). Calculations showed that approximately 15148 m³ of rainwater could be collected annually on the campuses. This amount corresponds to about 42% of the total annual usage water (not potable) consumption (38239 m³), providing a volumetric reliability of 42.19%. This level of water saving corresponds to an annual monetary saving of approximately 630010 TRY (17746.78 \$) based on current tariffs. The total installation cost of the system, including tanks, filters, and pumps (excluding labor), was calculated to be approximately 11.63 million TRY (327608.73 \$). Based on this cost and the annual savings data, the system's initial investment is projected to have a payback period of approximately 19 years. These results indicate that the project is technically feasible, environmentally beneficial, and economically viable in the long term for AÇÜ.

Keywords: Water saving, Rain water harvesting, Sustainability, SWOT analysis, Cost analysis.

Öz

Su, yaşamın temel kaynağı olup sürdürülebilir yönetimi küresel bir önceliktir. Artan nüfus ve iklim değişikliği tatlı su kaynaklarını tehdit ederken, yağmur suyu hasadı (YSH) önemli bir alternatif sunmaktadır. Bu çalışma, Artvin Çoruh Üniversitesi'nin (AÇÜ) Merkez ve Seyitler yerleşkelerinde YSH sistemlerinin teknik, çevresel ve ekonomik uygulanabilirliğini araştırmıştır. Üniversitenin ilgili birimlerinden alınan 2023 yılı çatı alanı, çatı malzemesi ve su tüketim verileri ile Artvin'in yıllık yağış miktarı (691.6 mm) temel alınarak analizler yapılmıştır. Hesaplamalar, yerleşkelerde yıllık yaklaşık 15148 m³ yağmur suyu toplanabileceğini göstermiştir. Bu miktar, yıllık toplam kullanım suyu tüketiminin (38239 m³) yaklaşık %42'sini karşılayarak %42.19'luk bir hacimsel güvenilirlik sağlamaktadır. Bu oranda su tasarrufu, güncel tarifelerle yıllık yaklaşık 630010 TL'lik (17746.78 \$) bir mali tasarrufa denk gelmektedir. Sistemin tanklar, filtreler ve pompalar dahil toplam kurulum maliyeti (işgücü hariç) yaklaşık 11,63 milyon TL (327608.73 \$) olarak hesaplanmıştır. Bu maliyet ve yıllık tasarruf verileriyle, sistemin ilk yatırımını yaklaşık 19 yılda geri ödeyeceği öngörülmüştür. Bu sonuçlar, projenin AÇÜ için teknik olarak mümkün, çevresel açıdan faydalı ve uzun vadede ekonomik olarak değerlendirilebilir olduğunu göstermektedir.

Anahtar Kelimeler: Su tasarrufu, Yağmur suyu hasadı, Sürdürülebilirlik, SWOT analizi, Maliyet analizi.

1 Introduction

Water, an indispensable natural resource for the continuity of life on earth, has formed the basis of civilizations throughout history. Today, however, factors such as rapidly growing world population, industrialization, environmental pollution, unconscious consumption habits and climate changes due to global warming are putting unprecedented pressure on potable and usable clean water resources. The consumption of water before the water cycle can be completed in its natural course has made water scarcity a global problem and increased the strategic importance of water day by day. The fact that global water consumption has increased sixfold in the last 100 years [1] and that water scarcity was identified by the World Economic Forum as one of the world's top three risks in 2014 reveals the seriousness of the situation [2]. Global water demand, which is increasing by around 1% annually due to population growth, economic developments and changing

consumption patterns, is expected to accelerate further in the next two decades [3]. This picture forces countries to take urgent and effective measures on water management.

Water is a fundamental element not only for human life but also directly related to many critical areas such as energy production, food security, ecosystem health, economic development and national security [4],[5]. Increasing water demand in sectors such as agriculture, industry, urbanization and energy necessitates the development of sustainable water management strategies. In this context, the evaluation of alternative water resources is of great importance. Rainwater harvesting (RWH) is an ancient method based on the principle of collecting and reusing rainwater and runoff water [1].

Rainwater collected from rooftops, especially in urban areas, can be used for domestic (toilet reservoir, garden irrigation, etc.), industrial, agricultural and environmental purposes depending on the need for treatment.

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This method not only helps conserve limited freshwater resources but also offers the potential for economic savings in water bills by reducing municipal water consumption. It can also contribute to reducing the risk of flooding and flooding by managing surface runoff during heavy rainfall. There are successful RWH practices in Türkiye and including Siemens Gebze [6], Borusan Oto İstinye [7] and Konya Science Center [8]. The aim of this study is to analyze the feasibility of RWH in Artvin Çoruh University (AÇÜ) campus within the framework of sustainable water management principles. The study will calculate the potential network water savings that can be achieved by collecting and reusing rainwater at the university, assess the economic feasibility of the implementation and demonstrate its contribution to sustainability goals. With this analysis, in addition to providing a potential economic contribution to the university budget, it will also contribute to the sustainability goals of protecting water resources and leaving a sustainable environment for future generations.

2 Materials and methods

2.1 Working area

Artvin Çoruh University is a state university located in the Eastern Black Sea Region of Türkiye. Although the university has campuses in different locations, the largest and most centrally located campuses are the Central and Seyitler Campuses. The Central Campus is home to the administrative units of the Rectorate as well as important academic units such as the Faculty of Education, Faculty of Science and Letters, Faculty of Health Sciences and Vocational School of Health Services. There are also intensively used social and cultural facilities such as Nihat Gökyiğit Congress and Culture Center and Central Library (Figure 1) [9]. The main sources of current water consumption in AÇÜ Central Campus are the sanitary facilities (toilets and sinks) in the buildings (Table 1).



