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ASSESSMENT OF RAINWATER HARVESTING POTENTIAL AND UTILIZATION SCENARIOS AT THE CAMPUS SCALE: THE CASE OF DÜZCE UNIVERSITY

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ABSTRACT

This study aims to determine the rainwater harvesting (RWH) potential at the campus scale within the Düzce University Konuralp Campus. The amount of collectable rainwater was calculated based on the surface areas of rooftops, impervious grounds, and green spaces across the campus, using 2024 meteorological precipitation data and runoff coefficients corresponding to surface types. According to the results, the annual RWH potential is approximately 197,201 m^3, of which 76% originates from rooftops, 23% from impervious surfaces, and 1% from green areas. It was found that the harvested rainwater could fully meet the irrigation, ornamental pond, and reservoir water demands within the campus. Additionally, this implementation could enable approximately 94,907 m^3 of water savings, 151,851 kWh of energy savings, and a reduction of 199,998 kg in CO_2 emissions annually. The study emphasizes that system design and management tailored to local climatic conditions are critical for the sustainable use of water resources. The findings demonstrate that RWH systems offer an effective environmental and economic solution for university campuses and similar institutional sites.

Keywords: Sustainability, Rainwater harvesting, Water conservation, Carbon footprint reduction.

1 INTRODUCTION

In recent years, increasing urbanization, climate change, and population density have posed significant threats to the sustainability of natural water resources. One of the major issues in this context is the ineffective management of rainwater. The rise in impervious surfaces due to dense construction prevents rainwater from infiltrating the soil, thereby reducing groundwater recharge and increasing surface runoff, which in turn heightens the risk of floods

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and flash flooding. This situation imposes substantial pressure not only on urban infrastructure systems but also on the natural environment and water resources [1]; [2]; [3].

RWH was developed as a strategy to address these challenges by collecting and reusing rainwater from various surfaces. Rainwater can be harvested from rooftops, roads, parking lots, and other impervious surfaces, and, with appropriate treatment and storage systems, can be used for non-potable applications such as landscape irrigation, reservoir replenishment, cleaning, and fire protection [4]; [5]; [6]. Two main types of RWH systems are commonly implemented: rooftop RWH systems, which collect water exclusively from roof surfaces, and runoff-based RWH systems, which gather surface runoff from other impervious areas. A critical parameter in system design is the runoff coefficient, which represents the proportion of rainfall that becomes surface runoff, reflecting the retention and conveyance characteristics of different surfaces.

Particularly in large, systematically planned areas such as university campuses, RWH systems offer significant water-saving potential and represent valuable opportunities for sustainable water management. In recent years, RWH has gained attention in both legislation and academic literature in Türkiye. The “Rainwater Harvesting System Guide,” published by the Ministry of Environment, Urbanization, and Climate Change in 2021, encourages the integration of rainwater systems into new building projects and promotes the use of rainwater as an alternative resource in urban areas [7]. These developments highlight a shift in perspective, recognizing rainwater not as waste but as a reusable resource.

The number of academic studies on RWH in Türkiye has steadily increased. For instance, at a university campus, the potential volume of rainwater that could be harvested from rooftops was assessed, and its potential applications for irrigation and cleaning were evaluated [8]. Similarly, at Ege University, the annual rainwater harvesting potential at the campus scale was assessed, demonstrating that a considerable portion of the campus water demand could be met through rainwater collection [9]. Studies conducted at universities in different climatic regions further emphasize that RWH potential varies with local climate and geographical conditions, highlighting the importance of designing systems tailored to site-specific characteristics. In the international literature, there is extensive discussion on the economic, environmental, and flood mitigation benefits of RWH systems [10]; [11].

Although previous studies have examined RWH in various Turkish universities, the RWH potential of Düzce University Konuralp Campus has not been assessed. Previous studies

in Türkiye indicate that RWH systems can significantly contribute to water savings, energy reduction, and CO_2 emission mitigation. However, variations in local climate and campus infrastructure necessitate site-specific assessments to optimize system design and management. This study addresses this gap by providing a detailed, site-specific evaluation.

