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Research Article

Assessing the potential of rainwater harvesting and reuse for sustainable university campus

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ABSTRACT

Water resource management, one of the paradigms for creating sustainable universities, ensures that universities manage the quantity of water used and maintain the quality. Water resource management models that begin with campus priority create input for cities at a higher scale. Water resource management encompasses a variety of sustainable practices. One of the most applicable is the reuse of rainwater. The study aims to propose site-specific solutions for reusing harvested rainwater and contribute to nature and the water cycle. In the study, the Rational Method was used to calculate the amount of rainwater. Hardscape (roads, parking lots), landscaped areas (landscaped and wooded areas) and roofing materials within the campus were determined and the amount of rainwater was calculated for each material. In a year, the total water consumption was calculated at 54,773,000 liters. The valuable volume of annual rainwater is 296,400,000. It can be seen that a volume that is approximately 5 times the amount of water required is achieved.

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INTRODUCTION

Water, one of the essential natural resources, is indispensable for human civilization and life on Earth. Recently, the increase in human population and environmental degradation in many countries worldwide, especially in developing countries, have limited people's access to clean drinking water. As landscapes are transformed for agriculture, industry and urban development, many water sources are being altered or eliminated [1]. As a result, users have gradually become aware of the interrelationships and the extent of environmental changes and ecological services. The development of environmental science and policy also brought new developments, and from the 1980s onwards, the concept of sustainable development emerged.

It is emphasized that sustainable development, which is generally recognized, must be considered in its entirety with its environmental, economic and social dimensions. For environmental sustainability and sustainable development practices to be successful, they must also be integrated into education systems. Universities can serve as models in which sustainable management practices and technologies for cities are developed and tested [2–4]. To achieve environmental sustainability in universities, studies are being conducted in the areas of environment and infrastructure, energy and climate change, waste manage-

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ment, water use, transportation, education and research. Due to the water crises that have occurred and will occur in recent years, studies on water efficiency, rainwater harvesting, recycling and reuse of wastewater have begun to gain momentum. Higher education institutions have the potential to promote sustainable and integrated water management through education, research, services and business activities [5].

At this point, the current need to address water management on campus is highlighted by the United Nations, "2005- 2014: UN Decade of Education for Sustainable Development" and "International Decade for Action "Water for Life", 2005–2015" through the development of programs. Both programs were created to draw special attention to sustainability and water issues in higher education, which are seen as necessary for ensuring environmental sustainability. By linking them to social and economic considerations, students can adopt new behaviors to protect the world's natural resources, which are important for human development and survival. For this reason, it is emphasized that the protection and restoration of the Earth's ecosystems is an important task [6, 7]. As a result, the United Nations has declared 2018 to 2028 as the international decade of action, "Water Action Decade 2018–2028". The aim is to implement and promote the sustainable development and integrated management of water resources and to implement and promote relevant programs and projects to achieve social, economic and environmental goals. The focus is on promoting cooperation at all levels to achieve internationally agreed water-related goals and targets, including those in the 2030 Agenda for Sustainable Development [8].

United Nations by 2030; by halving the amount of untreated wastewater, improving water efficiency, including rainwater harvesting, wastewater treatment, recycling and reuse technologies, integrated water resources management, reducing pollution, significantly increasing recycling and restoring safety, it emphasizes improving water quality worldwide. As a result, the study presents research findings that support the articles of "Goal 6 Clean Water and Sanitation" and "Goal 11 Sustainable Cities and Communities" of the UN Sustainable Development Goals.

Urban transitions that provide benefits for climate mitigation, adaptation, human health and well-being, ecosystem services, and reducing the vulnerability of low-income communities are promoted through inclusive long-term planning that takes an integrated approach to physical, natural, and social infrastructure. Green/natural and blue infrastructure (such as rain gardens, dry wells, bioswales, infiltration basins) support carbon uptake and storage and, either individually or in combination with grey infrastructure, can reduce energy consumption and the risk of extreme events such as heat waves, floods, heavy rains and droughts, while providing co-benefits for health, well-being and livelihoods [9].

Significance

Water problems around the world are becoming visible through digital data. It is estimated that 3.5 billion people could be affected by water scarcity by 2025, while demand will increase by up to 30% by 2050. Unsustainable management and climate change severely threaten the world's water systems. The problem of climate change is worsening, and its consequences are leading to increased floods and droughts, changes in rainfall patterns and rising sea levels [10].