Figure 1. Artvin Çoruh University Central campus.

Table 1. Water consumption analysis 2023 (Centre).

			2023 - Water Consumption (3 Year Average)												
			Consumption(m³)												
No	Water Meter No	Building	January	February	March	April	May	June	July	August	September	October	November	December	TOTAL
1	948	Congress Cultural Centre	21	16	23	20	26	21	30	27	26	31	36	51	328
2	946	Faculty of Arts and Sciences	856	561	681	231	341	342	351	260	253	589	921	669	6055
3	949	Faculty of Education	687	186	301	302	492	461	450	890	433	1184	956	646	6988
4	1022	Central Library	270	49	240	118	186	24	30	9	0	97	176	97	1296
TOTAL			1834	812	1245	671	1045	848	861	1186	712	1901	2089	1463	14667

Seyitler Campus, another important campus of AÇÜ, is located approximately 3 kilometers from the city center. This campus is home to a wide range of academic and research programs. There are educational units such as the Faculty of Forestry, Faculty of Business Administration, Faculty of Tourism, Faculty of Sports Sciences, Faculty of Engineering, Institute of Graduate Studies and Artvin Vocational School. In addition, some specialized centers also operate on this campus which is a large Sports Hall with an indoor area of approximately 3500 m² on the campus (Figure 2). Water consumption in Seyitler Campus is realized in areas such as the use of toilets and sinks in buildings and cafeteria activities (Table 2).

2.2 Factors affecting rainwater harvesting

The viability of a rainwater harvesting system depends to a large extent on the region's rainfall amount and regime (distribution of rainfall over the year), the length of dry seasons, and the status of other available water sources. In particular, the distribution of rainfall over the year is a critical

factor in determining the extent to which RWH can compete with or supplement other water supply systems [10].

To develop an effective RWH and utilization project, the first step in the planning stage is to compare the amount of rainwater that can potentially be harvested with the demand in the area where this water will be used. The key elements that need to be considered in RWH projects can be broadly categorized into two main categories: first, the precipitation characteristics specific to the region where the project will be implemented (amount, frequency, intensity, etc.); and second, the technical components of the harvesting system to be used (collection area, storage volume, filtration, etc.).

2.2.1 Precipitation characteristics of Artvin province

Located in the Eastern Black Sea Region of Türkiye, the province of Artvin, especially the central district, is located in a climate zone showing transition characteristics from Black Sea climate to continental climate.



Figure 2. Artvin Çoruh University Seyitler campus.

Table 2. Water consumption analysis 2023 (Seyitler).

2023-Water Consumption (3 Year average)															
Consumption (m ³)															
No	Water Meter No	Building	January	February	March	April	May	June	July	August	September	October	November	December	TOTAL
1	1614	Seyitler	2530	2096	2311	1333	1399	1185	1583	2268	2420	1797	2301	2076	23299
2	1895	Campus	3	4	7	25	8	11	23	4	3	0	3	8	99
3	1998		0	0	0	0	0	0	174	0	0	0	0	0	174
TOTAL			2533	2100	2318	1358	1407	1196	1780	2272	2423	1797	2304	2084	23572

The average annual total precipitation of the region is 691.6 mm. Precipitation varies throughout the year, with the highest precipitation recorded in December (85.6 mm) and the lowest in August (29.1 mm). The average annual temperature is 12.4 °C. Looking at the seasonal distribution, the winter season is the period with the highest rainfall with 241.7 mm, while the summer season is the driest with 109.4 mm (Table 3). Artvin's rainfall regime is characterized by a pronounced summer drought and the wettest period coinciding with winter. The fact that the difference between spring and autumn precipitation is less than in the Mediterranean Region supports that the region is a transition type between the Mediterranean and Black Sea regimes [12].

2.2.2 System components

2.2.2.1 Roof material coefficient

Determining the amount of rainwater that can be collected from roofs, i.e. calculating the potential rainwater yield, is essential for the technical and economic analysis of harvesting projects. The main factors taken into account in this calculation are the total roof area, the average annual rainfall and the runoff coefficient, which varies according to the type of roof material. Based on meteorological data, the potential volume of rainwater that can be harvested can be estimated through the following Equation (1) [1][13][14]:

$$\Sigma W = A \times M \times \alpha \times \beta \quad (1)$$

- ΣW : Total rainwater harvesting (m³),
- Rainwater collection area (A): It refers to the total roof area (m²),
- Rainfall (M): Refers to the total annual rainfall (mm/m²),
- Roof coefficient (α): Indicates that not all rain falling on the roof surface can be recycled ($\alpha=0.8$ & $\alpha=0.9$),
- Filter efficiency coefficient (β): It is specified as 0.9 in German standards [13]. It is the efficiency coefficient of the first filter used for the separation of rainwater collected from the roof from solids. It is a coefficient determined by considering that a certain portion of rainwater cannot pass through the filter ($\beta = 0.9$) [15].

The roof coefficient is a critical variable in determining RWH potential. A dimensionless factor, it expresses how much of the total rainfall falling on a given collection surface can be collected by runoff and essentially represents collection efficiency. Its value depends on the physical characteristics of the surface (type of material, slope, roughness) and hydraulic conditions (rainfall intensity). Due to the inevitable losses in the collection process, it is necessary to use the runoff coefficient to calculate the actual amount of water that can be extracted from the roof. Reference runoff coefficients for various roofing materials are summarized in Table 4. Some structures within the university have metal roofing, while others have concrete roofing. In this research, $C=0.90$ for new metal roof surfaces and $C=0.80$ for concrete pavement roofs were adopted in the calculations.