The deepening global water crisis, coupled with the impacts of urbanization and uncertainties from climate change, underscores the need for sustainable water management. Reducing water consumption and utilizing alternative water sources, particularly in large campus areas, are essential for both environmental sustainability and economic efficiency. In this context, on-site rainwater collection and reuse emerge as a highly feasible solution.

The aim of this study is to analyze the RWH potential specifically for the Düzce University Konuralp Campus, based on surface area, precipitation volume, and runoff coefficient data. Within the scope of the study, rooftops, impervious grounds, and landscaped areas are evaluated separately to provide a realistic estimation of water potential. The extent to which harvested rainwater can meet various campus water demand scenarios, including landscape irrigation, reservoir supplementation, and cleaning purposes, is also examined.

This study is limited to the Konuralp Campus of Düzce University and uses 2024 meteorological precipitation data. Long-term variations and other campus areas are not included in this assessment. By focusing on a site-specific analysis and applying different runoff coefficients for various surface types, this study makes a local and original contribution and provides practical recommendations for sustainable water management in university campuses and large institutional facilities.

2 METERIAL AND METHOD

2.1 Study Area

This study was conducted within the boundaries of Düzce University's Konuralp Campus. Located in the Western Black Sea Region, the campus experiences a humid climate with consistent rainfall throughout the year. Comprising educational buildings, administrative offices, roads, parking lots, and green spaces, the campus encompasses various surface types that offer diverse potentials for rainwater harvesting. Furthermore, since a large portion of the campus consists of impermeable or semi-permeable surfaces, these areas were systematically analyzed. A visual representation of the campus is provided in Figure 1.



Figure 1. Düzce University Konuralp Campus

2.2 Data Used

2.2.1 Area Data

The areas of impermeable surfaces such as building roofs, roads, and parking lots, as well as green spaces (semi-permeable surfaces), were calculated based on the campus plan of Düzce University. The data related to these areas are presented in Table 1.

Table 1. Area data [12].

Surface Type	Area (m^2)
Roof surfaces	233.468
Asphalt and concrete	85.746
Green/landscaped areas	30.000

The roof area was calculated as 1.15 times the building footprint area. This coefficient represents a surface area correction factor recommended for moderately sloped roofs and is an average value within the range of 1.10 to 1.20 reported in the literature [8]; [13].

2.2.2 Precipidation Data

Precipitation data for Düzce province were obtained from the 2024 statistics published by the General Directorate of Meteorology (MGM) [14]. Monthly and annual average precipitation amounts are presented in Table 2.

Table 2. Precipitation data (mm)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
90,7	70,5	74,9	59,6	62,6	70,1	47,2	50,6	51,6	80,2	79,3	100,7	838

2.2.3 Runoff Coefficiends

The runoff coefficient (C) is a parameter that indicates the proportion of rainfall on a surface that becomes surface runoff. As the coefficient increases, the amount of collectable water also increases. The runoff coefficients used in this study according to surface types are shown in Table 3. Additionally, the filter efficiency coefficient (E) for the collected rainwater before filtration was taken as 0.90 [15].

Table 3. Runoff coefficients by surface type

Surface Type	Runoff Coefficient (C)	Ref.
Roof surfaces	0,85-0,95	[16]; [17]
Asphalt and concrete	0,70-0,90	[5]
Green/landscaped areas	0,10-0,30	[8]

2.3 Calculation Method

The amount of collectible rainwater (Q) was calculated separately for each surface type using the following formula.

$$Q = CxYxAxExCF \quad (1)$$

Where;

Q: Amount of collectible rainwater (m^3)

C: Runoff coefficient

Y: Average precipitation (mm)

A: Area (m^2)

E: Filter efficiency coefficient

CF: Represents the conversion factor.

