H.TAŞÇI IZMIR KATIP CELEBI UNIVERSITY 2021

IZMIR KATIP CELEBI UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

ECONOMIC ANALYSIS OF WATER STORAGE BY RAINWATER HARVESTING TECHNIQUE AT IZMIR KATIP CELEBI

M.Sc. THESIS

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Department of Civil Engineering

Thesis Advisor: Asst. Prof. Dr. Erman ÜLKER

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İZMİR KÂTİP ÇELEBİ ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ

İZMİR KÂTİP ÇELEBİ ÜNİVERSİTESİ YAĞMUR SUYU HASADI TEKNİĞİ İLE SU DEPOLANMASININ EKONOMİK ANALİZİ

YÜKSEK LİSANS TEZİ

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ŞUBAT 2021

Hadya TAŞÇI, a **M.Sc.** student of **IKCU Graduate School of Natural and Applied Sciences**, successfully defended the thesis entitled **"ECONOMIC ANALYSIS OF WATER STORAGE BY RAINWATER HARVESTING TECHNIQUE AT IZMIR KATIP CELEBI UNIVERSITY"**, which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my family

FOREWORD

I would like to thank my advisor Asst. Prof. Dr. Erman ÜLKER, for his kind guidance of my Master's thesis, spent a lot of time advising my research work. His motivation, patience, and rich knowledge encouraged me to complete this research. I sincerely appreciate him for giving me the opportunity to work with him.

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List of Abbreviations

IKCU	Izmir Katip Celebi University
ORCID	Open Researcher and Contributor ID
RWHS	Rainwater Harvesting System
PBP	Payback Period
NPV	Net Present Value
DPBP	Discounted Payback Period
ROI	Return on Investment
IRR	Internal Rate of Return
S	Rainwater Harvesting Potential [m^3] = $R.A.Cr$
R	Monthly Rainfall, [m]
A	Catchment Area, [m^2]
Cr	Runoff Coefficient
Q	Flow Rate of Water, [m^3/h]
V	Volume of Water, [m^3]
T	The Time of Filling, [h]
ΔP	Pump Delivery Pressure, [Pa] = $\rho.g.h + L.P_L$
ρ	The Density of Water, [kg/m^3]
g	The Earth's Gravity, [m/sec^2]
h	Height of the Water from the Pump to Fixtures, [m]
L	Lengths of Flow Pipes, [m]
P_L	Pressure Loss, [Pa/m]
P	Power Consumption, [kW] = $Q.\ \Delta P/\eta$
η	Efficiency of the Pump

ECONOMIC ANALYSIS OF WATER STORAGE BY RAINWATER HARVESTING TECHNIQUE AT IZMIR KATIP CELEBI UNIVERSITY

ABSTRACT

In this thesis, the economic analysis of water storage by rainwater harvesting technique at Izmir Katip Celebi university (IKCU) was studied. The data from the flowmeters, which were installed in the men-women toilets in the central classrooms, were recorded, and the catchment area was calculated. According to the data, the amount of rainwater to be collected can meet the water demand in the toilets flushing. The economic analysis of the rainwater harvesting (RWH) was made for three scenarios their difference in initial cost by the calculations of the payback period (PBP), the net present value (NPV), the discounted payback period (DPBP), the Return on Investment (ROI), and the Internal Rate of Return (IRR). In this study, a water storage simulator model was developed based on 81 years of historical data to demonstrate the rainwater harvesting system's performance that takes into account the rainfall fluctuations. The comparison between the economic analysis and water storage simulator results proved that all of the three scenarios are cost-effective, and the payback period ranges from two to three years. Implementing the RWH technique at IKCU will reduce the current workload on municipalities and the university budget.

Keywords: Rainwater harvesting, toilet flushing, economic analysis, storage, simulator.

İZMİR KÂTİP ÇELEBİ ÜNİVERSİTESİ YAĞMUR SUYU HASADI TEKNİĞİ İLE SU DEPOLANMASININ EKONOMİK ANALİZİ

ÖZET

Bu tez çalışmasında, İzmir Katip Çelebi Universitesinde yağmur suyu hasadı tekniği ile su depolanmasının ekonomik analizi gösterilmiştir. Merkezi sınıflarda erkek-kadın tuvaletine takılan sayaçların verileri toplanmış ve hasad alanı hesaplanmıştır. Verilere göre, toplanacak yağmur suyu miktarı tuvaletlerin su kullanımını karşılayabileceği anlaşılmaktadır. Yağmur suyu hasadının ekonomik analizi, geri ödeme süresi (PBP), net bugünkü değer (NPV), indirimli geri ödeme süresi (DPBP), yatırım getirisi (ROI) ve iç verim oranı (IRR) hesaplamaları ile ilk maliyetinde farklı olan üç senaryo üzerinden yapılmıştır. Bu çalışmada, yağış dalgalanmalarını hesaba katan, yağmur suyu hasadı sisteminin performansını tanımlamak için 81 yıllık geçmiş verilere dayalı bir su depolama simülatör modeli geliştirilmiştir. Yapılan ekonomik analiz ile su depolama simülatörü sonuçları karşılaştırırken, üç senaryonun uygun maliyetli olduğu ve geri ödeme süresinin iki ila üç yıl arasında değiştiği gösterilmiştir. Böylelikle, İKÇÜ'de yağmur suyu hasadı tekniğinin uygulanması belediye ve üniversite bütçesi üzerindeki mevcut yükü azaltacağı yönünde sonuçlar elde edilmiştir.

Anahtar Kelimeler: Yağmur suyu hasadı, tuvalet sifonu, ekonomik analizi, depolama, simülatör.

1. INTRODUCTION:

Water is the most valuable of the natural and renewable sources on our planet; it is the only commodity on earth for which there is no economic substitute. All living things need water to survive. The water demand is increasing day by day so the stress on water supply systems is increasing.

Although the earth has an abundance of water, unfortunately, only 2.5% of the world's water is fresh water and usable by humans; most are held in ice caps and glaciers [1]. According to the official statistics, the major world lives underwater scarcity, which means the world is facing an insufficient freshwater resource to meet all the human demands. The water shortage has a large influence on the development of civilizations. According to the World Resources Institute (WRI), Turkey was classified as one of the countries facing high water-stress, as shown in (Figure 1.1).

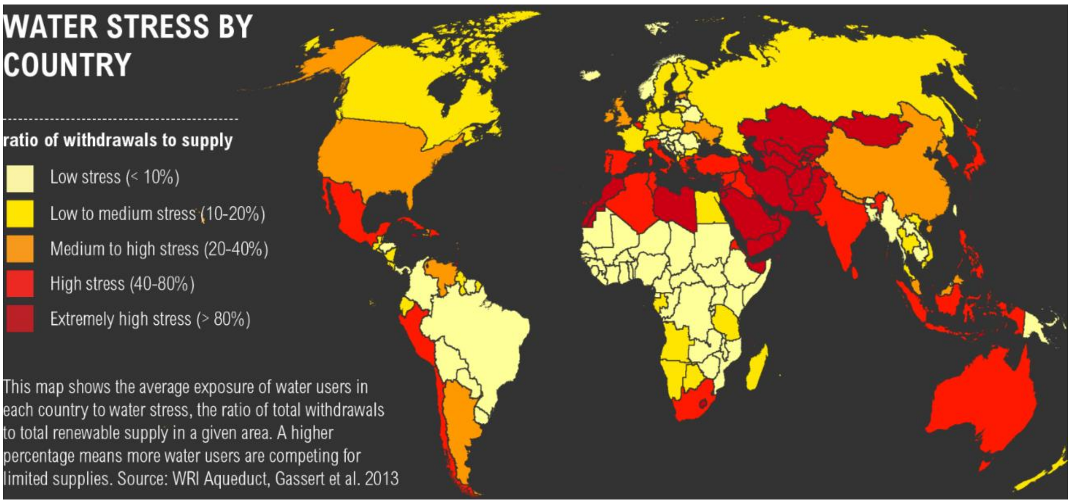

Figure 1.1 Map shows the average water-stress by country according (WRI), [2]

Water scarcity is caused by water pollution, agriculture, manufacturing and other industries, population growth, and water overuse without any care. In addition to climate change, it is an essential factor in causing droughts in some areas and floods in others. So, alternative resources such as green technologies have gained interest among researchers and engineers. Scientific studies have proven that the main water levels are declining over time, including surface water and groundwater.

Rainwater is considered a secondary source, although rain is the source of all water. The rain falls on the earth, a significant portion of the rainwater flows on the surface of lands as surface water and some portion seep into the ground as groundwater, some portion evaporates to the atmosphere. Thus, the rainwater harvest (RWH), the water collection technique, became cost-efficient by developing economic conditions [3].

The collection, storage, and use of rainwater from roofs is a simple method to reduce the demand for public water resources and waste treatment facilities. It is suitable for various uses such as toilet flushing, garden irrigation, and laundry without intensive filtering.

In public facilities such as universities, toilet flushing is the highest use of water, and therefore, the application of rainwater harvesting systems (RWHS) would be a useful method to reduce the workload on Municipalities.

1.1 Problem Statement

Turkey is one of the countries suffering from water stress. According to the Turkish Statistical Institute, the average quantity of water per person per day is 217 liters, while in Izmir, the daily quantity of water is 173 liters per person [4]. Izmir is a metropolitan city, and water demand increases gradually day by day. Therefore, it is inevitable to look for alternative water resources. Same as other metropolitan Izmir also has several public facilities such as universities, town halls, etc. In those places, most of the water consumption is for toilet flushing and irrigation purposes. The surface water resources of Izmir, three rivers–Kucuk Menderes, Bakircay, Gediz–, lakes–five natural, thirteen dam lakes–, fourteen ponds–can be named. Izmir's municipality uses those water resources in account with underground springs for supplying drinking water, industrial and agricultural purposes, and public facilities' needs. Due to increased water consumption and population growth, several fluctuations were observed in the main basins' underground water levels. For example, the water level in the Kucuk Menderes basin decreased 22 m between 2005 and 2017. The Gediz basin's water level increased 16 m between 1994 and 2013, and after that, this value fell 11 m in 2017 [5].

This study deals with the economic analysis of water storage by the rainwater harvesting system at Izmir Katip Celebi University.

Izmir city has an average rainfall that suits applying rainwater harvesting system (RWHS); the average annual rainfall is about 711.1 mm [6]. According to academic sources, the regions where the average rainfall is higher than 300 mm are considered suitable for applying rainwater collection systems. For this reason, (RWH) can be a good candidate for alternative resources in IKCU due to low filtering and its economic aspect.

1.2 Research Objectives

This study's intended purpose is the economic analysis of water storage by the rainwater harvesting technique in Izmir Katip Celebi University. The main objectives of this thesis are:

- Relieving the Municipalities from the current workload to supply enough water to the community.
- Utilize drinking water resources more efficiently by Municipalities by protecting underground water levels.
- Reducing the current pressure on the university budget.
- This thesis has an essential role in evaluating the performance of the rainwater harvesting system in IKCU.

1.3 Thesis Organization

This thesis comprises six chapters. Chapter 1 serves as an introduction to the problem statement and research objectives. Chapter 2, "Literature Review," provides a review of rainwater harvesting techniques, including projects implemented in ancient history up to this day from all over the world. The main part of this chapter summarizes rainwater harvesting systems in arid and semi-arid regions and storage methods for supplying potable and non-potable use and shows the importance of rainwater harvesting systems for facing water scarcity and control floods. Chapter 3 describes the rainwater harvesting system and storage system by determining the essential data, meteorological data such as total annual rainfall, and calculating the catchment area. Chapter 4 presents the economic analysis of rainwater storage by discriminating between designs for supporting the decision process. Chapter 5 presents the cases of rainwater harvesting potential by a water storage simulator. According to the economic analysis and water storage simulator studies, chapter 6 shows the results of comparisons to evaluate which is the most cost-efficient rainwater harvesting strategy in the building to prove that if the rainwater harvesting system can be installed at Izmir Katip Celebi University.

2. LITERATURE REVIEW

This chapter demonstrates an extensive review of scientific resources, experience, and current rainwater harvesting systems from ancient times to this day. While the rainwater harvesting technique is not a new concept, several states have successfully conducted field projects with RWHS.

2.1 Background

In the past, implementing rainwater harvesting was very simple; the rainwater was collected from the roofs of buildings, and no type of treatment [7]. Rainwater harvesting systems have been used since 4500 B.C. by the Nabateans and other people of the Middle East and Asia [8].

In the last years, there are many researches focused on alternative water resources, especially in the countries that have freshwater resources that are limited as Australia, South Africa, China, Brazil, and Paraguay. Rainwater harvesting has been the main source of water supply for potable and non-potable uses. The harvesting of rainwater depends on essential parameters that are important to know the catchment areas to construct harvesting systems and reduce the water shortage because there are economic and social impacts of water shortage on the cities [9].

Rooftop water collection, stepped water well, and tanks were the most common traditional systems [10]. The rooftop water collection technique was used for all the purposes and drinking water by collecting the rainwater after falling on the rooftop and transport the collected water by channels to the tank for storage, as shown in (Figure 2.1) [11].

Figure 2.1 Rooftop water collection technique used in Madhya Pradesh villages [12]

Another way to collect rainwater is named stepped water well that comprises a huge open surface to harvest and store the rainwater, as seen in (Figure 2.2) [13].

Figure 2.2 Stepped water well in Rajasthan, India

In addition to the most common system to date is the tank, which was used widely in the arid regions to collect rainwater. Tanks have been used to provide drinking water for that the inlets, and wire nets covered open holes to prevent the trash from accessing across the well. These tanks' structures were with a dome-shaped lid to protect the collected water from evaporation; this system could also be of different sizes and shapes, as seen in (Figure 2.3) [13].

Figure 2.3 Tanka

The researchers have been developing new methods and strategies to capture and store rainwater; some are inspired by nature, like biomimetic approaches such as Namibia University Hydrological Center Building and Warka Tower shown in (Figures 2.4, 2.5), respectively [14].