2.2.2.2 Roof surface area

The total roof areas of the buildings in the Central and Seyitler campuses of AÇÜ and the potential amount of rainwater that can be collected annually from these areas are presented in Table 5.

2.2.2.3 Volume determination and tank selection for storage

The tank volume is a critical parameter that directly affects the initial investment cost of the system. In this study, the approach to determine the required storage volume is based on the maximum potential volume of water that can be harvested in the month of the year when the highest rainfall is expected (December). Therefore, the storage capacity of the system was calculated using the data of December, the wettest month, through Equation (2) [17].

$$V = A \times M_{max} \times \alpha \times \beta \quad (2)$$

Here

V: Required tank volume (L)

A: Rainwater collection area (m²)

M_{max}: Amount of precipitation for the month with the highest rainfall (mm/m²)

α : Roof coefficient

β : Filter efficiency coefficient

Table 3. Artvin annual precipitation data [11].

ARTVIN	January	February	March	April	May	June	July	August	September	October	November	December	ANNUAL
Measurement Period (1949-2023)													
Average Temperature (°C)	2.7	3.8	7	11.9	15.9	18.8	20.9	21.2	18.3	14.2	9.1	4.5	12.4
Average Rainy Days	13	12.76	13.56	12.79	14.13	12.79	8.24	8.17	8.61	10.99	11	11.73	137.8
Total Monthly Rainfall Amount (mm)	84.6	71.5	60.8	53.2	53.1	49.2	31.1	29.1	37.9	60.4	75.1	85.6	691.6

Table 4. Runoff coefficient of rainwater collection surface [16].

Roof Material Coefficient	
Water Retention Surface	Flow Coefficient
Tiles	0.75-0.90
Old Tiles	0.75-0.80
New Tiles	0.80-0.90
Metal Roofs	0.70-0.90
Old Metal Roofs	0.70-0.80
New Metal Roofs	0.80-0.90
Coatings	0.50-0.80
Concrete Coating	0.60-0.80
Brick Coating	0.50-0.60
Floors	0.01-0.30
Sloping ground floor (uncompressed) less than 10%	0.01-0.10
Sloping ground floor (compressed) less than 10%	0.15-0.30
Natural Rock Flooring	0.20-0.50
Green Fields	0.05-0.10

Table 5. Center and Seyitler campus roof areas.

Central Campus		Seyitler Campus		Roof Area m ²
C1 Block Education Faculty Classroom	1249	Forest Faculty		4584
C2 Block Faculty of Health Sciences Classroom	1249	Engineering Faculty		1085
C4 Block Faculty of Health Sciences Offices	597	Artvin MYO		1085
C5 Block Canteen Building	494	Social Indoor Facility		2683
C6 Block Education Faculty Offices	713	Indoor Gym		2744
A1 Block Faculty of Arts and Sciences Classroom	1249	Building Works		291
A2 Block Health MYO Classroom	1249	Research Laboratory		967
A4 Block Health MYO Offices	597	Furniture Workshop		1720
A5 Block Rectorate Canteen	494	Greenhouse		252
A6 Block Faculty of Arts and Sciences Offices	713			
Congress Center	2248			
Central Library	875			

The tank volume calculation (Equation 2) is based on December data ($M_{max} = 85.6$ mm), which is the month with the highest annual monthly rainfall in Artvin province. The tank volume determined as a result of this calculation is a factor that significantly affects the cost of the system, as storage tanks are usually the most costly component in any rooftop collection system. Therefore, selecting the most appropriate tank type is critical. The shape, size, material and location of the tank must meet the functionality as well as be in aesthetic harmony with its surroundings. There are tanks of different shapes and capacities made of various materials such as polyethylene, polyester (fiberglass) and metal, which are widely available in the market [18].

2.2.2.4 Considerations in selecting a suitable tank

Water tanks usually constitute the most important item of investment in rainwater storage systems. Despite the initial cost, the system is expected to pay for itself thanks to the savings that will be achieved over time by using the stored rainwater instead of municipal water. However, not only the economic payback period but also the long-term environmental impacts should be taken into consideration when selecting a storage tank. Choosing a long-lasting, durable material with minimal environmental impact will reinforce the project's contribution to sustainability and a clean future.

Determining the optimum tank size and type requires a careful analysis of the following key factors:

- Rainwater potential and system reliability: The amount of water that can be harvested based on the regional rainfall regime and the effective roof area where rainwater will be collected, and the percentage of this amount that meets the targeted water demand (% reliability).
- Total water demand: The total amount of water required for the applications that the system will serve (e.g. toilet reservoirs, garden irrigation, car washing, etc.).
- Physical space constraints: The dimensions and location of the physical space available for the placement of the storage tank.
- Integration with mains water: The state of the existing municipal water infrastructure and whether or how the stormwater system will be supported or integrated with municipal water as needed.

An integrated assessment of these factors allows for designing a storage solution that is both technically efficient and economically viable.

2.2.2.5 Volumetric reliability analysis

Volumetric reliability refers to the probability of a storage system to meet the water demand of users in a given time period [19]. In this study, volumetric reliability for water consumption for general use is calculated by dividing the amount of rainwater supplied (and consumed) by the system

by the total water demand that is intended to be met. Equation (3) was used for this calculation.