This calculation was performed using Microsoft Excel, with separate sheets created for each surface type to input area, coefficient, and precipitation data. The total amount of collectible water was determined by summing the quantities obtained from all surface types.

2.4 Assumptions

All surfaces are assumed to be well-maintained, clean, and capable of providing unobstructed runoff.

It is assumed that all precipitation occurs as rainfall.

Factors such as evaporation, initial losses, and system efficiency have been neglected or reserved for advanced analysis stages.

It is assumed that rainwater can be collected entirely on-site and stored without losses.

This methodology allowed for the quantitative estimation of the collectible rainwater potential at Düzce University Konuralp Campus under simplified yet realistic assumptions.

3 FINDINGS

In this study, the RWH potential across the Düzce University Konuralp Campus was calculated by taking into account precipitation data and runoff coefficients determined based on surface types. The calculations were performed for three main surface categories: roof surfaces, hard surfaces (including asphalt and concrete roads and parking areas), and green/landscaped areas.

Table 4. Monthly collectible rainwater amount

Month	Collectible rainwater amounts by surface type (m^3)		
	Roof Surfaces	Asphalt and concrete	Green/landscaped areas
January	16.199	4.900	245
February	12.592	3.808	190
March	13.377	4.046	202
April	10.645	3.220	161
May	11.181	3.382	169
June	12.520	3.787	189
July	8.430	2.550	127
August	9.037	2.733	137
September	9.216	2.787	139
October	14.324	4.332	217
November	14.163	4.284	214
December	17.985	5.440	272
Total	149.670	45.269	2.263

For each surface type, the annual and monthly amounts of collectible rainwater were calculated using the respective surface areas, runoff coefficients, and the 2024 monthly average precipitation data for Düzce province. A total annual RWH potential of 197,201 m^3 was identified, of which 76% can be obtained from roof surfaces, 23% from hard surfaces, and only 1% from green/landscaped areas. The monthly amounts of collectible rainwater by surface type are presented in Table 4.

According to these data, the highest RWH potential was recorded from roof surfaces in December, with 17,985 m^3. A noticeable decline in the amount of collectible rainwater was observed during the summer months, parallel to the decrease in precipitation. In particular, the volume of rainwater that could be harvested from roofs in July dropped below 9,000 m^3. Including the warmer months of June and September, the total amount of collectible rainwater during this period was 51,653 m^3. The annual distribution of the total harvesting potential is illustrated in Figure 2, while the proportional distribution by surface type is presented in Figure 3.