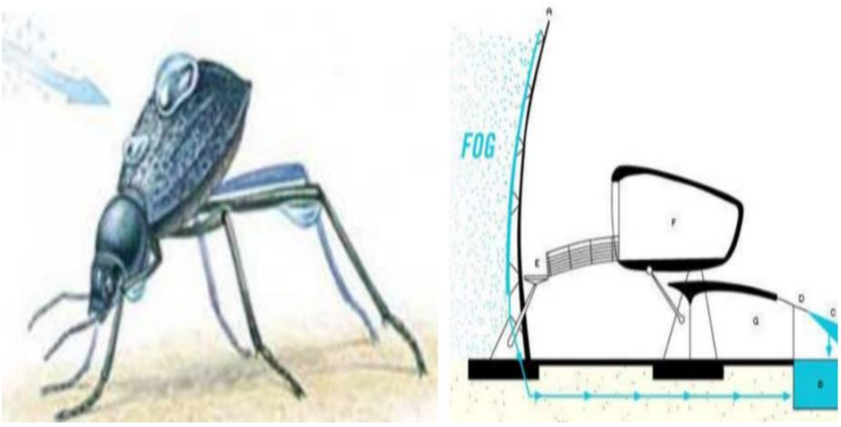

Figure 2.4 Namibia Bug and Namibia Hydrology Center

Figure 2.5 Warka Tower

The small dams and runoff control for agricultural purposes have been used in ancient history, for instance, the rice terraces in the Philippines, as seen in (Figure 2.6), this system is used to this day, besides the earth dams that have been used to control runoff in Egypt [15].

Figure 2.6 The rice terraces in the Philippines

Tunis; in the fourteenth century, the cistern was an essential element as a primary part of the house, and also in Amman, a cistern in the house is a prerequisite even today. The Yerebatan Sarayi in Istanbul, Turkey, is the largest cistern in the world. It was built entirely underground during Caesar Justinian's period. (A.D. 527- 565), The cistern's dimensions are 140m, 70m, with a capacity of 80,000 cubic meters, as seen in (Figure 2.7) [16].

Figure 2.7 Yerebatan Sarayi in Istanbul

Rainwater has been used widely as the only source for providing water in tropical islands. In Uganda, every house has a tank to store the rainwater, and people can access the tank's water at a low cost [17].

Some countries like India, Sri Lanka, Kenya, Egypt, etc., depended on domestic roof water harvesting (DRWH) in the 5th century B.C. There are many methods and types of domestic roof water harvesting that have been developed over time to new and different systems worldwide. Tamil Nadu people stored the rainwater from the public places separately and used the collected water for many purposes like drinking water, bathing, and domestic uses, and called them oranges [18].

The term water harvesting was used first by Geddes of the University of Sydney. The history of rainwater harvesting systems goes back several thousand years, especially in the Middle East and Asia civilizations. In the Negev desert, the rainwater was harvested from the runoff of hillsides and stored to use this collected water for agricultural and domestic purposes from 2000 B.C [19].

Much evidence has been found in India of stone-rubble structures that date back to the third millennium B.C. In Sardinia, the roof runoff was the primary water source from the 6th century B.C. In Roman villas and cities that also used, rainwater was the main source of domestic uses and drinking water, as shown in (Figure 2.8) [20].

Figure 2.8 Roman villas used rainwater for domestic uses and drinking water

Many areas around the world have evidence of rainwater harvesting systems utilization like Turkey (Ozis, 1982; Hasse, 1989), Japan, China (Gould & Nissen-Peterson, 1999), Western Europe (La Hire, 1742; Hare, 1900; Doody, 1980; Leggett et al., 2001a), North and South America (McCallan, 1948; Bailey, 1959; Moysey & Mueller, 1962; Gordillo et al., 1982; Gnadlinger, 1995) and Australia (Kenyon, 1929). Over 200,000 rainwater tanks provide supplies to individual households and small communities in the USA (Lye, 1992). In Canada, the harvested rainwater is used for drinking water in rural areas (Fewkcs, 2006) [20].

2.2 Rainwater Harvesting over the World

Rainwater harvesting systems were used thousands of years ago all over the world. RWHS have been practiced in arid and semi-arid regions as an alternative water source to cover most of the needs such as irrigation, domestic purposes, water for livestock, and drinking water. There are many examples of rainwater harvesting systems from all over the world.

2.2.1 Rainwater harvesting system in China

China is one of the world's largest countries and has the world's largest population, which means the amount of water requirements is higher than any other country; there are enormous water resources but no spatial or temporal distribution of these water resources. The loess plateau of Gansu province in northwest China, the status there is very critical, where the region is dry, the annual rainfall is about 300 millimeters, and the groundwater is also scarce. The 1-2-1 Rainwater Catchment Project in Gansu province was implemented in (1995 – 1996). The name of this project 1-2-1 refers to each household receives one area of rainwater catchment, two large underground water tanks with capacity (30-50 m^3 in volume), and one part of the land to grow cash crops.

Only in two years, the project implementation has been solved the potable water problem with a population of 1.26 million in the middle and eastern of Gansu province [21]. In Gansu Province, 2,183,000 rainwater tanks were built until 2000 year. These tanks' total capacity is 73.1 million m^3, supplying the irrigation for 236,400 ha of land and potable water for 1.97 million people, some examples of applications as seen in (Figure 2.9) [22].

Figure 2.9 (a) Daping village domestic water management. (b,c) household appliances

2.2.2 Rainwater harvesting system in Japan

In Tokyo, the Ryogoku Kokugikan Sumo-wrestling Arena was built in 1985 in Sumida City; this facility used a large-scale rainwater harvesting system by collecting the water from the roofs of houses for supplying drinking water, irrigation purposes, and fire-fighting. The catchment surface area is 8,400 m^2; the collected rainwater drains into an underground tank of 1,000 m^3 to store and air conditioning and toilet flushing. To this day, about 750 buildings have been used rainwater harvesting systems in Tokyo [22]. Rainwater harvesting systems can reduce storm drainage load and flooding in city streets (Figure 2.10) shows the flood after heavy rains in 2019.

Figure 2.10 Floods after heavy rains in the southwestern city of Saga, August 2019

2.2.3 Rainwater harvesting system in Malaysia

Implementing rainwater harvesting for a residential house, a mosque, and a government building has been applied in Putrajaya. TANGKI NAHRIM is the software that was developed to determine the optimal rainwater system, such as the volume of storage and rainfall. This software contains the rainfall database for all states in Malaysia. Malaysia began using the rainwater harvesting system as an alternative resource in 1999 after the drought, which was in 1998. Rainwater harvesting systems can be considered as a solution to save treated water [23].

2.2.4 Rainwater harvesting system in Taiwan

In recent years Taiwan was facing many problems in urban areas, such as droughts and increasing demand for water, which caused a severe water shortage. At the same time, there were many obstacles to development in several fields because of water scarcity. An alternative resource had to be found; this resource was rainwater collection to save the limited freshwater. The authors focused on the method of the rainwater drainage system in existing buildings of Taiwan. They studied the economic and technical factors that affect the system [24].

2.2.5 Rainwater harvesting system in Germany

Germany, Berlin, in the DaimlerChrysler Potsdamer Plate buildings, the rainwater harvesting systems have been included as a part of the large-scale urban redevelopment since 1998 to control flooding and save water by collecting the rainwater that falling on the rooftops 32,000 m^2 of 19 buildings and storing it in underground tanks 3500 m^3 to use it in toilet flushing and irrigation purposes as seen in (Figure 2.11).

Bless-Luedecke-Strasse building in Berlin, the rainwater can be discharged from all the roofs into a separate public rainwater sewer and transferred into a tank with a capacity of 160 m^3. The water goes through several stages of filtration for utilization in toilet flushing and irrigation purposes. About 58% of the rainwater can be retained; the savings of drinking water was estimated at 2,430 m^3/year and thus preserving the groundwater tanks of Berlin [25].

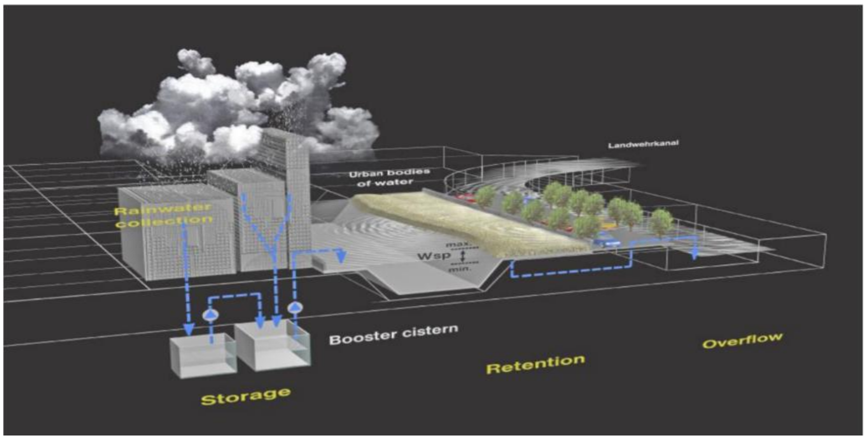

Figure 2.11 Potsdamer Platz in Berlin, Germany

2.2.6 Rainwater harvesting system in United Kingdom

The United Kingdom (UK), particularly in the south and east of the UK, faces severe water shortages because of the higher temperature in summers, increasing demand, and lack of rainfall in some years. According to the statistics, about 55% of treated main water is used for households in the UK. It is believed that the utilization of rainwater can be reduced by about 25% of household water consumption. In the UK the rainwater can be used for toilet flushing. Thus, the UK government is supporting rainwater harvesting to face water stress [26].

2.2.7 Rainwater harvesting system in Australia

In Australia, the large cities used rainwater tanks to save the main water. The studies found that a 5 m^3 tank of harvested rainwater can meet 96% to 99% of the demand for toilets and laundry in Sydney, and this study was in the driest year [27].

2.2.8 Rainwater harvesting system in the United States of America

In the United States of America (USA), There is legislation to regulate and implement rainwater harvesting systems in some states such as Arizona, Colorado, Illinois, North Carolina, Ohio, Oklahoma, Oregon, Rhode Island, Texas, Utah, Virginia, Washington, U.S. Virgin Islands, and Hawaii. Ohio uses the harvested rainwater even for drinking water. Colorado allows rainwater harvesting for non-potable uses. The studied 1979 showed that about 67,000 tanks are in the state of Ohio. In Oklahoma, awareness campaigns were launched on the necessity of rainwater harvesting. Many financial incentives were offered to implement rainwater harvesting systems; for example, Austin offers a 30% for the cost of tanks that up to $500 and sells rain barrels below cost. As we see in (Figure 2.12), a model of tanks in the USA is used for residential purposes [28].

Figure 2.12 Residential rainwater collection system uses tanks, Arizona, USA

San Fran’s Pier 27, California, United States, has two tanks added to save the collected rainwater. Two water tanks' capacity is 2,600 gallons, where demand per person for toilet flushing was estimated at 15,000 gallons/month. San Fran’s Pier 27 is a two-story structure, its area about 88,000-square-foot besides an adjacent public plaza that its area 2.5 acre as shown in (Figure 2.13). The drainage system of the roof collects the rainwater from the area of 48,790 square feet. The collected rainwater crosses after the pipes' filtration processes to the over-ground cisterns to use it for toilet flushing and irrigation purposes [29].

Figure 2.13 Three aboveground rainwater collection tanks at Pier 27

2.2.9 Rainwater harvesting system in Turkey

There is a study to estimate the potential of rainwater harvesting at Sakarya University. The water need was determined that can be met by using rainwater rather than economic analysis [30].

In Bulent Ecevit University, a rainwater harvesting system was proposed to relieve the pressure on municipalities. This system aims to supply the central campus with harvestable water instead of a water distribution network. Through rainfall data analysis and collectible rainwater volume determining, the most economical system was selected for storage and distributions to be the best alternative solution [31].

Siemens factory, Eser Holding, Sabanci Nanodam, and THY-Pratt Whitney Aircraft Engine Maintenance Center are examples of green buildings that use rainwater in Turkey. Water utilization has been reduced by 59% in the Eser Holding project (Figure 2.14). In order to achieve this object, the load on the network was reduced by making a Rainwater Plan for water efficiency. Rainwater falling on the land was collected and used in landscape irrigation, and the use of water was minimized thanks to the installation of waterless urinals, gray water treatment systems, flow-regulated taps, and rainwater collection systems [32].

Figure 2.14 Eser Holding Head Office (First LEED Platinum Certified Building)

In the THY-Pratt Whitney Aircraft Engine Maintenance Center, the rainwater is collected from the rooftop and stored in 500 m^3 tanks. The stored water is filtered and used throughout the facility and for irrigation purposes. The total water savings exceed 60% [33].

3. METHODOLOGY OF RAINWATER HARVESTING

The building with laboratories and classrooms in Izmir Katip Celebi University was selected for RWHS implementation. Typically, rainwater harvesting systems have three main components, collection, transportation, and storage systems. The evaluation of the harvested rainwater, accumulation, recovery, and utilization is determined by considering essential factors that affect the project cost such as precipitation amount, collection surface areas such as shape and size, flow coefficient, storage volume and area, filtration processes, meteorological data, and the end-use purposes.

Rainwater harvesting is a technology used to collect water from the rooftops of buildings on rainy days and convey it to storage tanks. Studies have proven that successful rainwater harvesting projects are generally associated with efficient storage. Water storage tank comes in various sizes, shapes, and materials; but the main criterion is the volume of water it can hold. The water tank size and capacity can be estimated by determining the water requirement volume and the captured rainwater.

3.1 Water Demand of the Main Campus Center Classrooms at IKCU

The water demand of the main campus center classrooms is met by the municipality's local water distribution network. The building with laboratories and classrooms was selected in this study due to the majority of water consumption. The network system in the basement of the building was examined to measure the water quantity used in the toilet reservoir. As a result of the examination, there are two different lines, one leading to the hand sinks and the other leading to the toilet closets. In order to measure the discharge water, flowmeters were installed on the supply pipes for sinks and toilet-urinals of men and women toilets.

The flowmeters are connected to the water lines that go to the reservoirs to obtain the measurements. This process was applied separately for male and female toilets in order to determine optimal divergence. The total number of male and female toilets is 24 in the building. Measurements were taken from four toilets -male and female- two toilets in F Block and two on the laboratory side. The flowmeter, which is used in the toilet pipeline, is shown in (Figure 3.1).

Figure 3.1 Used flowmeter in the toilet

3.1.1 Flowmeters data

Flowmeters were installed on supply pipes for sinks and toilet-urinals of men's and women's toilets. Four toilets were examined, and their data collected. Data were got daily for a month, then weekly for a month as presented in (Tables 3.1. 3.2. 3.3 and 3.4).

Table 3.1 Measurements of daily water demand in male and female toilets (Litre) in laboratories side.