Rv: Volumetric reliability is ratio of available rainwater supply to demand

$$Rv = (Water\ Supply / Water\ Demand) \times 100 \quad (3)$$

3 Findings

3.1 SWOT analysis

The analysis conducted in this study to assess the potential of a rainwater harvesting system on the AÇÜ campus revealed the strengths, weaknesses, opportunities and potential threats of the project. This analysis provides a comprehensive perspective on the feasibility and sustainability of the project:

3.1.1 Strengths (S):

o **High rainfall potential:** The fact that Artvin province receives annual precipitation above the average of Türkiye is the most important strength that forms the basis of the project. This provides a favorable natural condition for RWH and storage.

o **Significant water savings:** Calculations have shown that approximately 15148.13 m³ of rainwater can be collected annually on the AÇÜ campus. With a volumetric reliability rate of 42.19%, it is estimated that an average annual saving of 42% in municipal water consumption can be achieved if the system is commissioned. However, achieving this 42% savings depends on the collected volume being used for non-potable water (e.g., toilets and cleaning). Since sanitary and cleaning uses generally account for the majority of water consumption in educational buildings, this target can be achieved provided that the plumbing lines are separated.

This is a significant gain in both environmental and economic terms.

o **Natural and clean resource:** Rainwater is a natural and relatively clean alternative suitable for many uses (toilet reservoirs, garden irrigation, car washing, etc.) with proper collection and simple filtration methods.

o **Reduced load on the network:** The use of collected rainwater will reduce the demand on the municipal water network [1].

o **Potential to reduce flood risk:** Controlled collection of roof water, especially during heavy rainfall, can reduce the risk of localized flooding by reducing runoff.

o **Simple system structure:** RWH systems are generally relatively simple to install and operate, requiring no complex technology or constant monitoring.

o **Sustainability:** While there are good examples of sustainability around the world, awareness is beginning to grow in Türkiye that sustainability can be achieved.

3.1.2 Weaknesses (W):

o **High initial investment cost:** The most prominent weakness of the project is the high initial investment cost due to the fact that the system will be integrated into the existing buildings later.

o **Long payback period:** In the feasibility analysis, it is calculated that the system will pay back the initial investment

cost in a long period of approximately 19 years. This reduces the short-term economic attractiveness of the project.

o **Lack of awareness:** The lack of awareness of rainwater as a valuable and reusable resource in Türkiye in general could be a barrier to adoption and support for the project.

o **Acceptability:** Despite awareness of RWH systems and examples of their implementation, a lack of acceptability has been observed. Users prefer traditional methods over implementing RWH systems that are open to development.

o **Reinforcement challenges and water quality:** Collected rainwater can only be treated and used for non-potable purposes. Since potable water is required for sinks and cafeterias, it must be completely separated from the rainwater network. Installing a dual plumbing system in existing buildings to supply both potable water and water for other purposes may be technically and economically challenging.

o **Legislative inadequacy:** The fact that the legal framework for the integrated management of water in terms of quantity and quality and specific legislation to promote or regulate RWH is not yet fully established in Türkiye is an uncertainty for the long-term management and expansion of the project.

The Regulation on Rainwater Collection, Storage and Discharge Systems in Türkiye was published in the Official Gazette by the Ministry of Environment Urbanization (the number 30105 and the date 23.06.2017).

The types of RWH systems are listed in Appendix 1 of the regulation. In the section, BS 8515 (2009) standard provides information on the design, installation, testing, and maintenance of RWH systems used for water consumption purposes. The BS 8515 (2009) standard covers topics related to the supply of rainwater for domestic water (such as washing water, toilet water, and garden irrigation water, which are not expected to meet drinking water quality standards) and for domestic, commercial, etc. water needs in industrial and public areas. This standard does not include provisions for water requirements related to drinking, food preparation and cooking, dishwashing, and personal hygiene. Although there are no specific provisions regarding the use of rainwater as firefighting water or commercial irrigation water, these areas are excluded from the scope of the standard [20].

3.1.3 Opportunities (O):

o **Long-term sustainability and resource security:** Despite the 19-year payback period, the fact that rainwater is a natural and renewable resource means that it will provide a continuous benefit (water savings) throughout the operational life of the system. This provides a safeguard against water costs and the risk of water scarcity in the long term.

o **Sustainability awareness and education:** The realization of the project will be a concrete example and educational tool for university students, staff and the local community on sustainability, water conservation and environmental awareness. This awareness that will be passed on to future generations is an opportunity beyond the monetary value of the project. Furthermore, the visibility of such green systems transforms the university into a 'living lab,' strengthening social sustainability. This transformation encourages a behavioral shift among students regarding water consumption habits and establishes the university as a social role model,

inspiring the local community in Artvin to adopt climate-resilient practices.

o **A model project for Artvin:** The fact that this is a pioneering RWH project to be implemented on the university campus in the city of Artvin has the potential to set an example for local governments and other institutions. This is an important opportunity to contribute to the city's sustainability vision.

o **Increased environmental awareness and technological developments:** Increased environmental awareness in society can facilitate the acceptance and support of such projects. Furthermore, artificial intelligence and other technological advances may enable the development of more efficient and intelligent RWH systems in the future.

o **Indirect contribution to reducing grid losses and leakages:** By reducing network water use, it can indirectly contribute to overall water management efforts and potential improvements to reduce leakage rates.