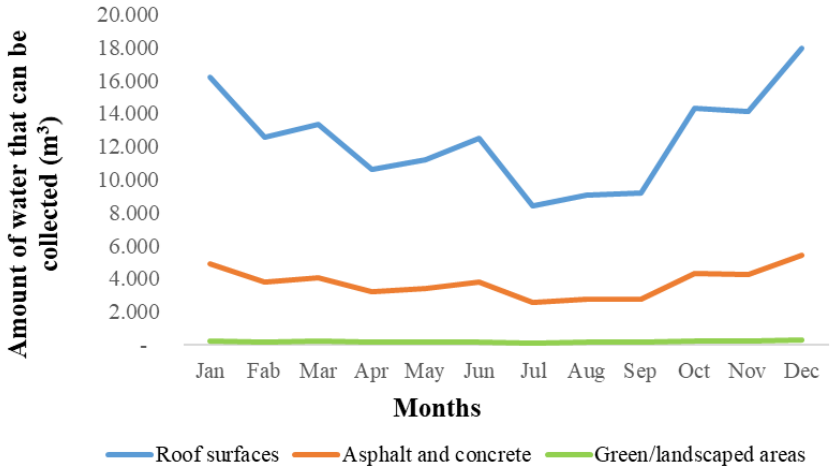


Figure 2. Monthly collectible rainwater amount

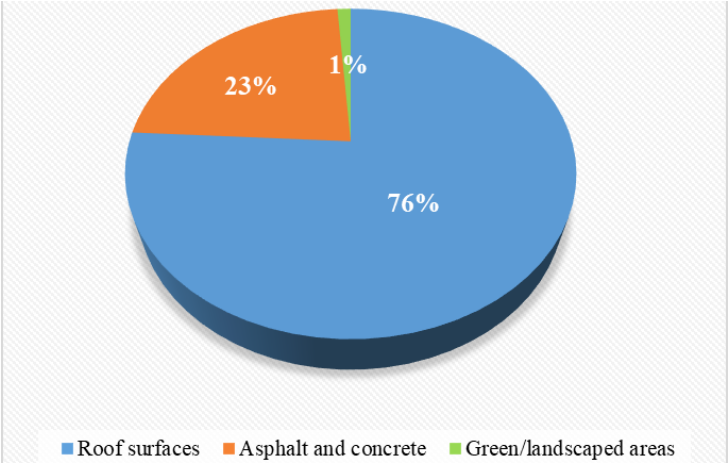


Figure 3. Annual proportions of collectible rainwater by surface type

As shown in Figure 3, roof surfaces account for 76% of the total collectible rainwater, representing the highest potential. Hard surfaces (asphalt and concrete) contribute 23%, while the amount that can be harvested from green/landscaped areas remains at around 1%. This finding indicates that RWH systems in campus areas should be primarily roof-focused in order to maximize potential efficiency.

4 RAINWATER UTILIZATION SCENARIOS

This section presents various scenarios for the potential use of harvested rainwater within the Düzce University Konuralp Campus. These scenarios are designed not only to demonstrate the environmental benefits of rainwater harvesting, but also to highlight its potential economic advantages.

4.1 Use as Irrigation Water

The annual water demand for irrigating the green areas on the campus is approximately 28,800 m^3. Irrigation typically takes place during the warmer months, including June through September [18]. Considering the annual volume of harvestable rainwater, it is evident that the entire irrigation demand can be met through rainwater harvesting. Even the volume of rainwater collected solely during the irrigation period (June–September) is sufficient to cover the demand. The fact that the rainwater collected during this same period can be directly used for irrigation suggests additional advantages in terms of storage requirements.

4.2 Use in Ornamental Pools

There are 12 ponds and ornamental pools located within the campus botanical garden, with a total water volume of approximately 1,600 m^3 [18]. When evaluated in the context of the annual harvestable rainwater volume, it is clear that the entire water requirement for these pools can be met through rainwater harvesting. In fact, even the rainwater collected from green/landscape areas which represent only 1% of the total catchment surface would be sufficient to meet this demand.

4.3 Use in Toilet Reservoirs

The annual water demand for toilet flushing systems on the campus is approximately 64,507 m^3 [18]. When compared to the annual volume of potentially harvestable rainwater, it is evident that this entire demand could also be met through rainwater collection systems.

5 DISCUSSION

The RWH potential calculations conducted specifically for the Düzce University Konuralp Campus in this study reveal significant opportunities for sustainable water management at the campus scale. These findings are consistent with previous studies reported in the literature. For instance, research analyzing the feasibility and potential of rainwater harvesting at university campuses has shown that harvested rainwater can significantly contribute to meeting campus water demand [19].

Moreover, several studies focusing on rainwater harvesting applications in university campuses have demonstrated substantial contributions to overall water demand, including implementations that achieved notable water savings through rainwater collection systems [20]. In addition, integrated spatial analysis approaches, such as GIS-based sustainability assessments, have been applied to evaluate environmental performance at university campuses, emphasizing the role of geospatial data in campus-level carbon and sustainability evaluations [21]. Furthermore, studies conducted at large institutional and campus-scale facilities indicate that integrated rainwater harvesting systems can provide considerable water savings and broader sustainability benefits [22].