DATE	Male's Measurements (Liter)		Female's Measurements (Liter)	
	SINK	CLOSET	SINK	CLOSET
25-Nov-2019	1453	10234	816	4024
26-Nov-2019	1615	10981	920	4334
27-Nov-2019	1799	11730	1012	4650
28-Nov-2019	2020	14208	1207	5031
29-Nov-2019	2207	14877	1285	5262
30-Nov-2019				
1-Dec-2019				
2-Dec-2019	2397	16281	1620	5827
3-Dec-2019	2597	17719	1908	6378
4-Dec-2019	2713	18370	1955	6616
5-Dec-2019	2919	19930	2163	7192
6-Dec-2019	3075	21893	2450	7559
7-Dec-2019				
8-Dec-2019				
9-Dec-2019	3184	30176	2651	8210
10-Dec-2019	3314	31530	2900	8628
11-Dec-2019	3458	32463	3103	9048
12-Dec-2019	3604	33125	3203	9247
13-Dec-2019	3734	33715	3380	9520
14-Dec-2019				
15-Dec-2019				
16-Dec-2019	4538	46136	4139	11694
17-Dec-2019	4724	47847	4299	12092
18-Dec-2019	4815	48888	4393	12347
19-Dec-2019	5041	51389	4599	12867
20-Dec-2019	5214	52293	4830	13483

The daily water consumption is the subtracting the accumulated values of measurements.

Table 3.2 Daily water consumption in male and female toilets (Litre) in laboratories side.

Weeks	Male's Water Demand (Liter)		Female's Water Demand (Liter)	
	SINK	CLOSET	SINK	CLOSET
	162	747	104	310
	184	749	92	316
	221	2478	195	381
	187	669	78	231
1st Weekend	190	1404	335	565
	200	1438	288	551
	116	651	47	238
	206	1560	208	576
	156	1963	287	367
2nd Weekend	109	8283	201	651
	130	1354	249	418
	144	933	203	420
	146	662	100	199
	130	590	177	273
3rd Weekend	804	12421	759	2174
	186	1711	160	398
	91	1041	94	255
	226	2501	206	520
	173	904	231	616
4th Weekend	624	8720	626	1052
Total Monthly Demand (Liter)	4385	50779	4640	10511
Average Daily Demand (Liter)	219.25	2538.95	232	525.55

Table 3.3 Weekly water demand in male and female toilets (Litre) in laboratories side.

DATE	Male's Measurements (Liter)		Female's Measurements (Liter)	
	SINK	CLOSET	SINK	CLOSET
27-Dec-2019	5838	61013	5456	14535
3-Jan-2020	6882	73383	6788	26461
10-Jan-2020	7633	84682	7422	50997
17-Jan-2020	8542	99701	8142	52651
Weekly Water demand				
1st week	1044	12370	1332	11926
2nd week	751	11299	634	24536
3rd week	909	15019	720	1654
Average Weekly Demand (Liter)	901.3	12896	895.3	12705.3

Table 3.4 Weekly water demand in male and female toilets (Litre) in F Block.

DATE	Male's Measurements (Liter)	Female's Measurements (Liter)
	CLOSET	CLOSET
6-Mar-2019	5218	8310
13-Mar-2020	21931	27726
Weekly Water demand		
Average Weekly Demand (Liter)	16713	19416

3.2 Rainwater Collection System

The application of an appropriate rainwater harvesting system is necessary, especially in areas where rainfall exceeds annually 300 mm. Various factors in the building affect the collection system's efficiency, including the effective roof area and the roofing material. In this study, determining the rooftop's annual precipitation and catchment area are essential components to assign the rainwater harvesting system's efficiency.

3.2.1 Precipitation estimation in Izmir

The region of Izmir has a typical Mediterranean climate because of its geographical location in western Turkey. There are great differences in the distribution of precipitation by month and season in Izmir, but the average annual precipitation from 1938 to 2019 is 711.1 mm. The regions where the average rainfall is higher than 300 mm are considered suitable for applying rainwater collection systems [34]. In Izmir, most of the rainfall concentrates between November and January; over 50 percent of the annual precipitation falls in winter, while in spring and autumn seasons 40 to 45 percent, and 2 to 4% in summer. The maximum and minimum average precipitation is 144.3 mm in December and 4.1 mm in July, respectively. The maximum and the minimum number of rainy days are 12.8 days in December and 0.5 days in July, respectively [35]. Information is shown graphically in (Figures 3.2, 3.3).

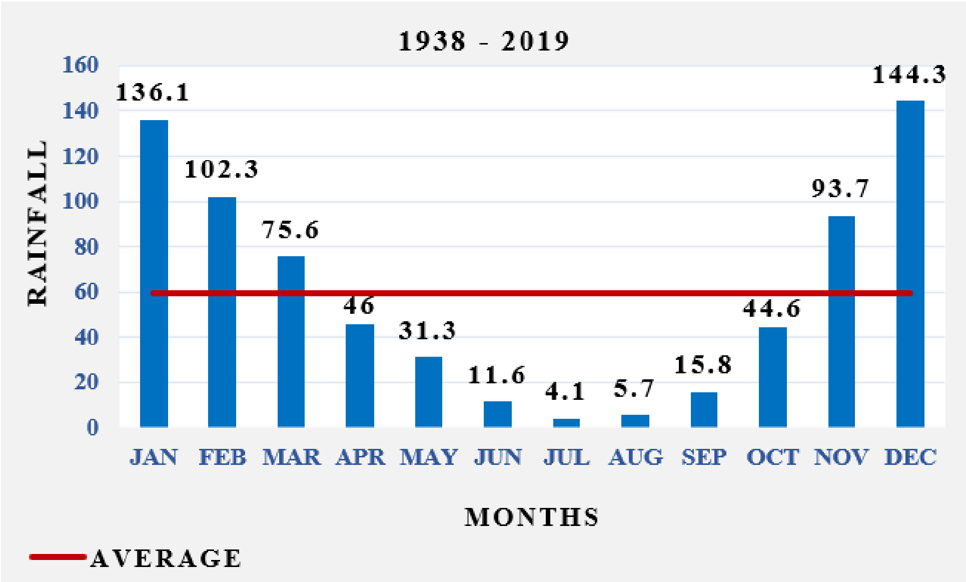

Figure 3.2 The average monthly precipitation in Izmir (mm) from 1938 to 2019

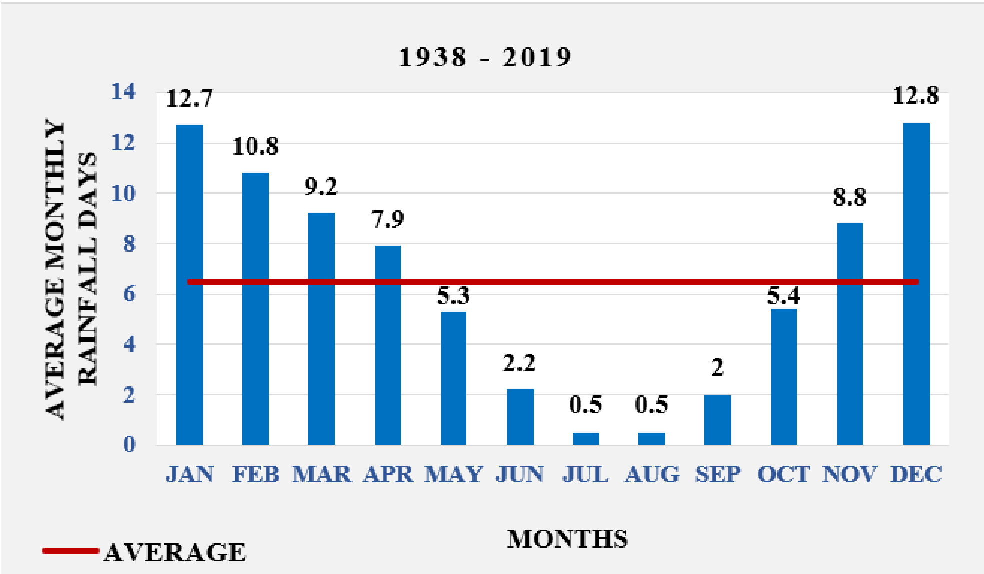

Figure 3.3 The average monthly rainy days in Izmir from 1938 to 2019

3.2.2 Roof characteristics and area calculation

Rainwater harvesting is a system that collects rainwater from the rooftop and stores it in a large cistern. The important parameters that affect the system's efficiency are precipitation, surface–area materials, runoff coefficients, and the cistern volume.

Izmir Katip Celebi University is constructed by several buildings. The main campus center with laboratories and classrooms was selected in this study because of the high water usage in this building. (Figure 3.4) shows the study area. Twenty-four toilets are throughout the building, as seen in (Figure 3.5).

Figure 3.4 Study Area in Izmir Katip Celebi University by Google Earth

Figure 3.5 The locations of the toilets in the campus

3.2.2.1 Roof material

In this study, the economic analysis of rainwater harvesting is determined based on the total roof area, the average annual rainfall, and the runoff coefficient, which differs according to the roof's material. Thus, the roof's material is an important factor in determining the harvestable rainwater on the roof. The runoff coefficient is a dimensionless factor that illustrates the effect of catchment losses and depends on the nature of the surface slope and rainfall intensity [36]. Therefore, there is a need to take the runoff coefficient into account because not all the falling water on a rooftop area can be collected. A runoff coefficient of many materials can be found in (Table 3.5). This study's roof type is metal roofing, so the runoff coefficient is 0.9.

Table 3.5 Runoff coefficient for different roof types [37].

Type of Roof	Runoff Coefficient
Galvanized Iron Sheet	0.90
Asbestos Sheet	0.80
Tiled Roof	0.75
Concrete Roof	0.70

3.2.2.2 Catchment area calculation using a pitched roof

The roof type of the studied building is a pitched roof, so the roof area can be calculated by dividing the building's width into right-angled triangles. Mathematical calculations will determine the surface area applied to the triangles. The technical drawings in AutoCAD obtained the dimensions of the flat roof. The catchment surface can be determined by collecting the horizontal surface area, half of the vertical height area, and half of the adjacent wall area [38].

Area of *ABCD* = roof plan $ABC'D'$ + *1/2** beveled surface $CDC'D'$ + *1/2** side wall ADE, as presented in (Figure 3.6).

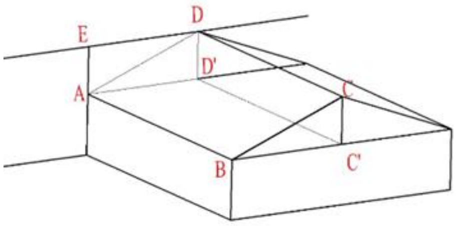

Figure 3.6 Drawing for Roof Area Calculation

The rooftop area was calculated by including the slope using two sections of roof plans. The result gives the roof area that is used for harvesting. The images are added in 2 sections to understand the calculation step by step (Figures 3.7, 3.8).

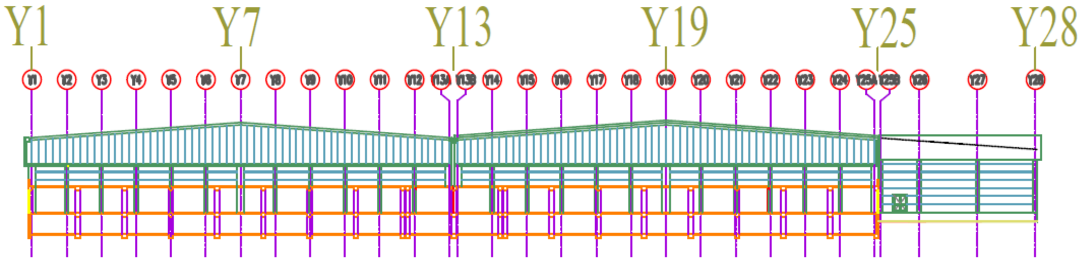

Figure 3.7 1st Section of Central Classes in Izmir Katip Celebi University

Area Y1→ Y7 = roof plan $ABC'D'$+1/2* beveled surface $CDC'D'$+1/2* side wall ADE

$$ABC'D' = 27.375 * 55.43 = 1517.39625\, m^2$$

$$\frac{1}{2}\, CDC'D' = \frac{1}{2} * 1.9163 * 55.43 = 53.11\, m^2$$

$$\frac{1}{2}\, ADE = \frac{1}{2} * 27.375 * 1.9163 = 26.229\, m^2$$

$$= 1517.39625 + 53.11 + 26.229 = 1596.735865\ m^2$$

Area Y1 →Y13 $= 1596.735865 * 2 = 3193.47173\ m^2$

Area Y13 →Y25 = $\text{Area Y1} \rightarrow \text{Y13} = 3193.47173\ m^2$

Area Y25 →Y28 = $ABC'D' = 20.45 \times 55.43 = 1133.5435\ m^2$

$$\frac{1}{2}\, CDC'D' = \frac{1}{2} * 1.4465 * 55.43 = 40.08975\ m^2$$

$$\frac{1}{2} ADE = \frac{1}{2} * 20.45 * 1.4465 = 14.79\ m^2$$

Area Y25 →Y28 = roof plan $ABC'D' + \frac{1}{2}$ beveled surface $CDC'D' + \frac{1}{2}$ side wall ADE

Area Y25 →Y28 $= 1133.5435 + 40.08975 + 14.79 = 1188.42\, m^2$

Total area Y1 →Y28 = $3193.47173 + 3193.47173 + 1188.427575.36346\ m^2$

Symmetrically, on the right total area Y1 →Y28 = $7575.36346\ m^2$

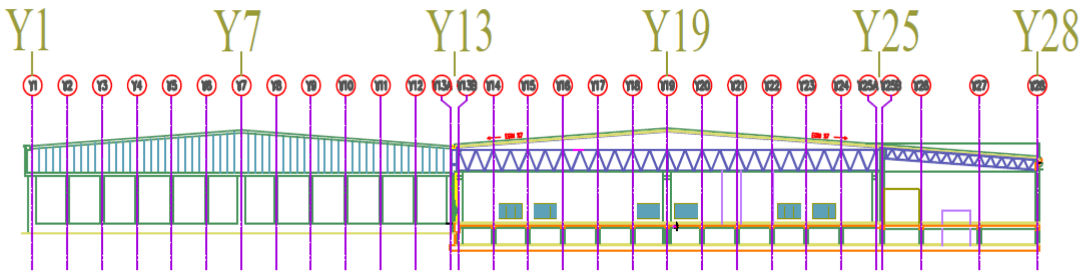

Figure 3.8 2nd Section of Central Classes in Izmir Katip Celebi University

No area Y1 →Y13

Area Y13 →Y19:

Percent slope = *7% ; 0.07* = $\frac{2.556}{x}$ $\rightarrow\ x\ =\ 36.514\ m$

$$ABC'D' = 36.514 * 256.7742 = 9375.85314\ m^2$$

$$\frac{1}{2}\ CDC'D' = \frac{1}{2} * 2.556 * 256.7742 = 328.15743\ m^2$$

$$\frac{1}{2}\ ADE = \frac{1}{2} * 2.556 * 36.514 = 46.664892\ m^2$$

Area Y13 →Y19 = roof plan ABC$'D'$ + $\frac{1}{2}$ beleved surface C$DC'D'$ + $\frac{1}{2}$ side wall ADE

Area Y13 →Y19 = $9375.85314 + 328.15743 + 46.664892 = 9750.675462\ m^2$

Area Y19 →Y28: Percent slope = 7% ; $0.07 = \frac{3.2382}{x}$ $\rightarrow$ x $= 48.0014\ m$

$$ABC'D' = 48.0014 * 256.7742 = 12325.52108\ m^2$$

$$\frac{1}{2}\ CDC'D' = \frac{1}{2} * 3.2382 * 256.7742 = 415.74311\ m^2$$

$$\frac{1}{2}\ ADE = \frac{1}{2} * 3.2382 * 48.0014 = 77.71907\ m^2$$

Area Y19 →Y28 = roof plan $ABC'D'$ + $\frac{1}{2}$ beleved surface $CDC'D'$ + $\frac{1}{2}$ side wall ADE

Area Y19 →Y28 = $12325.52108 + 415.74311 + 77.71907 = 12818.98326\ m^2$

There are six gaps in the middle of the building, the total area of spaces = $2014.112\ m^2$

By deletion the gaps area from building: Y19 →Y28

Area Y19 →Y28 without gaps = $12818.98326 - 2014.112 = 10804.87126\ \text{m}^2$

Total effective catchment area = $(7575.36346 * 2) + 10804.87126$

$= 25955.6056\ \text{m}^2$.