3.1.4 Threats (T):

o **Difficulty in recruiting qualified personnel:** Finding personnel with sufficient technical knowledge and skills for maintenance and repair activities, which are critical for the sustainability of the project, may be a challenge in a smaller and geographically isolated province such as Artvin. This is a potential threat to the longevity and efficiency of the system.

o **Impacts of climate change:** Potential impacts of global climate change on precipitation regimes could affect the long-term performance and reliability of the project.

o **General water stress and pollution increase:** Increasing overall water demand and pollution due to rapid population growth, urbanization and industrialization increase the pressure on clean water resources, increasing the importance of alternative sources such as rainwater, although atmospheric pollution may adversely affect rainwater quality and require additional treatment.

This SWOT analysis shows that the RWH project at AÇÜ has significant potentials, but also risks that need to be taken into

account, particularly the high initial investment cost and difficulty in finding qualified personnel. The project's long-term sustainability benefits and exemplary potential offer significant opportunities to overcome its weaknesses and threats through careful planning and management.

3.2 Annual rainwater harvesting amount on campuses

Table 6 shows the potential amount of rainwater that can be collected annually for the Central and Seyitler campuses of AÇÜ.

3.3 Storage volume and tank selection

Following the calculation of the potential amount of rainwater that can be collected from the roofs of the buildings, another critical step of the system, the determination of the storage tank volume, was carried out. In this study, the required storage volume was calculated based on the data for December ($M_{max} = 85.6$ mm), the month with the highest monthly rainfall recorded for Artvin province. When designing the storage solution, the shape, size, material and location of the tanks need to be carefully considered in terms of environmental impact and visual harmony.

Depending on the available space and technical requirements, different configurations can be considered for tank placement, such as reducing the tank height and increasing the floor area, increasing the height and reducing the area, or using multiple small tanks in a modular structure instead of a single large tank.

Considering the amount of rainwater collected and the structure of university campuses, the most appropriate approach for this study was to install separate storage tanks to serve each building. For buildings where the calculated storage volume exceeds 100 m³ (100 tons), multiple tanks of standard sizes (e.g. 100 tons) were considered instead of one large tank for ease of operation and installation. For example, the required storage volume for the Faculty of Forestry at Seyitler Campus is planned to be met with a combination of 3 piece 100 ton and 1 piece 20 ton tank. The number and sizes of tanks proposed for each location are detailed in Table 7.

Table 6. Amount of rainwater that can be collected in the campuses.

Central Campus	Collectable Rainwater (m ³)	Seyitler Campus	Collectable Rainwater (m ³)
C1 Block Education Faculty Classroom	699.68	Forest Faculty	2567.94
C2 Block Faculty of Health Sciences Classroom	699.68	Engineering Faculty	607.81
C4 Block Faculty of Health Sciences Offices	334.44	Artvin MYO	607.81
C5 Block Canteen Building	276.74	Social Indoor Facility	1503.01
C6 Block Education Faculty Offices	399.42	Indoor Gym	1537.18
A1 Block Faculty of Arts and Sciences Classroom	699.68	Building Works	163.02
A2 Block Health MYO Classroom	699.68	Research Laboratory	541.71
A4 Block Health MYO Offices	334.44	Furniture Workshop	963.54
A5 Block Rectorate Canteen	276.74	Greenhouse	141.17
A6 Block Faculty of Arts and Sciences Offices	399.42		
Congress Center	1259.32		
Central Library	435.71		
TOTAL	6514.95		
		8633.18	15148.13

Table 7. Tank quantities.

Central Campus	Tank quantity	Seyitler Campus	Tank quantity
C1 Block Education Faculty Classroom	1 piece 90 tonne	Forest Faculty	3 pieces 100 tonnes + 1 piece 20 tonnes
C2 Block Faculty of Health Sciences Classroom	1 piece 90 tonne	Engineering Faculty	1 piece 80 tonnes
C4 Block Faculty of Health Sciences Offices	1 piece 45 tonne	Artvin MYO	2 pieces 80 tonnes
C5 Block Canteen Building	1 piece 35 tonne	Social Indoor Facility	2 pieces 100 tonnes
C6 Block Education Faculty Offices	1 piece 50 tonne	Indoor Gym	2 pieces 100 tonnes
A1 Block Faculty of Arts and Sciences Classroom	1 piece 90 tonne	Building Works	1 piece 25 tonnes
A2 Block Health MYO Classroom	1 piece 90 tonne	Research Laboratory	1 piece 70 tonnes
A4 Block Health MYO Offices	1 piece 45 tonne	Furniture Workshop	1 piece 100 tonnes + 1 piece 20 tonnes
A5 Block Rectorate Canteen	1 piece 35 tonne	Greenhouse	1 piece 20 tonnes
A6 Block Faculty of Arts and Sciences Offices	1 piece 50 tonne		
Congress Center	1 piece 100 tonne		
	+1 piece 60 tonne		
Central Library	1 piece 60 tonne		

3.4 Volumetric reliability analysis

Volumetric reliability indicates the probability that a storage system will meet users' water demand within a specific time period [19].

The volumetric reliability of water consumption was calculated by dividing the amount of rainwater provided by the system by the total water demand to be met.

Table 8 shows the monthly water consumption for toilets and general use at the Central and Seyitler campuses of AÇÜ and the potential efficiency (volumetric reliability) of RWH in meeting this consumption. Volumetric reliability values are calculated using Equation (3).