In these conditions where water is becoming increasingly scarce, securing water supply to avoid water scarcity becomes the primary concern of societies. Water scarcity generally refers to the demand and availability of freshwater in physical terms. Water security is defined as ensuring sustainable access to water in sufficient quantity and acceptable quality to protect against water-related pollution and water-related disasters and to ensure the continuity of the world's ecosystems while safeguarding livelihoods, human well-being and socio-economic development [11]. In addition to physical water scarcity, water security includes access to water services, protection from poor water quality and flooding, and appropriate water governance that ensures access to safe water [12]. Implementing the Sustainable Development Goals and climate-resilient strategies is crucial for water security. However, when implementing mitigation measures, care should be taken to ensure that the water footprint is not so large that it jeopardizes the Sustainable Development Goals and adaptation outcomes [13].

When estimating drinking water consumption for the future, it is assumed that Türkiye's population will reach 100 million in 2030. It is said that the amount of usable water per person, which is 1500 m^3 today, will be about 1100 m^3 / year in 2030. The annual drinking water demand, which was 5 billion m^3 in 2000, is estimated to reach 18 billion m^3 in 2030 [14]. The provision and protection of clean water for all should not only be accepted as a problem of developing countries but as a global priority, and sustainable water management practices should be introduced [12].

Rainwater is a resource that should be easy to collect on university campuses due to the large catchment areas and large impervious surfaces. If rainwater can be utilized, it will reduce the cost of stormwater management and alleviate the pressure of water scarcity through water conservation [15]. Based on these findings, the study's main objective is to re-evaluate rainwater, which is one of the most effective methods of water utilization, with proposed solutions on site and contributing to nature and the water cycle. Studies on rainwater harvesting usually only calculate the amount harvested from roof surfaces [16–19]. This study calculated the amount of rainwater harvested from hardscape, landscape and rooftop areas.

Rainwater Management

In historical management strategies, rainwater was often treated as a problem to be mitigated, a waste product to be eliminated or controlled [20]. Factors such as industrialization, migration and technological development are leading to increasing urbanisation. From a hydrological point of view, there are two important physical changes resulting from urbanisation. The first is the increasing proportion of impermeable surfaces such as roofs, roads,