3.2.3 Rainwater Supply in the Main Campus Center Classrooms

The quantity of available rainwater supply depends on the:

• Amount of rainfall • Catchment area • Runoff coefficient.

The volume of harvestable rainwater from the rooftop of the campus is calculated by using Gould and Nissen [39] Formula 1, the results as presented in (Table 3.6):

$$S = R \times A \times Cr \qquad (3.1)$$

Where:

S: rainwater harvesting potential (m^3)

A: catchment area (m^2), R: monthly rainfall (mm)

Cr: runoff coefficient.

Table 3.6 Monthly amounts of harvestable rainwater.

Central Classes Monthly Rainfall (1938 – 2019)	Catchment Area m^2 (A)	Average Monthly Rainfall mm (B)	Runoff Coefficient (C)	Rainwater Supply m^3 (A × B × C)
January	25955.6	136.1	0.9	3179.30
February	25955.6	102.3	0.9	2389.82
March	25955.6	75.6	0.9	1766.16
April	25955.6	46	0.9	1074.69
May	25955.6	31.1	0.9	726.61
June	25955.6	11.6	0.9	271.03
July	25955.6	4.1	0.9	95.80
August	25955.6	5.7	0.9	133.19
September	25955.6	15.8	0.9	369.20
October	25955.6	44.6	0.9	1042.22
November	25955.6	93.7	0.9	2189.68
December	25955.6	144.3	0.9	3372.28
Annual Rainfall	25955.6	710.9	0.9	16609.97

Determining the water storage volume requires calculating the maximum collected rainwater from the rooftop at each location; the water demand was taken in the academic weeks. According to flow meters' data, the average weekly demand is 436.11 m^3 of all toilets, as shown in (Table 3.7).

Table 3.7 The amounts of received rainwater per location.

Mon	Rainfall mm	Rainfall days	Daily Rainfall mm	Catchment area m^2	Runoff Coeff	Monthly Rainwater Supply m^3	Monthly Demand m^3	Cumulative difference from last Col m^3	Annual Overflow m^3	RW supply in rainy day m^3	Max RW storage in locations m^3
JAN	136.1	12.7	10.72	25955.6	0.9	3179.30	1250.76	1928.54	1928.54	250.34	20.86
FEB	102.3	10.8	9.47	25955.6	0.9	2389.82	1250.76	1139.06	3067.60	221.28	18.44
MAR	75.6	9.2	8.22	25955.6	0.9	1766.16	1667.05	99.10	3166.71	191.97	15.10
APR	46	7.9	5.82	25955.6	0.9	1074.69	1667.05	-592.37	2574.34	136.04	11.34
MAY	31.3	5.3	5.91	25955.6	0.9	731.28	1667.05	-935.77	1638.57	137.98	11.50
JUN	11.6	2.2	5.27	25955.6	0.9	271.03	416.76	-145.73	1492.83	123.19	10.27
JUL	4.1	0.5	8.2	25955.6	0.9	95.80	833.53	-737.73	755.10	191.60	15.10
AUG	5.7	0.5	11.4	25955.6	0.9	133.19	833.53	-700.34	54.76	**266.38**	**22.20**
SEP	15.8	2	7.9	25955.6	0.9	369.20	416.76	-47.56	7.20	184.60	15.38
OCT	44.6	5.4	8.26	25955.6	0.9	1042.22	1667.05	-624.83	-617.63	193	16.08
NOV	93.7	8.8	10.65	25955.6	0.9	2189.68	1667.05	522.63	-95	248.83	20.74
DEC	144.3	12.8	11.27	25955.6	0.9	3372.28	1667.05	1705.23	1610.22	263.46	21.95
						16614.65	**13753.67**				200.72

3.3 Rainwater Storage System

The storage rainwater system is one of the simplest operations of water self-supply. The storage system's essential element in a building is the storage cistern because the storage cistern's capacity is an important factor in estimating the system's cost and has a key role in operational and economic aspects. The sizing of a rainwater cistern is based on the end-user demand. Successful rainwater harvesting systems are generally associated with efficient storage [40].

3.3.1 Factors of rainwater storage

Many factors related to a storage system should be considered to ensure effective operation, such as location, planning, size, aesthetics, and functionality.

3.3.1.1 Location of the storage system

The harvestable rainwater can be stored at various locations may be stored inside or outside of a building, depending on the technological suitability, efficiency, and economy. Storage in both locations has many advantages and disadvantages. The studied building comprises one floor, and the roof type of the building is a pitched roof. Therefore, storing rainwater on the middle floors or on the rooftop is not possible because storing the rainwater on the building's rooftop requires a flat roof. There are two appropriate rainwater tank location options in this study, either in the building's basement or outside of the building. Choosing between the two will depend on space, aesthetic appreciation, and cost-estimation.

3.3.1.2 Planning of rainwater storage system

The planning of a rainwater storage system is depending on the purpose of rainwater supplying in the building. Because the achievement of the desired level of water quality depends on determining the aim of end uses. Two types of storage systems are separate storage that needs separate pumping and separate piping. The other system is the combined storage used when mixed water quality is suitable for end-use, particularly for non-potable purposes. Then the storage system can be designed by one pumping and one piping system. In this study, a separate storage and pumping system were chosen to keep harvested water separate from the main water supply. The economic analysis was studied based on this design.

3.3.1.3 Sizing of the storage tank

The storage reservoir is the most expensive part of the rainwater harvesting technique. Therefore, the storage reservoir sizing is determined to accommodate the volume of harvestable rainwater from the building's rooftop and avoid unnecessary costs. There are various methods for determining the volume of rainwater storage reservoirs, such as Demand-Side and Supply-Side Approaches.

Demand-Side Approach or dry-season demand based on the required water consumption rates and the occupancy of the building. The required storage volume is determined as the following formula:

$$\text{Demand} = \text{Water use per day} \times \text{Population to be served} \times \text{Number of dry days} \quad (3.2)$$

Supply Side Approach or graphical methods is a method to estimate the storage-reservoir size. Identifying the rainwater volume for storing in this method requires data such as the rainfall data, catchment area, and the catchment surface's runoff coefficient. A runoff coefficient of the catchment material means the ability of rainfall collection from the catchment area. Rainwater that could be supplied from the catchment is determined as the following formula:

$$\text{Water demand} = \text{average water demand (L/P)} \times \text{users} \times \text{days of dry period} \quad (3.2)$$

$$\text{Rainwater supply} = \text{catchment area} \times \text{rainfall} \times \text{runoff coefficient} \quad (3.3)$$

Most of the academic weeks are concentrated in winter, and the number of users can be identified since the data of water demand volume was determined by installing the flow meters. Also, the rooftop area and rainwater supply volume were previously calculated as presented. The next step in sizing the storage tank is the shape of the tank. The cistern may be purchased from the market as appropriate to the available area, with various advantages of using prefabricated tanks. (Figure 3.9) shows a cylindrical horizontal tank;

1. It can be easily installed and dismantled.
2. Position can be easily shifted or relocated.
3. Capacity can be changed by replacement.

Figure 3.9 Storage tank

3.3.1.4 Aesthetics

A proposal regarding the tank may not be acceptable aesthetically. The shape, size, material, or location of tanks may cause an aesthetic disagreement. In case of disagreement regarding the tank size, there are alternative methods to get a solution:

1. Decrease the height and increase the area of the tank.
2. Increase the height and decrease the area of the tank.
3. Installing multiple small tanks instead of one large tank.

3.3.1.5 Functionality of a storage tank

An effective rainwater-harvesting system requires regular operation and maintenance. Tank material also plays an important role in the effective storage and the quality of stored rainwater. For this reason, fiberglass tanks were selected, which are preferred in water supplying thanks to their economic and long service life characters. The advantages of fiberglass tanks are:

1. Long service life.
2. Easily transported due to its light-weight.
3. Available in different sizes from 200 liters to 100 thousand liters.
4. It doesn't require maintenance for years; in case of any repair requirement, it can be easily repaired.

3.4 Filtration

Filtration is a mechanical operation that treats the rainwater to non-potable or portable standards. Gutters on the building's rooftop are uses to harvest the rainwater; then, the collected rainwater is guided by downpipes into a storage tank. Using a wire mesh screen on gutters will prevent the leaves and debris from going into the rainwater harvesting system. Moreover, removing other contaminants from the collected rainwater before going into a storage tank using a sand filter technique is effective and not expensive. The passage of the rainwater from the sand filter will prevent particles' deposit at the bottom of the tank, as seen in (Figure 3.10). Most of the university's water demand is for non-potable purposes. Therefore, the utilization of sand filters is a good technique in the rainwater harvesting system at IKCU.

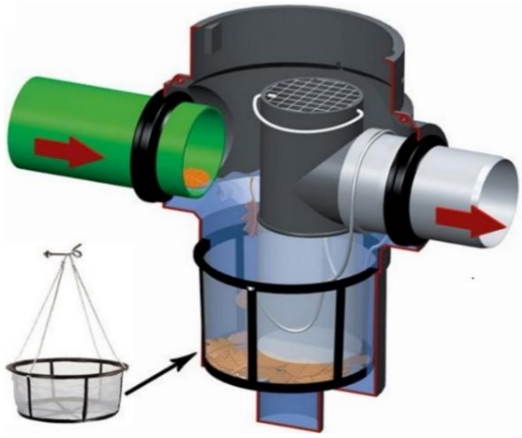

Figure 3.10 Type of pre-filter for rainwater harvest cistern

3.5 Rainwater-Distribution System

Distribution is the element responsible for water supplying with adequate pressure. In this system, rainwater is stored in the basement, where the water is lifted by pumping to the points of use at the upper level. This method is called Direct-Pumping System that using some automatic pressurizing devices in the pipe-network system, as shown in (Figure 3.11).

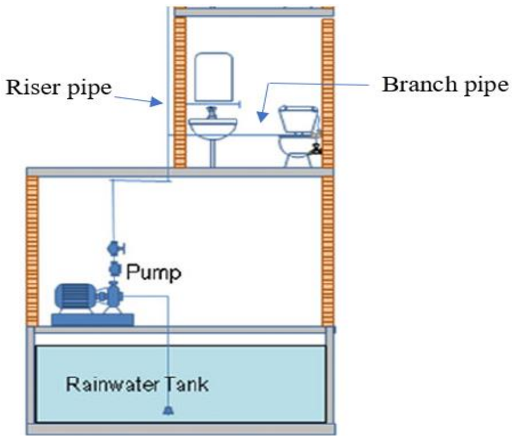

Figure 3.11 Direct-Pumping System

3.5.1 Pumping and flow of pump

A centrifugal pump is suitable for a rainwater supply system in the building. The pump flow is the volume of liquid that travels through the pump per unit time, which is in expressed liters per second (LPs) or liters per minute (LPm), etc.

$$\text{The required flow of pump } Q = \frac{V}{T} \quad (3.4)$$

Where; V is the volume of water to be filled in liters or m^3, and T is the time of filling. The pump's flow is based on the required flow into the building to meet the water demand. The distribution water system's efficiency depends on the efficiency of a pump between 70% and 93% for medium and large centrifugal pumps, no centrifugal pump with 100% efficiency. Calculations of the Pump Delivery Pressure and Power Consumption have an important role in choosing the pumps.

Pump Delivery Pressure:

$$\Delta P = \rho.g.h + L.P_L \qquad (3.5)$$

Power Consumption:

$$P = \frac{Q \times \Delta P}{\eta} \qquad (3.6)$$

Where; ΔP is pump delivery pressure (Pa), ρ is the density of water (kg/m^3), g is earth's gravity (m/sec^2), h is the height of the water from the pump to fixtures (m), L is the lengths of flow pipes (m), P_L is pressure loss (Pa/m), Q is the flow rate of water (m^3/h), and η is the efficiency of the pump.

Pressure loss is the loss of energy or head that occurs in a pipe flow due to friction; pressure loss is determined according to the required flow rate (Figure 3.12).