The calculations revealed significant seasonal variations in RWH potential and system efficiency. Especially in August, which is the hottest and driest period, the volume of rainwater collected decreases due to the decrease in rainfall. This, combined with the relatively high-water consumption during the same period, leads to a decrease in the volumetric reliability (Rv) value, which indicates water saving efficiency. On the contrary, the highest Rv values were obtained in December, when rainfall reaches its maximum despite high consumption. On an annual basis, the calculated data indicates an average volumetric reliability of 42.19% for both settlements. This indicates that the rainwater harvesting system has the potential to cover a significant portion of the total annual water consumption and can provide significant water savings. The calculated 42% water saving potential is consistent with international studies conducted in university settings. For instance, a study on a university building in Brazil reported potable water savings ranging from 49.7% to 72.4% [21]. Similarly, research at Wachemo University in Ethiopia indicated that harvested rainwater could meet approximately 51% of the annual water demand [22], and a study at Settat University in Morocco demonstrated savings of over 50% [23].

Furthermore, the calculated 42.19% reliability is volumetrically achievable because the water demand in educational buildings is dominated by non-potable uses. Literature indicates that sanitary (toilet flushing) and cleaning purposes typically account for 60-70% of total water consumption in schools and office buildings [24],[25]. Therefore, the harvested rainwater volume (42%) can be fully

utilized within the campus for these specific purposes, provided that a dual-plumbing system is retrofitted.

3.5 Budget saved

Cost analysis is a critical factor when deciding on the feasibility of a RWH system. The basis of this analysis is to determine the amount of potential water savings that the system will provide, which is calculated in this section of the study using Equation (4) [10]. To determine the economic value of the calculated savings, the water tariffs applied by Artvin Municipality, which vary according to the building function, were taken as a basis. The tariff for public institutions such as AÇÜ is set at 41.59 TL/m³ (approximately \$1.17/m³), including the wastewater fee. This amount is the 2024 tariff rate public buildings and universities. Also, the dollar exchange rate has been included in the calculations based on the average of the last three months of 2024, when the calculations began. This approach was considered because a fixed amount cannot be clearly determined in an inflationary process. This unit price was used to calculate the potential financial savings of the system.

$$S = Vh \times Wt$$

$$S = 15148.31 \text{ m}^3 \times 41.59 \frac{\text{TL}}{\text{m}^3} \quad (4)$$

$$S = 630010.73 \text{ TL } (\$17746.78)$$

S: Saved cost

Vh: the amount of rainwater collected in cubic meters (sum of Seyitler and Central Campus),

Wt: Water tariff in m³ including taxes for institutions in Artvin

3.6 Cost analysis

RWH systems at AÇÜ's Central and Seyitler campuses offer significant potential to reduce the university's water bills and create an additional water source for a reasonable investment. The realization of this system will not only bring economic and environmental benefits to the university, but also set a pioneering example of sustainable water management for the city of Artvin.

For this potential to become a reality and for the project to succeed, it is critical that the university administration and relevant decision-makers take the necessary steps to embrace such projects with high sustainability value

Table 8. Volumetric reliability for Central and Seyitler campus.

Months	Monthly Rainfall Amount(mm)	Central Campus	Seyitler Campus	Average %
		Volumetric Reliability Rv (%)	Volumetric Reliability Rv (%)	
January	84.6	46.72	41.69	
February	71.5	89.19	42.50	
March	60.8	49.46	32.74	
April	53.2	80.31	48.90	
May	53.1	51.47	47.11	
June	49.2	58.77	51.35	
July	31.1	36.59	21.81	
August	29.1	24.85	15.99	
September	37.9	53.92	19.53	
October	60.4	32.18	41.96	
November	75.1	36.41	40.69	
December	85.6	59.26	51.27	
Annual	691.6	47.76	36.62	42.19

In the cost analysis of the RWH system, the most important item is the storage tanks. The selection of these tanks and other necessary components (filters, piping, etc.) depends on the purpose for which the collected water will be used. In the case of the university buildings, since rainwater is intended to be used for toilets and cleaning, the system components have been determined in accordance with this purpose. (Note: Since campus irrigation is done with well water, it is not included in the cost of this system). In order to determine the tank costs, polyester, above ground, horizontal type water tanks of Izoplas company was examined and the detailed cost table based on these data is presented in Table 9.

In order to ensure that the collected water is of suitable quality for the specified purposes, the criteria specified in the "Regulation on Rainwater Collection, Storage and Discharge Systems" [20] were taken as basis. This regulation stipulates that water must be filtered before entering the tank to prevent the accumulation of solids in the tanks. The filter must have a minimum filtration efficiency of 90%, preventing the passage of solids larger than 1.25 mm [20]. For this reason, it is envisaged to place a vortex filter in the piping system between the rainwater collection channel in the buildings and the water tank. 28 stainless steel vortex filters were selected to filter rainwater and separate solids such as leaves, stones, etc. from the water. To meet this requirement, stainless steel vortex filters that separate coarse particles such as leaves and stones from the water were installed between the rainwater collection channel of each building and the storage tank. Vortex filter cost is given in Table 10.

Pressurization is required to deliver the stored water to the points of use in the buildings. submersible pumps are the equipment used to raise the water in the tank into the building by pressurising it. In order to transfer the water from the tanks to the building network, 28 stainless clean water submersible pumps added to the system. A submersible pump with a delivery capacity of 6000 L/hMax, a delivery head of 45 mMax and a submergence depth of 12 mMax was selected. The cost of the equipment is given in Table 11.

Considering that rainwater will be used in areas such as toilets and cleaning, and that there is a risk of odor formation due to microbial activity during the storage period in tanks, it is deemed appropriate to integrate sand filters and activated carbon filter units into the system as an additional treatment stage. Although these filters represent an additional cost

factor, they are considered necessary to maintain water quality and prevent odor problems in similar applications.