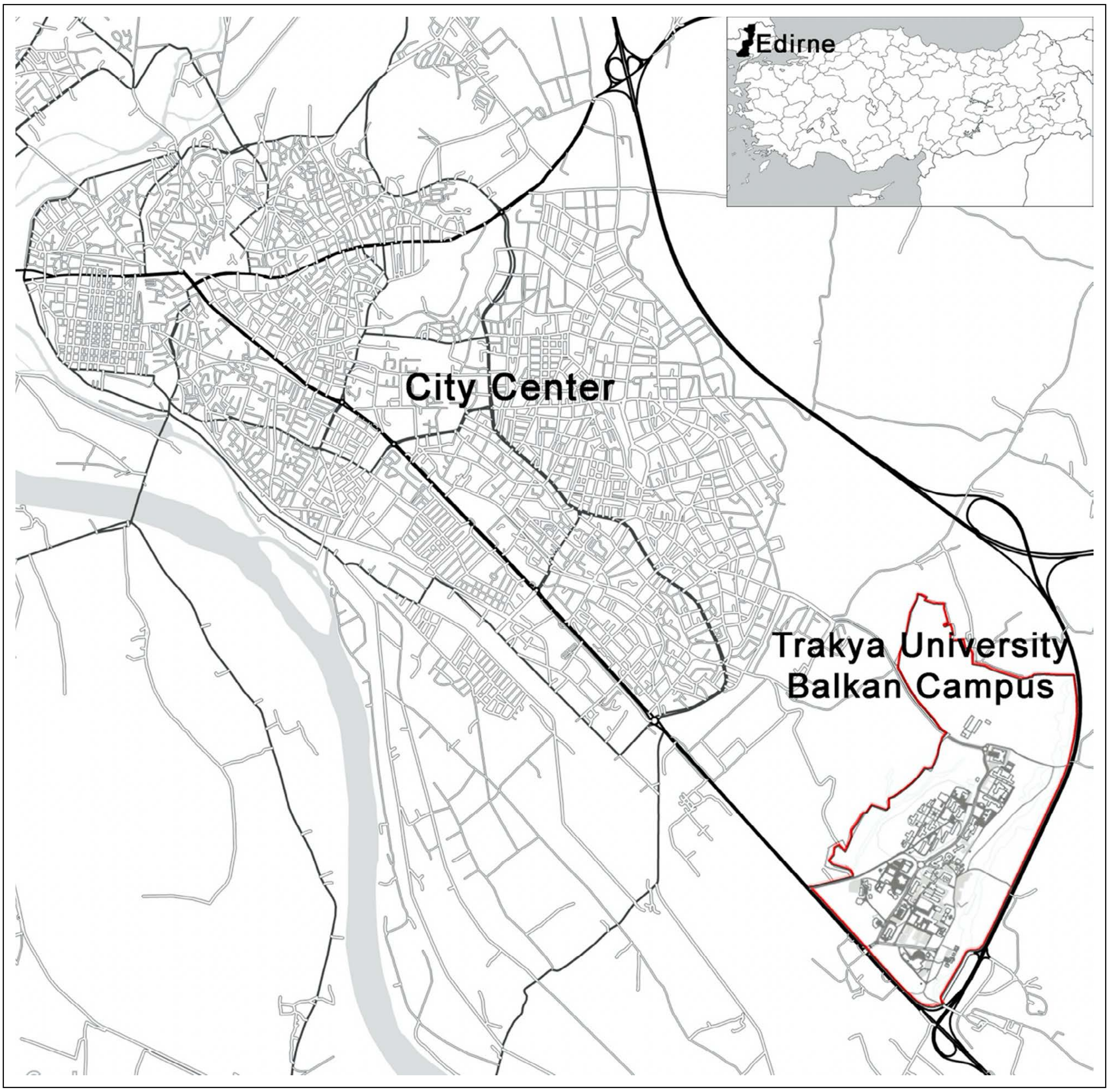

Figure 1. The study area location (Source(s): Created by authors).

parking lots and sidewalks. The second is the transformation of natural drainage systems into artificial transportation systems consisting of pipes and channels with a uniform slope [21].

The loss of vegetation cover and changes in surface properties such as roughness or permeability mean that precipitation is quickly converted into rainwater runoff. This leads to erosion, destroys habitat and deforms the natural channel [22–25]. In many cases, the volumes of rainwater after extremely intense, short periods of rain are too large for the drainage network to drain away. This leads to localised flooding and disruption to transport systems [26, 27].

Rainwater management, a distinction is made between traditional (convective) and sustainable methods [24, 28]. Traditional methods generally convey runoff from impervious surfaces to streams and rivers by the most direct and fastest route. Traditional methods refer to drainage systems consisting of devices such as downspouts, manholes, inlets, small gutters, street gutters, and curb inlets [29]. Sustainable practises follow a progressive hierarchy commonly known as the 'surface water management sequence', which consists of a series of measures to store, convey and minimise stormwater runoff and pollution [30].

MATERIALS AND METHODS

The Balkan campus of Trakya University was chosen as the study area. The campus is located at the coordinates 41°38'19.3"N and 26°36'58.1"E in the central district of the city of Edirne in Türkiye (Fig. 1). It covers an area of approximately 2,260 hectares.