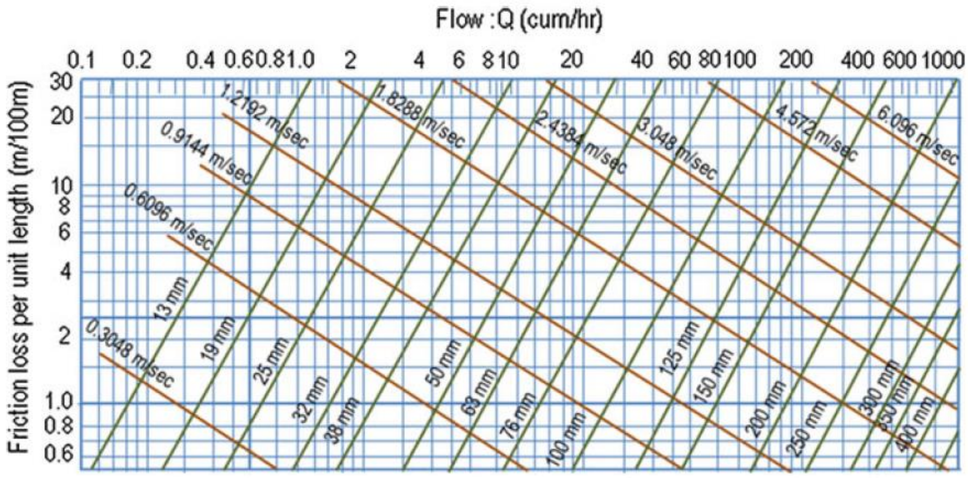

Figure 3.12 Friction loss in steel pipe

4. ECONOMIC ANALYSIS OF WATER STORAGE

Economic assessment of a system is an approach to determine the optimum use and cost-effectiveness, including comparing two or more alternatives under the assumptions and constraints. The economic analysis of the RWH was made for three scenarios by the calculations of the payback period (PBP), the net present value (NPV), the discounted payback period (DPBP), the Return on Investment (ROI), and the Internal Rate of Return (IRR).

4.1 Payback Period

The payback period (PBP) refers to the time to recover the cost of an initial investment. The payback period as a tool of analysis is often used because it is easy to apply. It does not account for the time value of money, risk, financing, or other important considerations. (PBP) is used as a preliminary evaluation and then supplemented by other evaluations, such as net present value (NPV) or the internal rate of return (IRR). (PBP) can be determined using a formula:

$$\text{PBP} = \frac{\text{Initial investment}}{\text{Cash inflows}} \quad (4.1)$$

4.2 Net Present Value

The net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows of the investments over the period. (NPV) shows the profitability of the project after accounting for the initial investment required to fund it. (NPV) can be determined using a formula:

$$\text{NPV} = \sum_{t=0}^{n} \frac{\text{Cash Flow}}{(1+\text{i})^{\text{n}}} - \text{Initial Investment} \quad (4.2)$$

Where; CF is the net cash flow over a period (the difference between the benefits and costs), i is the interest rate, and n is the number of years from now.

4.3 Discounted Payback Period

The discounted payback period (DPBP) calculates the time a project will recover the initial costs. The calculation is done by considering the time value of money and discounting future cash flows. (DPBP) can be determined using a formula:

$$\text{DPBP} = \text{Number of years before full recovery} + \frac{\text{Unrecovered discounted amount at the start of Year}}{\text{Discounted cashflow during the year}} \quad (4.3)$$

4.4 Return on Investment

Return on Investment (ROI) is a measure used to assign and evaluate an investment's efficiency and compare different investments' efficiency. The return on investment formula is:

$$\text{ROI} = \frac{\text{Net profit (over a period)}}{Investment} \times 100 \quad \text{or,}$$

$$\text{ROI} = \frac{\text{G}ain\ from\ investment - \text{Cost}\ of\ investment}{\text{Cost}\ of\ investment} \times 100 \quad (4.4)$$

4.5 Internal Rate of Return

The internal rate of return (IRR) is used to determine the potential investments' profitability, typically expressed in a percent range. The IRR assists in deciding whether to proceed with an investment. (IRR) formula is:

$$\text{IRR} = \frac{Cash\ Flows}{(1+i)^n} - \text{initial investment.} \quad (4.5)$$

Applying the economic analysis on RHWS requires determining initial investments and benefits. In this study, the benefits are estimated by the water used, but the initial investments change according to each scenario's assumptions. All the calculations were performed by Microsoft Excel.

4.6 Scenarios Study

In this study, the non-potable water demand was considered the same for all blocks except the laboratory side. According to the collected data, the average daily demand in F Block was 7.226 m^3 (male-female toilet) and 3.516 m^3 on the laboratory side. So, the annual overflow is estimated at 3749.6 m^3. The economic analysis of the rainwater harvesting system applying for over one scenario allows us to identify the optimal option in both practical and economic aspects. All scenarios were constructed by some assumptions as follows:

- The location is a male and female toilet.
- The flow demand is for 12 hours during the day.
- The toilet flushes discharged to the sewer system.
- Rainwater passes through a sand filter before being stored.
- The overflow from the tanks is discharged to the drainage system.
- The choice of the sand filter and pump sizes depends on the required flow rate.
- Tank sizes were determined to accommodate the maximum rainwater supply and fit the basement floor's height in case of the storage inside.
- The tank, sand filter, and pump costs were calculated as the initial cost of installation and purchase cost.

- If there is no stored water in storage tanks because of higher demand or rainwater shortage in some years, the water demand will be met using the municipality's main water.

4.6.1 Scenario 1

This scenario assumes that the collection of the harvestable rainwater is coming from the total catchment area. The maximum rainwater supply on a rainy day is 266.4 m^3. Selection may be a tank with 266.4 m^3 or three tanks with capacities of 100 m^3, 100 m^3, and 70 m^3, as shown in (Figure 4.1). However, the dimensions of large tanks are not compatible with the height of the basement. For this reason, the storage outside of the building was assumed.

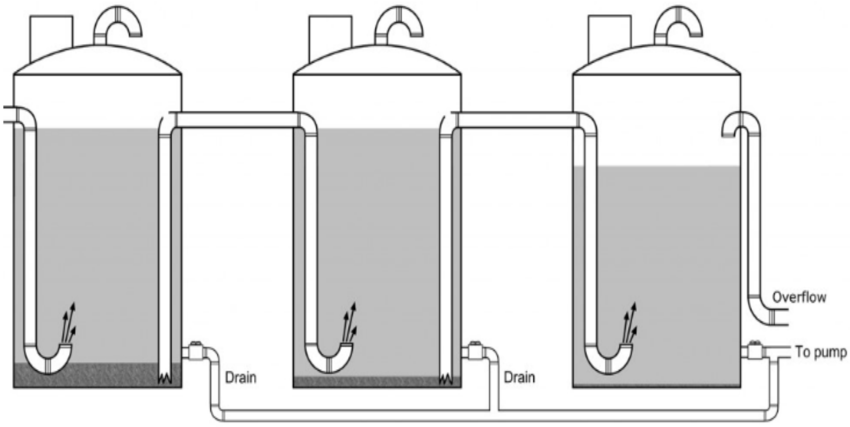

Figure 4.1 Connecting multiple tanks at the top

Calculations

RWH system saving in one year is determined by multiplying the unit price of water by the amount of rainwater that can be provided. According to the unit price of water, as seen in (Table 4.1), the total average annual savings was estimated at 159,500.6 TL.

Table 4.1 Unit price of water in Izmir.

Subscriber	Water price	Wastewater	Total
Schools (TL)	6.42	3.18	9.60

Determining the required capacity = $\frac{3.516\ m^3+(7.226\ m^3 \times 11\ toilets)}{12\ hours}$ = 6.92 m^3/h.

Average lenght of flow pipes is 443.6 m, the height of the floor or fluid is 2.6 m, pressure loss is determined from (Figure 3.12) for flow rate 6.92 m^3/h.

Pump Delivery Pressure: $\Delta P = \rho.g.h + L.P_L$

ΔP = 997 × 9.81 × 2.6 + 455 × 15 = 32254.5 Pa = 3.2 mSS.

Power Consumption: P = $\frac{Q \times \Delta P}{\eta} = \frac{0.002\ \frac{m^3}{sec} \times 32254.5\ Ps}{0.9}$ = 71.7 kilowatt

The maximum rainwater flow in rainy day is 266.4 m^3 as seen in (Table 3.7). Therefore, the sand filter should be selected to accommodate rainwater flow. The system's components cost in scenario 1 as seen in (Table 4.2), the economic analysis of scenario 1 in (Table 4.3), and the profit estimation of RHW System for over 20 years in (Table 4.4).

Table 4.2 The system's components cost in scenario 1.

Storage tanks with a capacity of 100 m^3	2 × 112000 ₺
Storage tank with capacity 70 m^3	1 × 7700 ₺
Sand filter 11 m^3/h	2 × 3205 ₺
Pump 5-15 m^3/h, 20-40 mSS	1 × 4847 ₺
Initial cost estimation	242957 ₺

The advantages of scenario 1

- Easy access for inspections.
- No cost for ground excavation.
- There is a need for fewer tanks and pumps
- Leakage or overflow from the tank will not make the floor wet.
- There is flexibility in choosing the height and size of the storage tanks.
- Installation of the pump may also be outside the building, with no noise and vibration for the occupants.

The disadvantages of scenario 1

- It is aesthetically undesirable.
- There is a chance of receiving sunlight inside the tank.
- There are risks of weather events and their implications.
- Any failure in the pump, tank, or filter makes the system completely out of service.

Table 4.3 Economic Analysis of Scenario 1.

Year n	Cash flow	Net Cash Flow	Interest Rate	Net Present Value	Cumulative Cash Flow
0	-242,957.00	-242,957.00	17%	-242,957.00	-242,957.00
1	132,030.68	-110,926.32	17%	112,846.74	-130,110.26
2	132,030.68	21,104.36	17%	96,450.20	-33,660.06
3	132,030.68	153,135.04	17%	82,436.07	48,776.01
4	132,030.68	285,165.72	17%	70,458.18	119,234.18
5	132,030.68	417,196.40	17%	60,220.67	179,454.85
6	132,030.68	549,227.08	17%	51,470.65	230,925.50
7	132,030.68	681,257.76	17%	43,992.01	274,917.52
8	132,030.68	813,288.44	17%	37,600.01	312,517.53
9	132,030.68	945,319.12	17%	32,136.76	344,654.29
10	132,030.68	1,077,349.80	17%	27,467.32	372,121.60
11	132,030.68	1,209,380.48	17%	23,476.34	395,597.94
12	132,030.68	1,341,411.16	17%	20,065.25	415,663.19
13	132,030.68	1,473,441.84	17%	17,149.78	432,812.98
14	132,030.68	1,605,472.52	17%	14,657.94	447,470.91
15	132,030.68	1,737,503.20	17%	12,528.15	459,999.06
16	132,030.68	1,869,533.88	17%	10,707.82	470,706.88
17	132,030.68	2,001,564.56	17%	9,151.98	479,858.86
18	132,030.68	2,133,595.24	17%	7,822.21	487,681.07
19	132,030.68	2,265,625.92	17%	6,685.65	494,366.72
20	132,030.68	2,397,656.60	17%	5,714.23	500,080.95
PBP (year)	**1.84**	**1.84**		**DPB (Year)**	**2.41**
IRR %	**54%**			**ROI%**	**887%**

Table 4.4 Profit estimation of RHW System for over 20 years.

Total water demand (m^3/year)	13753.2 m^3/year
Total water supplied (m^3/year)	16614.65 m^3/year
RWH system savings over a year (TL)	9.60 × 13753.2 = 132030.7 ₺
RWH system initial cost (TL)	242957 ₺
RWH system pay back period	1.84 years
RWH system discounted payback period	2.41 years
Return on Investment (ROI)	887 %
Internal Rate of Return (IRR)	54 %
RWH system savings over 20 years (TL)	2,397,656.60 ₺

4.6.2 Scenario 2

This scenario assumes that the harvestable rainwater collection is coming from one location is estimated at 2163 m^2 and the maximum rainwater supply on a rainy day is 22.2 m^3. Selection may be a tank with capacity 25 m^3 but outside of the building due to the inappropriate height of tank or three tanks with capacities 10 m^3, 10 m^3, and 3 m^3 inside the building. For aesthetic reasons, the assumption of the storage tank locations will be on the basement floor.

Calculations

Determining the required capacity:

Capacity of one toilet in laboratory side = $\frac{3.516\ m^3}{12\ hours}$ = 0.29 m^3/h.

Capacity of one toilet in classes side = $\frac{7.226\ m^3}{12\ hours}$ = 0.60 m^3/h.

Pump Delivery Pressure: $\Delta P = \rho.g.h + L.P_L$

$\Delta P1$ = 997 × 9.81× 2.6 + 455 × 3 = 26794.5 Pa = 2.7 mSS.

$\Delta P2$ = 997 × 9.81 × 2.6 + 455 × 9 = 29524.5 Pa = 2.9 mSS.

Power Consumption:

P1 = $\frac{Q \times \Delta P}{\eta} = \frac{8 \times 10^{-5}\ \frac{m^3}{sec} \times 26794.5\ \ Ps}{0.9}$ = 2.4 kilowatt

P1 = $\frac{Q \times \Delta P}{\eta} = \frac{1.7 \times 10^{-4}\ \frac{m^3}{sec} \times 29524.5\ \ Ps}{0.9}$ = 5.6 kilowatt

The maximum rainwater flow in rainy day is 22.2 m^3. The system's components cost in scenario 2 as seen in (Table 4.5), the economic analysis of scenario 2 in (Table 4.6), and the profit estimation of RHW System for over 20 years in (Table 4.7).

Table 4.5 The system's components cost in scenario 2.

Storage tanks with a capacity of 10 m^3	2×12 toilet $\times$ 7000 ₺
Storage tank with capacity 5 m^3	1×12 toilet $\times$ 4000 ₺
Sand filter 1 m^3/h	12×2227 ₺
Pump 0-5 m^3/h, 20-40 mSS	$12 \times$ 3486 ₺
Initial cost estimation	284556 ₺

The advantages of scenario 2

- It is aesthetically desirable.
- No cost for ground excavation.
- There is no chance of receiving sunlight inside the tank.
- In case of any failure in one location of the system is not affected by the other locations.

The disadvantages of scenario 2

- Leakage or overflow from the tank will make the floor wet.
- There is no flexibility in choosing the height and size of the storage tanks.
- Leakage from the tanks can cause deterioration of the soil's load-bearing properties that support the building foundation.

Table 4.6 Economic Analysis of Scenario 2.