Furthermore, to maintain water quality in the tank, ensure efficient system operation, and prevent odors that may develop over time, a sand filter and activated carbon filter, along with an inlet flow regulator (calming inlet), overflow siphon, and surface suction filter (floating filter) have been integrated into the system. These components are included in the cost items as a "rainwater set." The rainwater set to be placed in the storage tank constitutes a cost item. The cost of the storage tank's internal materials is provided in Table 12.

The total system investment cost was calculated for AÇÜ Central and Seyitler Campuses by summing the costs of all these components (excluding installation labor). This total cost forms the basis of the payback period analysis, the details of which are presented in Table 13.

Finally, the payback period is calculated to assess the economic feasibility of the proposed RWH system. This analysis is done to determine how long it takes to recover the total installation cost of the system through annual monetary savings (reduced water bills). Payback period is a key indicator used to understand whether a project is economically attractive; a shorter payback period usually means a more attractive investment. Although the RWH system consists of many components such as tanks, pumps, filters, etc., the payback period calculation is based on the total initial investment cost detailed in the previous sections. By dividing this cost by the monetary value of the estimated annual water savings that the system will provide, the payback period is determined using Equation (5). The total system cost refers to the total construction cost, but labor costs have been omitted.

$$\text{Payback Period} = \frac{\text{Total System Cost}}{\text{Amount saved per year}}$$

$$\text{Payback Period} = \frac{11630110.00}{630010.73} \quad (5)$$

$$\text{Payback Period} = 18.46 \text{ year} \sim 19 \text{ year}$$

The calculated payback period of approximately 19 years for the AÇÜ campus falls within the broader range reported in international literature, though it leans towards the longer end due to retrofitting costs.

Table 9. Tank cost [18].

Volume	Quantity	Unit Price (TL)	Total Price (TL)
100	9	500 000	4 500 000
90	4	460 000	1 840 000
80	2	400 000	800 000
70	1	340 000	340 000
60	2	265 000	530 000
50	2	215 000	430 000
45	2	202 000	404 000
35	2	145 000	290 000
25	1	126 000	126 000
20	3	100 000	300 000
TOTAL	28	2 753 000 (77549.29 \$)	99 560 000 (269295.77\$)

Table 10. Filter cost [26].

Buildings	Vortex filter quantity	Unit Price (TL)	Total Price (TL)
C1 Block Education Faculty Classroom	1	33150.00	33150.00
C2 Block Faculty of Health Sciences Classroom	1	33150.00	33150.00
C4 Block Faculty of Health Sciences Offices	1	15550.00	15550.00
C5 Block Canteen Building	1	8800.00	8800.00
C6 Block Education Faculty Offices	1	15550.00	15550.00
A1 Block Faculty of Arts and Sciences Classroom	1	33150.00	33150.00
A2 Block Health MYO Classroom	1	33150.00	33150.00
A4 Block Health MYO Offices	1	15550.00	15550.00
A5 Block Rectorate Canteen	1	8800.00	8800.00
A6 Block Faculty of Arts and Sciences Offices	1	15550.00	15550.00
Congress Center	2	33150.00	66300.00
Central Library	1	15550.00	15550.00
Forest Faculty	4	33150.00	132600.00
Engineering Faculty	1	33150.00	33150.00
Artvin MYO	1	33150.00	33150.00
Social Indoor Facility	2	33150.00	66300.00
Indoor Gym	2	33150.00	66300.00
Building Works	1	8800.00	8800.00
Research Laboratory	1	15550.00	15550.00
Furniture Workshop	2	33150.00	66300.00
Greenhouse	1	8800.00	8800.00
TOTAL	28	493150.00 (13891.5 \$)	725200.00 (20428.17 \$)

Table 11. Submersible pump cost [27].

Quantity	Unit Price (TL)	Total Price (TL)
28	13625 (383.80 \$)	381500 (10746.48 \$)

Table 12. Rain set, sand and active carbon filter [28].

Model	Quantity	Unit Price (TL)	Total Price (TL)
Rain set 3000	18	17400.00	313200.00
Rain set 0200	6	13100.00	78600.00
Rain set 0150	4	9800.00	39200.00

Table 12. Continued.

Model	Quantity	Unit Price (TL)	Total Price (TL)
Sand Filter (100 person)	4	13890.00	55560.00
Sand Filter (50 person)	13	12100.00	157300.00
Sand Filter (10 person)	4	11220.00	44880.00
Active Carbon Filter (100 person)	4	15650.00	62600.00
Active Carbon Filter (50 person)	13	12790.00	166270.00
Active Carbon Filter (10 person)	4	11450.00	45800.00
TOTAL	70	117400.00 (3307.04 \$)	963410.00 (27138.30 \$)

Table 13. Total system cost.

Tank Cost	9 560 000 (269295.77\$)
Submersible Pump Cost	381 500 (10746.48 \$)
Vortex Filter Cost	725 200 (20428.17 \$)
Rain Set Cost	963 410 (27138.30 \$)
TOTAL	11 630 110 (327608.73 \$)

For comparison, a university building study in Brazil reported a payback period of 8–9 years [21], while a large office building in the UK demonstrated periods between 6 and 11 years depending on tank optimization [24]. In contrast, a study at Settat University in Morocco calculated a remarkably short payback period of 3.25 years due to integrated alternative techniques and high water tariffs [23]. The relatively longer period in the study is attributed to the high initial investment required for retrofitting existing buildings with dual-plumbing systems and large storage tanks, a challenge less prominent in new constructions.

This study analyzed the feasibility of RWH systems at AÇÜ Central and Seyitler campuses from technical, environmental and economic perspectives. The findings show that the project offers significant water saving potential, but there are cost considerations that need to be taken into account.