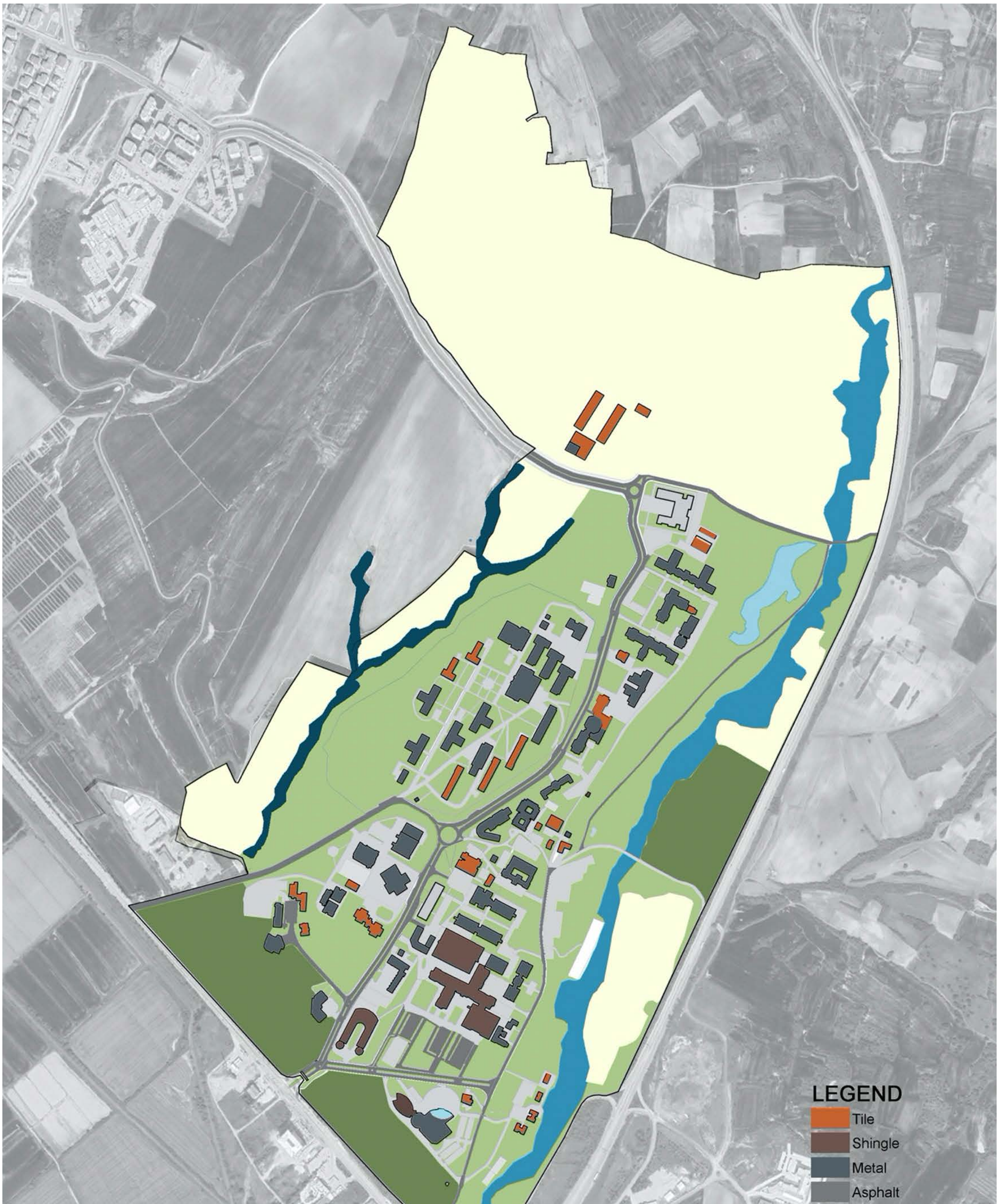

Figure 2. Material map within the campus (Source(s): Created by authors).

The campus includes buildings such as the rectorate, library, faculties, institutes, hospitals and dormitories. The campus is home to 24,000 students and 3,000 academic and administrative staff. There is also social housing on campus.

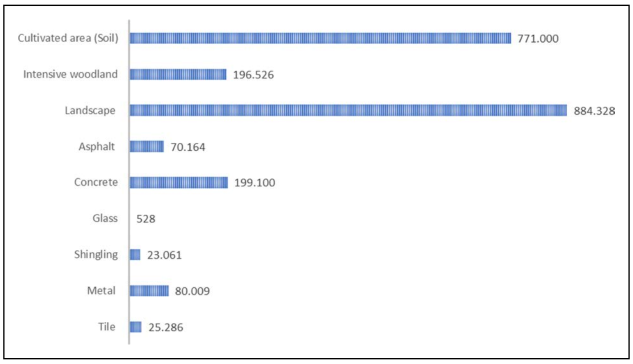

Figure 3. The collecting area in square meters (m^2).

Patients and visitors also actively use the medical school and dental hospital. There is no active water management program on campus. The municipal water supply is used within the building. Wells and the municipal water supply provide the water needed to irrigate the green areas. There are 15 wells in total, including nine active, three collapsed, and three construction wells.

The Rational Method was used to calculate the amount of rainwater on campus using equation (1) [31]. This method was developed in 1851 by Irish engineer Thomas Mulvaney and was widely used in the United States by Emil Kuichling. It was developed to predict peak rainfall runoff rates in impermeable urban areas. This method is still used today to calculate surface water runoff [20]. The Rational Method gives good results up to 1-1.5 km^2 and can be used in catchment areas up to 5 km^2 [32, 33]. Since the study area is approximately 2.3 km^2, the Rational Method was chosen.

$$V = \text{Sum}\ (R*A*RC/1000) \quad (1)$$

V: The rainwater yield in m^3 per year

R: The quantity of precipitation in liters per square millimetre (mm)

A: The collecting area in square meters (m^2)

RC: The efficiency coefficient in %

One thousand stands for the conversion factor from mm to m. Regularly maintained filter systems usually achieve a hydraulic efficiency of 0.9. Therefore, the total water volume is multiplied by the coefficient of 0.9 [34].