Year n	Cash flow	Net Cash Flow	Interest Rate	Net Present Value	Cumulative Cash Flow
0	-284,556.00	-284,556.00	17%	-284,556.00	-284,556.00
1	132,030.68	-152,525.32	17%	112,846.74	-171,709.26
2	132,030.68	-20,494.64	17%	96,450.20	-75,259.06
3	132,030.68	111,536.04	17%	82,436.07	7,177.01
4	132,030.68	243,566.72	17%	70,458.18	77,635.18
5	132,030.68	375,597.40	17%	60,220.67	137,855.85
6	132,030.68	507,628.08	17%	51,470.65	189,326.50
7	132,030.68	639,658.76	17%	43,992.01	233,318.52
8	132,030.68	771,689.44	17%	37,600.01	270,918.53
9	132,030.68	903,720.12	17%	32,136.76	303,055.29
10	132,030.68	1,035,750.80	17%	27,467.32	330,522.60
11	132,030.68	1,167,781.48	17%	23,476.34	353,998.94
12	132,030.68	1,299,812.16	17%	20,065.25	374,064.19
13	132,030.68	1,431,842.84	17%	17,149.78	391,213.98
14	132,030.68	1,563,873.52	17%	14,657.94	405,871.91
15	132,030.68	1,695,904.20	17%	12,528.15	418,400.06
16	132,030.68	1,827,934.88	17%	10,707.82	429,107.88
17	132,030.68	1,959,965.56	17%	9,151.98	438,259.86
18	132,030.68	2,091,996.24	17%	7,822.21	446,082.07
19	132,030.68	2,224,026.92	17%	6,685.65	452,767.72
20	132,030.68	2,356,057.60	17%	5,714.23	458,481.95
PBP (year)	**2.16**	**2.16**		**DPB (Year)**	**2.90**
IRR %	**46%**			**ROI%**	**728%**

Table 4.7 Profit estimation of RHW System for over 20 years.

Total water demand (m^3/year)	13753.2 m^3/year
`Total water supplied (m^3/year)	16614.65 m^3/year
RWH system savings over a year (TL)	9.60 × 13753.2 = 132030.7 ₺
RWH system initial cost (TL)	284556 ₺
RWH system pay back period	2.16 years
RWH system discounted payback period	2.90 years
Return on Investment (ROI)	728 %
Internal Rate of Return (IRR)	46 %
RWH system savings over 20 years (TL)	2,356,057.60 ₺

4.6.3 Scenario 3

This scenario assumes that the harvestable rainwater collection is coming from two locations that are estimated at 4326 m^2, and the maximum rainwater supply on a rainy day is 44.4 m^3. Selection may be a tank with a capacity of 45 m^3 or five tanks with capacities of 4 ×10 m^3 and 5 m^3 inside the building. For aesthetic reasons, the assumption of the storage tanks' locations will be on the basement floor in this scenario.

Calculations

Determining the required capacity:

Capacity of two locations = $\frac{7.226\ m^3 \times 2}{12\ hours}$ = 1.2 m^3/h.

ΔP = 997 × 9.81 × 2.6 + 455 × 11 = 30434.5 Pa = 3 mSS.

P = $\frac{Q \times \Delta P}{\eta} = \frac{3.3 \times 10^{-4} \frac{m^3}{sec} \times 32254.5\ Ps}{0.9}$ = 11.8 kilowatt

The maximum rainwater flow in rainy day is 44.4 m^3. The system's components cost in scenario 3 as seen in (Table 4.8), the economic analysis of scenario 3 in (Table 4.9), and the profit estimation of RHW System for over 20 years in (Table 4.10).

Table 4.8 The system's components cost in this scenario.

Storage tanks with a capacity of 10 m^3	4×6 toilet $\times$ 7000 ₺
Storage tank with capacity 5 m^3	1×6 toilet $\times$ 4000 ₺
Sand filter 2 m^3/h	6×1035 ₺
Pump 0-5 m^3/h, 20-40 mSS	6×3486 ₺
Initial cost estimation	219126 ₺

The advantages of scenario 3

- It is aesthetically desirable.
- No cost for ground excavation.
- There is no chance of receiving sunlight inside the tank.
- In case of any failure in one location of the system is not affected by the other locations.

The disadvantages of scenario 3

- There is need more tanks and pumps.
- Leakage or overflow from the tank will not make the floor wet.
- There is no flexibility in choosing the height and size of the storage tanks.
- Leakage from the tanks can cause deterioration of the soil's load-bearing properties that support the building foundation.
- The maintenance is difficult, and the potential of the faults in this scenario is high due to a large number of tanks, filters, and pumps.

Table 4.9 Economic Analysis of Scenario 3.

Year n	Cash flow	Net Cash Flow	Interest Rate	Net Present Value	Cumulative Cash Flow
0	-219,126.00	-219,126.00	17%	-219,126.00	-219,126.00
1	132,030.68	-87,095.32	17%	112,846.74	-106,279.26
2	132,030.68	44,935.36	17%	96,450.20	-9,829.06
3	132,030.68	176,966.04	17%	82,436.07	72,607.01
4	132,030.68	308,996.72	17%	70,458.18	143,065.18
5	132,030.68	441,027.40	17%	60,220.67	203,285.85
6	132,030.68	573,058.08	17%	51,470.65	254,756.50
7	132,030.68	705,088.76	17%	43,992.01	298,748.52
8	132,030.68	837,119.44	17%	37,600.01	336,348.53
9	132,030.68	969,150.12	17%	32,136.76	368,485.29
10	132,030.68	1,101,180.80	17%	27,467.32	395,952.60
11	132,030.68	1,233,211.48	17%	23,476.34	419,428.94
12	132,030.68	1,365,242.16	17%	20,065.25	439,494.19
13	132,030.68	1,497,272.84	17%	17,149.78	456,643.98
14	132,030.68	1,629,303.52	17%	14,657.94	471,301.91
15	132,030.68	1,761,334.20	17%	12,528.15	483,830.06
16	132,030.68	1,893,364.88	17%	10,707.82	494,537.88
17	132,030.68	2,025,395.56	17%	9,151.98	503,689.86
18	132,030.68	2,157,426.24	17%	7,822.21	511,512.07
19	132,030.68	2,289,456.92	17%	6,685.65	518,197.72
20	132,030.68	2,421,487.60	17%	5,714.23	523,911.95
PBP (year)	**1.66**	**1.66**		**DPB (Year)**	**2.12**
IRR %	**60%**			**ROI%**	**1005%**

Table 4.10 Profit estimation of RHW System for over 20 years.

Total water demand (m^3/year)	13753.2 m^3/year
Total water supplied (m^3/year)	16614.65 m^3/year
RWH system savings over a year (TL)	9.60 × 13753.2 = 132030.7 ₺
RWH system initial cost (TL)	219126 ₺
RWH system pay back period	1.66 years
RWH system discounted payback period	2.12 years
Return on Investment (ROI)	1005 %
Internal Rate of Return (IRR)	60 %
RWH system savings over 20 years (TL)	2,421,487.60 ₺

5. SIMULATION OF RAINWATER STORAGE AT IZMIR KATIP CELEBI UNIVERSITY:

A computer simulation imitates the operation of a system over time. The simulation's intended purpose is to present the underlying mechanisms that control the behavior of the system.

This thesis simulates the rainwater harvesting system at Izmir Katip Celebi University and assesses the rainwater harvesting system's potential. It was constructed by creating a web page, adding the system's data, and determining what data results to display from this simulation using HTML, CSS, and JavaScript. The home page of the simulation consists of three parts, the first one has the options, the second one has the table of results, and the last one has the charts.

The options page is a list that contains a set of inputs required for the simulation, such as; start date, city, catchment surface area, water demand, Rainfall days calculation method, and calculation period. There are two different modes of rainfall days calculation, random mode, and continuous uniform distribution mode.

The random mode is operated by dividing the amount of monthly rainfall by the number of rainy days in the same month; then, the program randomly selects the rainy days. While the continuous uniform distribution mode is operated by dividing the amount of monthly rainfall by the number of month days. The calculation period can be daily, weekly, or monthly as the user desire. Then the simulation displays the changes in the storage cistern during the selected period. The daily selection shows the cistern's state every day, while the weekly selection shows the cistern's state on the first, third, and fifth day of every week, and the monthly one shows the state of the cistern at the first, eleventh, and twenty-first day of each month. After giving the start command and during the simulation process, the volume of stored rainwater and the total savings change over the required time. The value of the total savings starts from a negative value that indicates the initial system cost, and by continuing the simulation process, this value starts to increase to be profit. Total savings is calculated according to the water used from the cistern. The system also presents the consumed main water volume and the overflow water volume. The total savings value changes according to the selected scenario.

The second page contains the table of simulation results: rainfall amount, water collected, water used, cash flow, and accumulated savings. Cash flow is the product of unit water price multiplied by the amount of water used.

The last page has the diagrams that include; cost by scenario, rainfall days, rainfall (mm), cash flow, overflow, and payoff. The costs of the systems were estimated and added as input data. The rainy days and the rainfall amount charts were determined according to the General Directorate of Meteorology. The cash flow chart presents the changes in cash flow and water supplied by the system over time, while the overflow chart shows the changes in excess water and the used main water over time. Whereas the payoff chart clarifies the potential time to cover the initial cost of each scenario. The simulation process evaluated many cases:

Case 1: The random mode for a daily period over five days of scenario 1.

In this case, no clarified results in charts due to the short selected time, as shown in (Figures 5.1, 5.2).

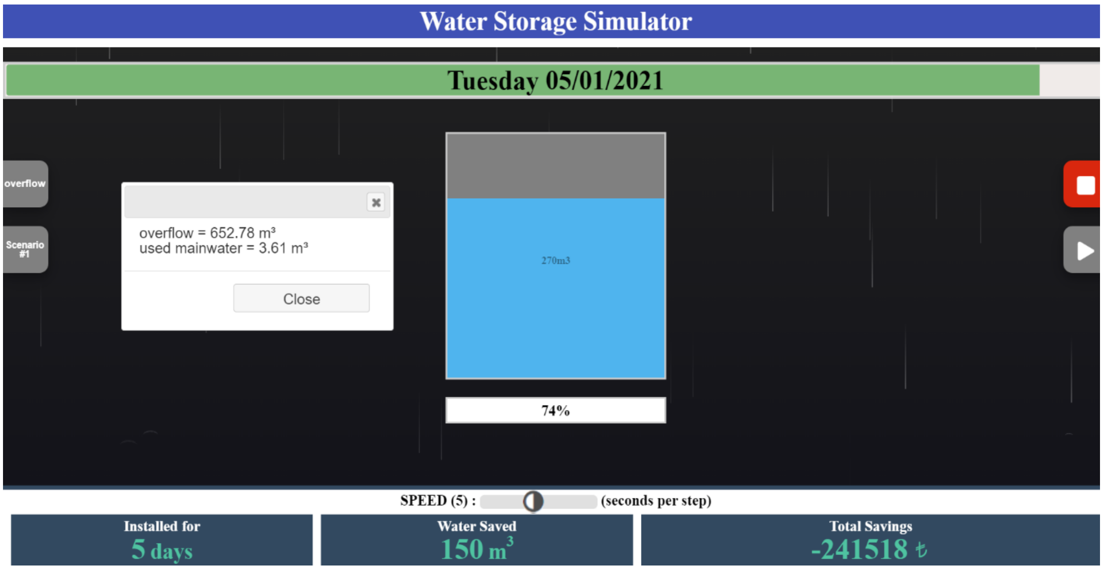

Figure 5.1 The water saved and total savings of case 1


RESULTS

Date	rainfall amount	water collected	water used	cash flow	accumulated savings
1 - Friday 01/01/2021	no rain	0.00 m³	0.000 m³	0.00 tl	-242957.00 tl
2 - Saturday 02/01/2021	10.72 mm	250.33 m³	3.611 m³	34.67 tl	-242922.33 tl
3 - Sunday 03/01/2021	10.72 mm	250.33 m³	3.611 m³	34.67 tl	-242887.67 tl
4 - Monday 04/01/2021	10.72 mm	250.33 m³	71.332 m³	684.79 tl	-242202.88 tl
5 - Tuesday 05/01/2021	10.72 mm	250.33 m³	71.332 m³	684.79 tl	-241518.09 tl

Figure 5.2 The Simulation results table of case 1

In case 1 that used the random mode for the daily period of scenario 1, about 74% of the cistern volume is filled, as seen in (Figure 5.1). No rain on the first day, as shown in (Figure 5.2), and the system in five days has about 150 m^3 of water saved in addition to 652.78 m^3 overflow volume. The amount of main water consumption over this time is 3.61 m^3. The initial cost of scenario 1 is 242957 TL; after five days, the value decreased to 241518 TL. There are no clarified results in charts due to the selected short time.

<u>Case 2:</u> The uniform distribution mode for a daily period over five days of scenario 1.

In this case, no clarified results in charts due to the short selected time, as shown in (Figures 5.3, 5.4).

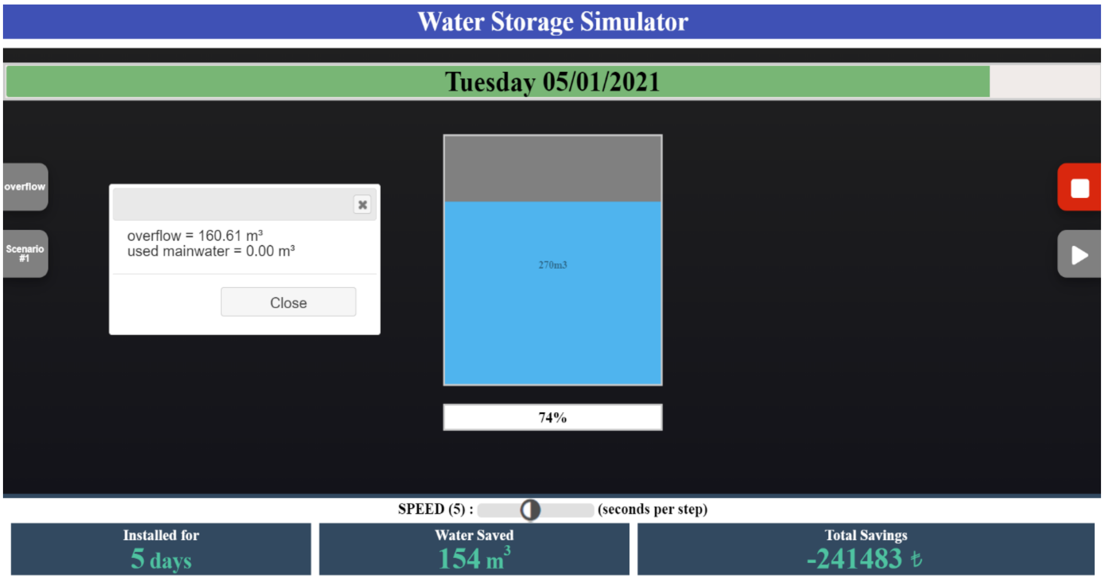

Figure 5.3 The water saved and total savings of case 2

RESULTS

Date	rainfall amount	water collected	water used	cash flow	accumulated savings
1 - Friday 01/01/2021	4.39 mm	102.56 m^3	3.611 m^3	34.67 tl	-242922.33 tl
2 - Saturday 02/01/2021	4.39 mm	102.56 m^3	3.611 m^3	34.67 tl	-242887.67 tl
3 - Sunday 03/01/2021	4.39 mm	102.56 m^3	3.611 m^3	34.67 tl	-242853.00 tl
4 - Monday 04/01/2021	4.39 mm	102.56 m^3	71.332 m^3	684.79 tl	-242168.22 tl
5 - Tuesday 05/01/2021	4.39 mm	102.56 m^3	71.332 m^3	684.79 tl	-241483.43 tl

Figure 5.4 The Simulation results table of case 2

In case 2, the same data used in case 1 but in this one, the rainfall days calculation was by the uniform distribution mode. Also, about 74% of the cistern volume is filled, as seen in (Figure 5.3). There is uniform rainfall that is calculated by dividing the amount of rainfall by the number of month days. The system has about 154 m^3 of water saved in addition to 160.61 m^3 overflow volume. No main water consumption over this time. The initial cost of scenario 1 is 242957 TL; after five days, the value decreased to 241483 TL.