From a technical perspective, Artvin's annual rainfall (691.6 mm), which is above the average for Türkiye, provides a favorable climatic background for RWH. Calculations show that approximately 15148 m³ of rainwater can be collected annually from existing roof areas. This potential, when assessed with appropriate collection (vortex filters), storage (polyester tanks in calculated volumes) and distribution (submersible pumps, additional filters) systems, can play an important role in reducing the university's municipal water consumption, especially for toilets and cleaning. Adopting filtration and storage methods that comply with the regulations will ensure that the collected water is of sufficient quality for the intended uses [20].

The environmental and sustainability benefits of the system are clear. The calculated average volumetric reliability (Rv) of 42.19% means that a significant portion of the annual water consumption can be met with rainwater, a renewable resource. This will reduce both pressure on the limited and costly to treat municipal water supply and reduce the ecological footprint of the university. Furthermore, the implementation of the project will serve as a tangible educational tool to raise awareness of water conservation and sustainability among students and staff.

The economic analysis of the project is the focus of the discussion. The most important weakness of the system is the high initial investment cost due to the fact that it will be integrated into the existing structure of the university buildings. The storage tanks constitute the majority of this cost. The payback period analysis based on the calculated public institution water tariff of 41.59 TL/m³ (including wastewater) is approximately 19 years. Although this may seem long at first glance, the Ministry of Agriculture and Forestry, General Directorate of Water Management has stated that payback periods of 20 years or less is an acceptable threshold for micro-scale RWH systems [16]. In this context, the calculated payback period of 19 years for AÇÜ indicates that the project is economically viable (efficient/profitable) in the long term perspective. Given that the university is a permanent institution and will operate for many years to come, an investment that will pay for itself in 19 years and generate sustained savings thereafter can be considered strategically valuable. Furthermore, the economic benefits calculated in this study are based on toilet and sanitation water use only; however, RWH systems inherently offer the potential for multiple uses (e.g. cooling towers, vehicle washing, fire-fighting tanks, decorative water features, specialized laboratory needs, construction activities, etc.).

The cost analysis indicates that retrofitting existing buildings significantly inflates the initial capital expenditure, particularly for dual-plumbing lines. This aligns with findings from the University of Cape Town, where retrofitting complex buildings yielded lower benefit-cost ratios compared to simpler structures like dormitories [29]. Similarly, a study at Wachemo University in Ethiopia estimated a substantial total installation cost of approximately \$128,466 for 94 buildings, highlighting the investment scale required for campus retrofits [22].

Despite these costs and the high embedded energy of RWH systems (approx. 12,359 MJ over 20 years), the environmental benefits of water autonomy justify the investment for public institutions [30].

Other elements identified in the SWOT analysis also support this discussion. While the simplicity of installation and operation of the system (Strengths) and the climatic suitability of Artvin support the technical success of the project, the lack of awareness and the lack of holistic water policies (Weaknesses) are obstacles to the expansion of the project. However, increasing environmental awareness and the potential for AÇÜ to set an example for Artvin with this project (Opportunities) indicate that these weaknesses can be overcome. The difficulty in finding qualified maintenance personnel (Threats) is an issue that needs to be taken into

consideration and a solution found during the planning phase of the project.

In conclusion, the installation of a RWH system at AÇÜ is technically feasible, environmentally beneficial and acceptable under the long-term economic evaluation criteria. Although the high initial investment cost and 19-year payback period are factors that reduce the short-term attractiveness of the project, given the university's sustainability goals, long-term water security, regional leadership role, and potential flexibility of use of the system, it can be argued that this investment is feasible and worthwhile.

4 Conclusion

The findings of this study show that the implementation of RWH systems on AÇÜ campuses is technically feasible, highly environmentally beneficial and an acceptable investment from a long-term economic perspective.

The potential for annual domestic water savings of approximately 42% would not only result in a significant reduction in the university's water bills but also alleviate pressure on the region's limited freshwater resources. The calculated payback period of 19 years is below the 20-year threshold value set by the General Directorate of Water Management of the Ministry of Agriculture and Forestry of the Republic of Türkiye and determined by expert opinions. This confirms that the project can be considered economically rantable, i.e. efficient and rational. Considering that the university is a permanent institution, a system that pays for itself in 19 years and provides continuous net savings afterwards is a strategic investment.

The implementation of RWH technology at AÇÜ will not only bring institutional benefits but also set a pioneering example of sustainable water management for Artvin province and region. Such practices also have the potential to reduce the burden on municipalities to provide sufficient and clean water to the public.

In conclusion, RWH is a promising approach that will contribute to increasing the amount of water available in Türkiye, developing a culture of sustainability, promoting water conservation awareness and leaving a more livable environment for future generations. It is critical that this valuable potential offered by rainwater, a natural resource, is not ignored. Accordingly, it is strongly recommended that relevant ministries and public institutions support and expand the installation of RWH systems in residential buildings of appropriate scale, especially in public and commercial buildings with large roofs, through financial incentives and legal regulations.

5 Authors' contributions statements

This study is based on the first author's master's thesis. In this study, Esra Atak Çelebi, was responsible for the conception of the idea, study design, data collection, analysis, literature review, and manuscript writing. Elanur Adar Yazar, contributed to the study design, manuscript writing, evaluation and review of the obtained results, copyediting, and final content verification of the study.

6 Ethics committee approval and conflict of interest statement

"Ethics committee approval is not required for the prepared manuscript". "There is no conflict of interest with any individual or institution in the prepared manuscript".

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