RESULTS AND DISCUSSION

According to the “Köppen Climate Classification”, Edirne is classified as a “Csa climate with warm winters, very hot and dry summers (Mediterranean climate)”. Summer temperatures are above 22°C [35]. According to measurements taken between 1930–2021, the average annual temperature in Edirne province is 13.7°C and the average annual rainfall is 604.4 mm [36].

The materials on the campus were determined by overlaying on-site observations, measurements and Google Earth maps. A digital map was created showing the area covered by each material: tile, metal, shingle, glass, concrete, asphalt, landscape, intensive woodland, and cultivated area (soil) (Fig. 2).

Table 1. The efficiency coefficient

Material	The yield coefficient	References
Tile	Worn old: 0,75	[37]
	Unworn old: 0,80	[37]
	New: 0,90	[37]
Metal	Wavy old: 0,70	[37, 38]
	Unwavy old: 0,75	[37, 38]
	Wavy new: 0,85	[37, 38]
	Unwavy new: 0,90	[37, 38]
Shingle	Worn old: 0,70	[39]
	Unworn old: 0,75	[39]
	New: 0,80	[39]
Glass	0,90	[39]
Concrete	0,60-0,80	[37]
Asphalt	0,80	[34]
Landscape	0,05-0,10	[40]
Intensive woodland	0,10	[40]
Cultivated area	Plane: Sandy-loamy: 0,30	[32]
	Clayey-silty-loamy: 0,50	[32]
	Clayey: 0,60	[32]
	Undulating: Sandy-loamy: 0,50	[32]
	Clayey-silty-loamy: 0,60	[32]
	Clayey: 0,70	[32]
	Sloping: Sandy-loamy: 0,52	[32]
	Clayey-silty-loamy: 0,72	[32]
	Clayey: 0,82	[32]

The collection areas within the campus, which are square meters in material type, are shown in Figure 3. The respective area was calculated using the material map.

All of the yield coefficients are shown in Table 1. The accepted yield coefficients are tile (0.8), metal (0.75), shingle (0.75), glass (0.9), concrete (0.7), asphalt (0.8), landscape (0.05), intensive woodland (0.1) and cultivated area (soil) (0.72).

Using Equation 1, the total amount of rainwater harvested on the Balkan Campus of Trakya University was calculated as 494,000 m^3/year (Table 2).

The useful volume of all rainwater is based on the following equation (2) [34];

$$Vn = \text{Minimum of}\ (BWa\ \text{or}\ ER) \times 0.06 \quad (2)$$

With the following meanings here:

Vn Useful volume

BWa Annual process water requirements

ER Rainwater yield in liters per year (l/a)

Table 2. Calculation for Determining the Rainwater Yield, Reuse, and Useful Volume of Rainwater Reservoirs (The authors edited it from [34])

Rainwater yield				**Annual quantity of precipitation**					
Collection Area A [m²]		**Yield Coefficient e**		**A_{eff} [m²]**		**Precipitation Quantity h [mm/m²]**		**Hydrl. Filter Efficiency**	
Tile	25.286	x	0,8	=	20.228				
Metal	80.009	x	0,75	=	60.000				
Shingle	23.061	x	0,75	=	17.295				
Glass	528	x	0,9	=	475				
Concrete	199.100	x	0,7	=	139.300				
Asphalt	70.164	x	0,8	=	56.131	604.4		e.g. 0.9	
Landscape	884.328	x	0,05	=	44.216				
Intensive woodland	196.526	x	0,1	=	19.652				
Cultivated area	771.000	x	0,72	=	555.120				
				∑	912.491	x	604.4	x	0.9
				Annual rainwater yield in 1				=	494.000
Process water requirements									
Drainage object		Process water requirements in m³ per day and pers.		Number of persons		Period of time in days per year		Process water requirements in m³ per year	
Toilet			0,009			Year			
		∑	0,009	x	27.000	x	1	= (1)	243
Garden watering		Garden size in m²							
		∑	884.328					= (2)	54.530
Process water requirements ∑ (1) + (2) in m³ per year =								54.773	
Process water requirements ∑ (1) + (2) in lt per year =								54.773.000	
Useful volume of the rainwater reservoir									
6 % of the annual process water requirements or annual rainwater yield									
Useful volume in liters =		494.000.000		[l/a] x 0,06				= 296.400.000	

As a result of this study, the rainwater harvested on the Balkan campus of Trakya University will be reused for irrigation in reservoirs and green areas. The average volume of the reservoir is calculated at 9 liters. It is estimated that an average of 243,000 liters of water is needed per year. The amount of water required to irrigate the green areas is considered the total water requirement of the plants on campus. The amount of water required to irrigate the plants annually is 54,530,000 liters. Total water expense was calculated as 54,773,000 liters.