<u>Case 3</u>: The random mode for a weekly period over seventeen weeks of scenario 1 (Figures 5.5, 5.6, 5.7, 5.8 and 5.9).

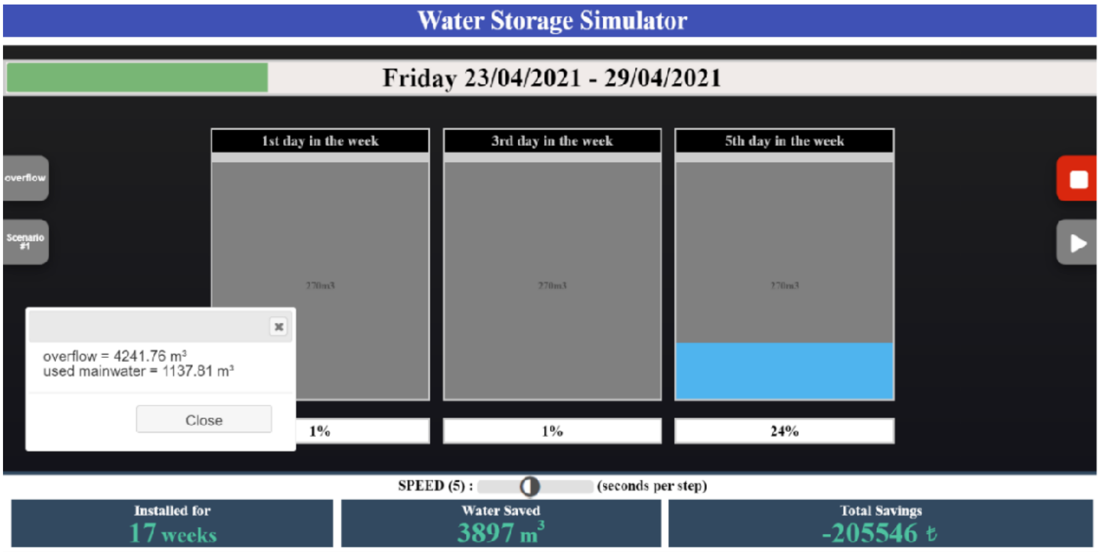

Figure 5.5 The water saved and total savings of case 3

RESULTS

Date	rainfall amount	water collected	water used	cash flow	accumulated savings
1 - Friday 01/01/2021 - 07/01/2021	10.72 mm	250.33 m^3	213.996 m^3	2054.36 tl	-240902.64 tl
2 - Friday 08/01/2021 - 14/01/2021	42.87 mm	1001.33 m^3	325.276 m^3	3122.65 tl	-237779.99 tl
3 - Friday 15/01/2021 - 21/01/2021	21.43 mm	500.67 m^3	341.332 m^3	3276.79 tl	-234503.20 tl
4 - Friday 22/01/2021 - 28/01/2021	21.43 mm	500.67 m^3	92.998 m^3	892.78 tl	-233610.42 tl
5 - Friday 29/01/2021 - 04/02/2021	29.66 mm	692.87 m^3	25.277 m^3	242.66 tl	-233367.76 tl
6 - Friday 05/02/2021 - 11/02/2021	28.42 mm	663.80 m^3	25.277 m^3	242.66 tl	-233125.10 tl
7 - Friday 12/02/2021 - 18/02/2021	47.36 mm	1106.33 m^3	296.161 m^3	2843.15 tl	-230281.96 tl
8 - Friday 19/02/2021 - 25/02/2021	47.36 mm	1106.33 m^3	363.882 m^3	3493.27 tl	-226788.69 tl
9 - Friday 26/02/2021 - 04/03/2021	9.47 mm	221.27 m^3	344.943 m^3	3311.45 tl	-223477.24 tl
10 - Friday 05/03/2021 - 11/03/2021	32.87 mm	767.82 m^3	363.882 m^3	3493.27 tl	-219983.97 tl
11 - Friday 12/03/2021 - 18/03/2021	8.22 mm	191.95 m^3	363.882 m^3	3493.27 tl	-216490.70 tl
12 - Friday 19/03/2021 - 25/03/2021	8.22 mm	191.95 m^3	147.362 m^3	1414.68 tl	-215076.03 tl
13 - Friday 26/03/2021 - 01/04/2021	8.22 mm	191.95 m^3	191.954 m^3	1842.76 tl	-213233.27 tl
14 - Friday 02/04/2021 - 08/04/2021	5.82 mm	136.02 m^3	185.307 m^3	1778.95 tl	-211454.31 tl
15 - Friday 09/04/2021 - 15/04/2021	5.82 mm	136.02 m^3	136.017 m^3	1305.77 tl	-210148.55 tl
16 - Friday 16/04/2021 - 22/04/2021	11.65 mm	272.03 m^3	272.035 m^3	2611.53 tl	-207537.01 tl
17 - Friday 23/04/2021 - 29/04/2021	11.65 mm	272.03 m^3	207.349 m^3	1990.55 tl	-205546.46 tl

Figure 5.6 The Simulation results table of case 3

In case 3 that used the random mode for a weekly period over seventeen weeks of scenario 1 (Figures 5.5, 5.6), about 24% of the cistern volume is filled. The rainfall amount refers to the total rainfall in each week. The system over seventeen weeks has about 3897 m^3 of water saved in addition to 4241.76 m^3 overflow volume. The amount of main water consumption over this time is 1137.81 m^3, and the initial cost of scenario 1 decreased to 205546 TL. The cash flow chart in (Figure 5.7) shows the proportional relationship between the cash flow and the water supplied by water; it is an increased value. There is a need for main water; it is about 510 m^3; on the other hand, the overflow was estimated at 4200 m^3, as seen in (Figure 5.8). The payoff chart illustrates the possible time to cover the initial cost in each scenario. Scenario 2 needs more time to cover the initial cost, as seen in (Figure 5.9).

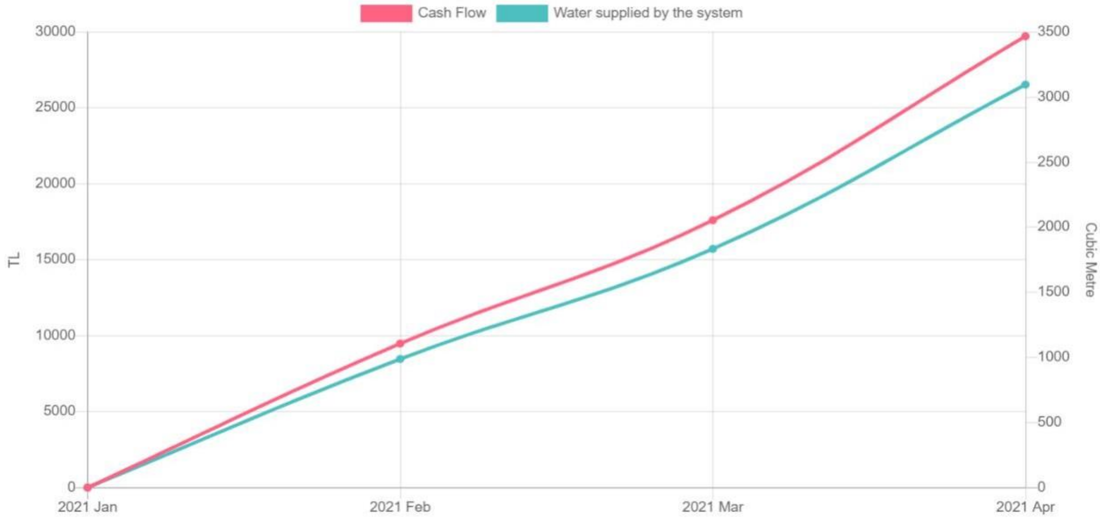

Figure 5.7 Cash flow chart of case 3

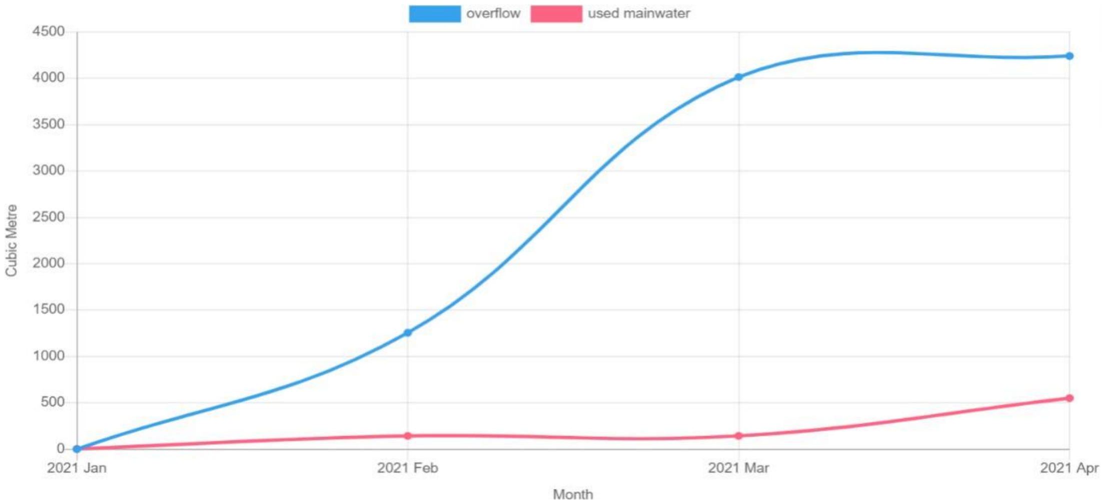

Figure 5.8 Overflow chart of case 3

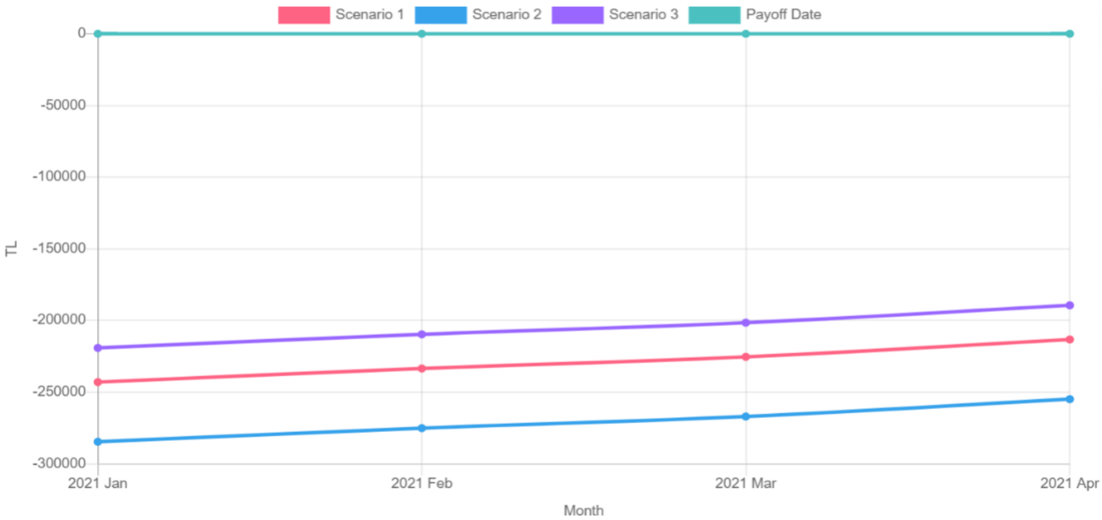

Figure 5.9 Payoff chart of case 3

Case 4: The uniform distribution mode for a weekly period over 17 weeks of scenario 1 (Figures 5.10, 5.11, 5.12, 5.13 and 5.14).