In the present study, the estimated annual harvestable rainwater potential of 95,386 m^3 for Düzce University is sufficient to fully meet the current demands for irrigation (28,800 m^3/year), ornamental pool filling (1,600 m^3/year), and toilet reservoir usage (64,507 m^3/year). This result indicates a 100% match between water supply and demand at the campus scale and demonstrates a higher level of system integration compared to many examples reported in the literature.

Beyond water supply benefits, rainwater recovery systems also offer advantages in terms of energy consumption, economic costs, and carbon emissions [23]; [24]. For example, the provision of 1 m^3 of potable water at Düzce University requires 1.6 kWh of energy and incurs a cost of 0.28 USD [18]. Consequently, the use of alternative water sources contributes not only to water savings but also to reductions in energy use and operational costs. Supporting this perspective, a related study conducted at the same campus reported that the reuse of swimming pool water resulted in annual savings of 94,907 m^3 of water, 151,851 kWh of energy, and 26,574 USD, along with a reduction of 199,998 kg of CO_2 emissions [12]. These findings suggest that rainwater harvesting systems can provide similarly multifaceted environmental and economic benefits.

Nevertheless, the realization of this potential depends on several structural and managerial factors. The quality of collection surfaces, filtration efficiency, storage infrastructure capacity, and user behavior directly influence system performance. Additionally, climate change–induced variations in precipitation patterns may affect the long-term reliability of rainwater harvesting systems. Therefore, to enhance system resilience, multi-use strategies, seasonal planning, and smart water management approaches should be considered.

Overall, this study demonstrates that rainwater harvesting contributes not only to water conservation but also to reductions in carbon footprint and operational costs, offering a multidimensional sustainability approach. However, further studies incorporating advanced modeling and detailed energy–carbon analyses are recommended to strengthen the quantification of these benefits. Finally, the literature emphasizes that social acceptance, user behavior, and institutional policies play a critical role in the successful adoption and long-term performance of rainwater harvesting systems [25]. In the context of Düzce University, effective system operation should therefore be supported not only by technical adequacy but also by strong institutional commitment and awareness-raising initiatives.

6 CONCLUSION

This study evaluated the RWH potential at the campus scale, using Düzce University's Konuralp Campus as a case study, and revealed that the volume of collectable rainwater is sufficient to meet the current irrigation, ornamental pool, and toilet reservoir demands. The estimated annual potential of 95,386 m^3 corresponds to 100% of the campus's annual water needs. This finding highlights a significant opportunity for sustainable water management and points to the potential for enhancing the university's environmental and economic performance.

The results of the study demonstrate that RWH has the potential not only to save water but also to reduce energy consumption and carbon emissions. Compared to similar applications in the literature, the Düzce University case is notable in that it proposes an integrated system capable of meeting nearly the entire water demand. However, for successful implementation, improvements to structural infrastructure, consideration of seasonal variability, and the guidance of user behavior in line with sustainability principles are essential.

In this context, the following recommendations can be proposed:

Infrastructure planning for rainwater collection and storage systems at the campus level should be carried out, and the suitability of roof and surface areas should be analyzed.

Safe use and efficient management should be ensured through filtration, disinfection, and smart sensor-based monitoring systems.

Educational programs, informative signage, and pilot implementations should be implemented to raise user awareness.

An integrated management approach aligned with institutional sustainability goals should be adopted to jointly evaluate water, energy, and carbon savings.

In conclusion, this study demonstrates that campus-scale RWH systems can provide not only environmental but also economic and institutional benefits. It offers a solid scientific basis for developing sustainable campus policies. Future comparative studies in different climate zones would be valuable for assessing the generalizability of the proposed system.

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Statement of Research and Publication Ethics

The study is complied with research and publication ethics.

Artificial Intelligence (AI) Contribution Statement

This manuscript was entirely written, edited, analyzed, and prepared without the assistance of any artificial intelligence (AI) tools. All content, including text, data analysis, and figures, was solely generated by the author.

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