According to equation (2), 296,400,000 liters were calculated as the valuable volume of the annual harvested rainwater volume. It can be seen that a volume that is approximately 5 times the amount of water required is achieved. Proper storage areas are required to reuse the rainwater collected across the campus effectively. A hydrological map was created to determine the location of the storage tanks. It was created by determining the flow directions of the rainwater by the area curves after determining the 5 m curves and the hydrological networks in the area using the ArcMAP program. Due to the size of the area and the different water flow directions, the campus was divided into zones. The water flow directions, the main roads and the buildings on the campus were used to determine these regions. Suggestions were made for the location of the tank in each region (Fig. 4).

After storing rainwater in tanks, various sustainable solutions can be offered in place of residual rainwater or storage. One of these is the rain garden. In this context, a suggestion for a rain garden on campus was developed (Fig. 5). It is located on Prof. Dr. Cahit Arf Boulevard. On the boulevard there is a road for vehicles, a cycle path, a pedestrian path, a green area and a passageway for pedestrians with wheelchairs. The existing road and cycle path have been retained. A green area is planned adjacent to the cycle path. The green area here is specifically designed as a rain garden. The plants used in the proposed rain garden areas are compatible with natural vegetation. Plants that have a high tolerance to factors such as frost, temperature and drought and that do not require chemicals were preferred. In addition, plants with specific water requirements were selected for the three levels of water demand - high, medium and low - in the rain gardens. Next, the pedestrian path was designed and seating was installed. To provide continuity between the walkway and the street, wrought iron grates were placed on the rain gardens to create a transition [37–40].

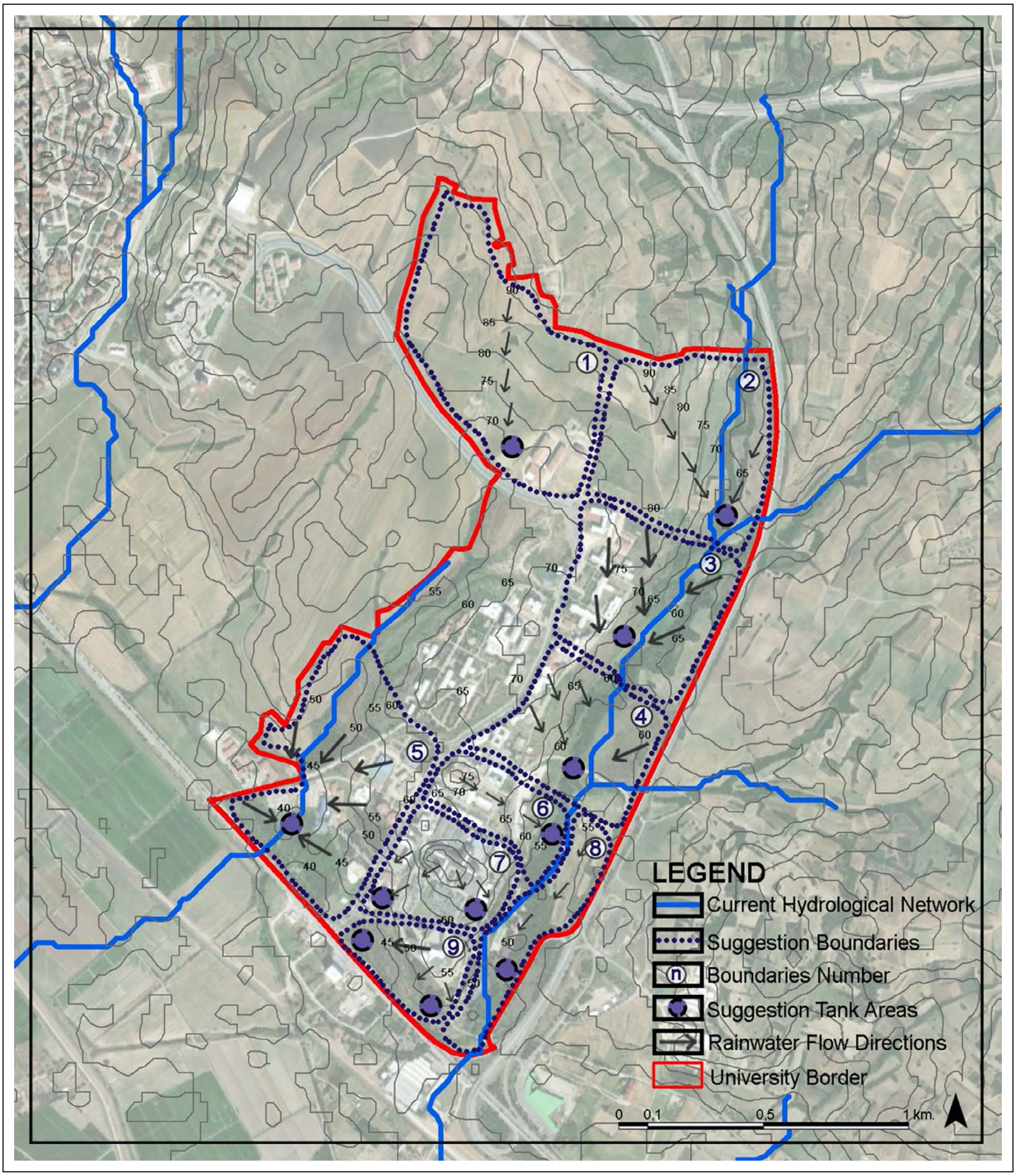

Figure 4. Suggestion tank areas (Source(s): Created by authors).

CONCLUSION

Since most of the water consumed in cities cannot be safely returned to nature, underground and surface water resources are diminishing. The benefits of the water reuse strategy include cost savings, protection of groundwater resources, reduction of natural water abstraction and long-term water supply [41–44]. Due to its species-specific properties, reclaimed water can be used to irrigate urban and residential landscapes, for industrial purposes, for the water needs of air conditioning systems and as a backup source for fire protection [45]. Rainwater makes up a significant portion of the water used to meet irrigation needs, reducing the amount of rainwater that cannot be controlled on-site [46, 47]. Irrigation of urban landscapes with recycled water has become one of the practices that can significantly contribute to the sustainability of existing urban water resources and urban green spaces [48, 49]. Depending on the

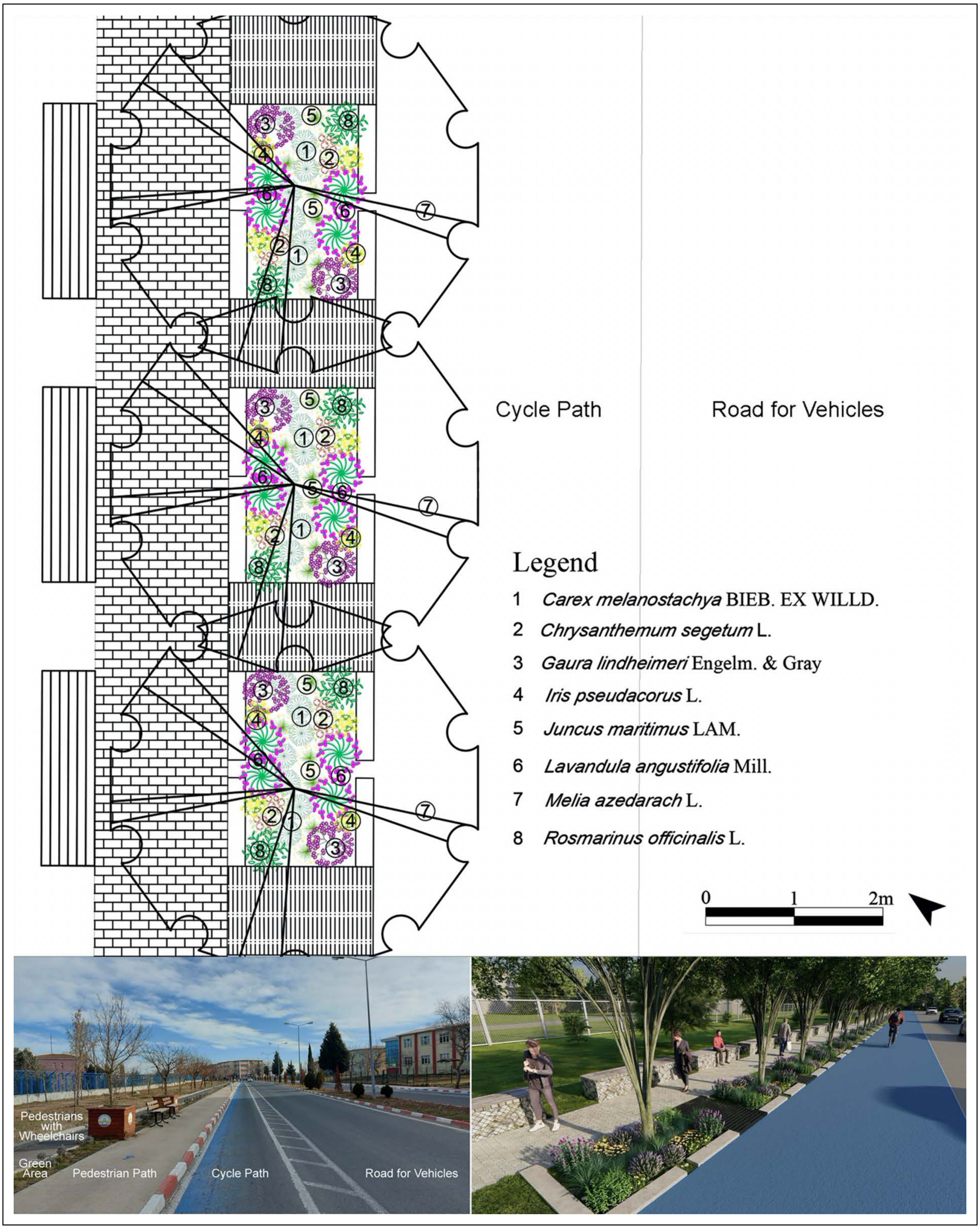

Figure 5. Suggestion for a rain garden (Source(s): Created by authors).

morphological and physiological structure of the plant, the amount of water it consumes and the amount of irrigation water that needs to be supplied to the plant will vary. Since the amount of water consumed by each plant is different, the water consumption of plants must be determined [50].

To create a healthy landscape with recycled water, several factors must be considered, including local climatic conditions, plant and soil characteristics, water quality depending on the sensitivity of plant species, and soil texture and drainage [51].

For water to be used for irrigation, policymakers need to make and implement decisions on water harvesting. In the "Regulation Amending the Planned Areas Zoning Regulation" published by T.C. Ministry of Environment, Urbanization and Climate Change in the Official Gazette No. 31538 in 2021, Article 5, Paragraph a states: "The mechanical installation projects of buildings to be built on plots larger than 2000 m^2 must include a rainwater collection system to collect rainwater to be collected from the roof surface, if necessary filtered and collected in a tank and used to flush the building's toilets. ... The part of the collected rainwater that exceeds the needs of the building's toilets can be used in the garden or other common areas by indicating it in the installation project...". The implementation of these practices through the creation of legal infrastructures increases the contribution to the water cycle. It should be ensured that the practices started on a small scale are made widespread in public areas or in areas that can serve as an example to society, such as universities.

In this study, the Balkan campus of Trakya University was chosen as the study area because it is the size of the city and university campuses are a prototype of cities. The study evaluated the potential amount of rainwater that could be harvested on the campus. Three different results were obtained from the study. The amount of rainwater that could be captured by different materials on campus and the amount of this water that would meet the needs of the reservoir and irrigation of plants were determined. It turns out that the amount obtained is about five times the amount of water needed. It is also possible to create solutions such as rain gardens that are sustainable and functional while improving visual quality.

This study aims to show that it is possible to harvest water from roofs, but also from other hardscapes and green areas. Most studies in the literature, such as the examples of Karadeniz Technical, Ege, Sinop, Bursa Uludağ Universities, focus only on roof areas. [16-19]. This has the disadvantage that the water potential to be collected is reduced in these studies. In the application phase, the collection of roof surfaces can be started as this is the easiest surface to harvest. For areas such as roads or parking lots, a system should be set up by creating drainage channels. You should bear in mind that the costs will increase in the first phase. It should also be considered that there are applications throughout the campus, such as Istanbul Technical University Ayazağa campus [52]. Studies were conducted on the campus where permeable surfaces were created, water was harvested and channeled.

If these applications are realised, we can foresee that TL 1,230,000 will be paid for 54,773 m^3 of water consumption at a price of TL 22.5[1] per unit/m^3. The profit to be realised will represent a significant share for the public institutions. As a result of these measures, the reuse of rainwater reduces the reliance on groundwater resources and municipal water supplies. In addition, rainwater that enters rivers without being considered surface water or that causes flooding in cities is eliminated on site and effective water use is ensured.

DATA AVAILABILITY STATEMENT

The author confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

There are no ethical issues with the publication of this manuscript.

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