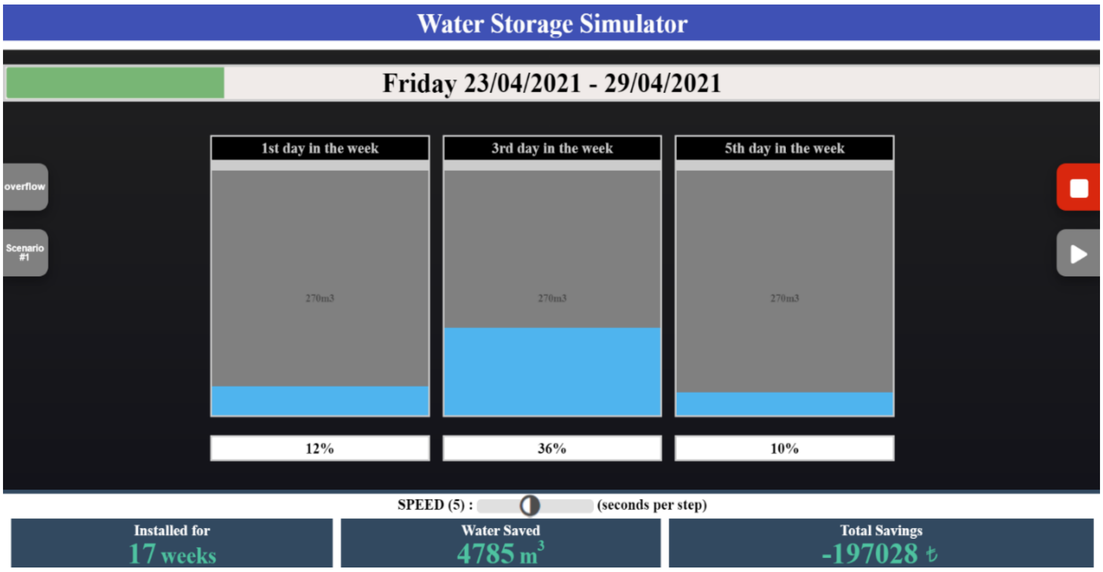

Figure 5.10 The water saved and total savings of case 4

RESULTS

Date	rainfall amount	water collected	water used	cash flow	accumulated savings
1 - Friday 01/01/2021 - 07/01/2021	30.73 mm	717.89 m^3	296.161 m^3	2843.15 tl	-240113.85 tl
2 - Friday 08/01/2021 - 14/01/2021	30.73 mm	717.89 m^3	363.882 m^3	3493.27 tl	-236620.59 tl
3 - Friday 15/01/2021 - 21/01/2021	30.73 mm	717.89 m^3	363.882 m^3	3493.27 tl	-233127.32 tl
4 - Friday 22/01/2021 - 28/01/2021	30.73 mm	717.89 m^3	92.998 m^3	892.78 tl	-232234.54 tl
5 - Friday 29/01/2021 - 04/02/2021	27.79 mm	649.05 m^3	25.277 m^3	242.66 tl	-231991.88 tl
6 - Friday 05/02/2021 - 11/02/2021	25.57 mm	597.42 m^3	25.277 m^3	242.66 tl	-231749.22 tl
7 - Friday 12/02/2021 - 18/02/2021	25.57 mm	597.42 m^3	296.161 m^3	2843.15 tl	-228906.08 tl
8 - Friday 19/02/2021 - 25/02/2021	25.57 mm	597.42 m^3	363.882 m^3	3493.27 tl	-225412.81 tl
9 - Friday 26/02/2021 - 04/03/2021	20.72 mm	483.90 m^3	363.882 m^3	3493.27 tl	-221919.54 tl
10 - Friday 05/03/2021 - 11/03/2021	17.07 mm	398.77 m^3	363.882 m^3	3493.27 tl	-218426.27 tl
11 - Friday 12/03/2021 - 18/03/2021	17.07 mm	398.77 m^3	363.882 m^3	3493.27 tl	-214933.01 tl
12 - Friday 19/03/2021 - 25/03/2021	17.07 mm	398.77 m^3	363.882 m^3	3493.27 tl	-211439.74 tl
13 - Friday 26/03/2021 - 01/04/2021	16.17 mm	377.62 m^3	363.882 m^3	3493.27 tl	-207946.47 tl
14 - Friday 02/04/2021 - 08/04/2021	10.73 mm	250.73 m^3	363.882 m^3	3493.27 tl	-204453.20 tl
15 - Friday 09/04/2021 - 15/04/2021	10.73 mm	250.73 m^3	271.993 m^3	2611.13 tl	-201842.08 tl
16 - Friday 16/04/2021 - 22/04/2021	10.73 mm	250.73 m^3	250.725 m^3	2406.96 tl	-199435.11 tl
17 - Friday 23/04/2021 - 29/04/2021	10.73 mm	250.73 m^3	250.725 m^3	2406.96 tl	-197028.15 tl

Figure 5.11 The Simulation results table of case 4

In case 4, the same data used in case 3 but in this one, the rainfall days calculation was by the uniform distribution mode. (Figures 5.10, 5.11) show that the system saved water about 4785 m^3, and the initial cost of scenario 1 decreased to 197028 TL. The (Figure 5.12) presents that the water supplied value is higher than the cash flow value. The system does not need the main water, but the overflow value is estimated at 3600 m^3 in (Figure 5.13). The payoff chart in (Figure 5.14) is the same as case 3.

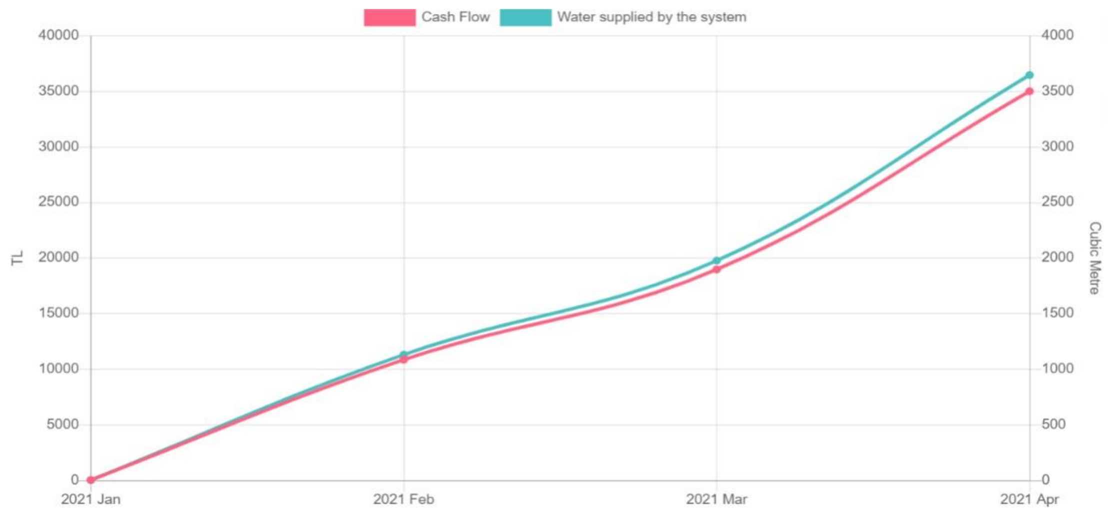

Figure 5.12 Cash flow chart of case 4

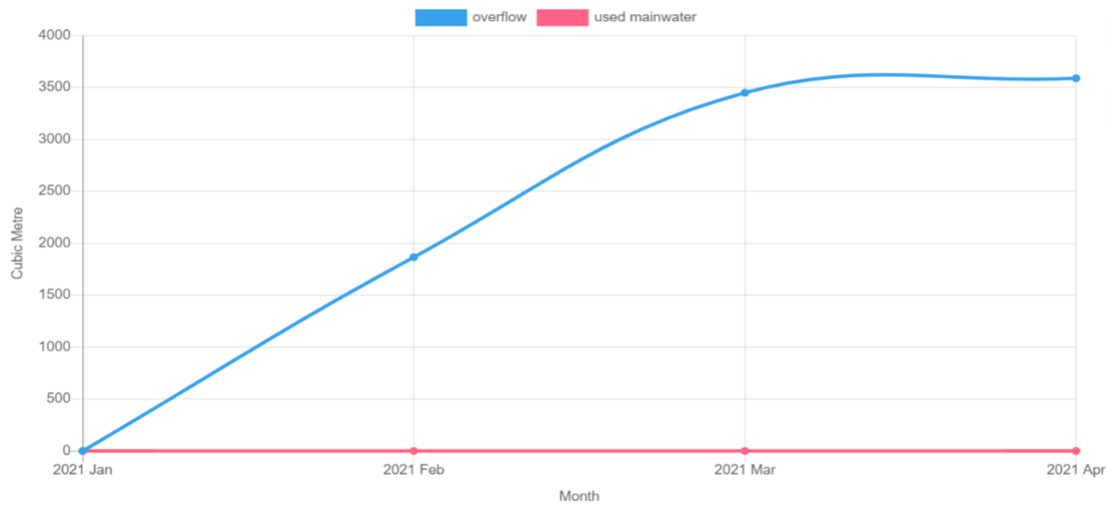

Figure 5.13 Overflow chart of case 4

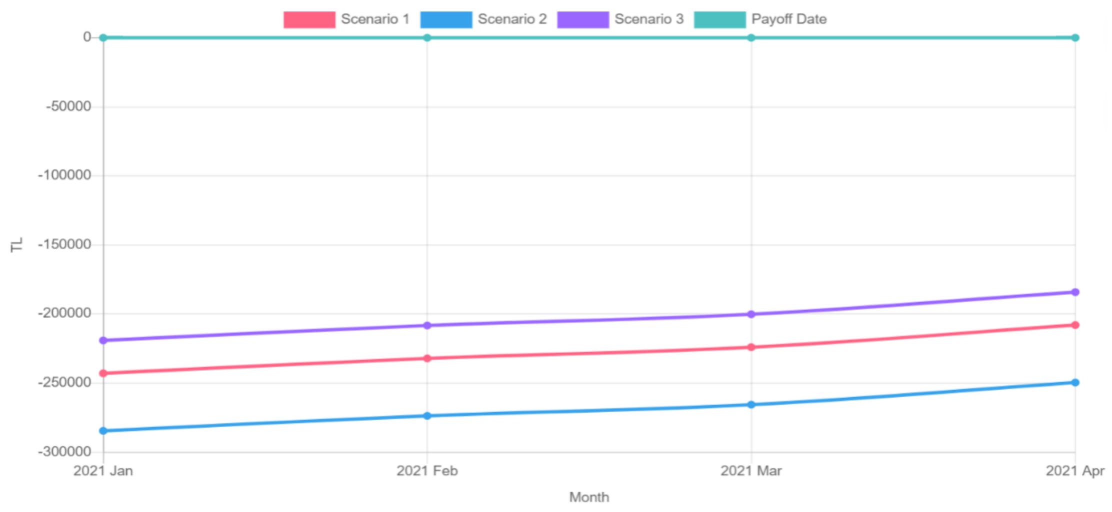

Figure 5.14 Payoff chart of case 4

Case 5: The random mode for a monthly period over 42 months of scenario 1 (Figures 5.15, 5.16, 5.17, 5.18 and 5.19).

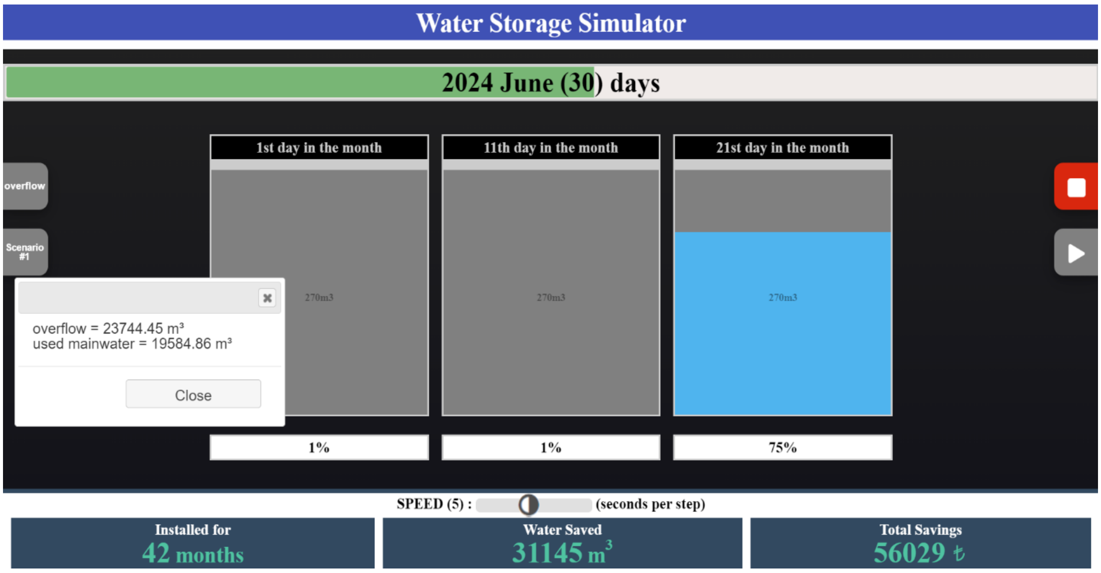

Figure 5.15 The water saved and total savings of case 5

RESULTS

Date	rainfall amount	water collected	water used	cash flow	accumulated savings
19 - 2022 July (31) days	no rain	0.00 m³	87.058 m³	835.76 ₺	-126904.07 ₺
20 - 2022 August (31) days	22.80 mm	532.60 m³	532.597 m³	5112.93 ₺	-121791.14 ₺
21 - 2022 September (30) days	15.80 mm	369.08 m³	295.277 m³	2834.66 ₺	-118956.48 ₺
22 - 2022 October (31) days	57.81 mm	1350.53 m³	973.089 m³	9341.66 ₺	-109614.82 ₺
23 - 2022 November (30) days	106.48 mm	2487.26 m³	1262.028 m³	12115.47 ₺	-97499.35 ₺
24 - 2022 December (31) days	135.28 mm	3160.10 m³	1335.485 m³	12820.66 ₺	-84678.70 ₺
25 - 2023 January (31) days	139.31 mm	3254.33 m³	1127.756 m³	10826.46 ₺	-73852.24 ₺
26 - 2023 February (28) days	113.67 mm	2655.20 m³	913.760 m³	8772.10 ₺	-65080.14 ₺
27 - 2023 March (31) days	73.96 mm	1727.59 m³	1332.382 m³	12790.87 ₺	-52289.27 ₺
28 - 2023 April (30) days	34.94 mm	816.10 m³	872.108 m³	8372.24 ₺	-43917.04 ₺
29 - 2023 May (31) days	29.34 mm	685.36 m³	685.359 m³	6579.45 ₺	-37337.59 ₺
30 - 2023 June (30) days	5.27 mm	123.17 m³	36.110 m³	346.66 ₺	-36990.94 ₺
31 - 2023 July (31) days	16.40 mm	383.10 m³	334.998 m³	3215.98 ₺	-33774.95 ₺
32 - 2023 August (31) days	11.40 mm	266.30 m³	28.888 m³	277.32 ₺	-33497.63 ₺
33 - 2023 September (30) days	23.70 mm	553.62 m³	515.927 m³	4952.90 ₺	-28544.73 ₺
34 - 2023 October (31) days	57.81 mm	1350.53 m³	1184.393 m³	11370.17 ₺	-17174.56 ₺
35 - 2023 November (30) days	95.83 mm	2238.53 m³	1358.035 m³	13037.14 ₺	-4137.42 ₺
36 - 2023 December (31) days	191.65 mm	4476.81 m³	1511.532 m³	14510.71 ₺	10373.28 ₺

Figure 5.16 The Simulation results table of case 5

In case 5, the random mode was used for a monthly period of scenario 1, the initial cost decreased to 56029 TL, as seen in (Figure 5.15). No rain in July, as seen in (Figure 5.16), and in the 36th month, the initial cost was covered, and the profit process started. The system in 42 months has about 31145 m^3 of water saved in addition to 23744.45 m^3 overflow volume. The amount of main water consumption over this time is 19584.86 m^3. (Figure 5.17) presents the water supply value is higher than the cash flow value. The system uses the main water from time to time as shown in (Figure 5.18), the total consumption is estimated at 18000 m^3, but the overflow is about 23000 m^3, which means in case of overflow saving, there is no need for main water. The payoff chart in (Figure 5.19) shows the intersection points between the scenarios and the payoff line, scenario 1 in December 2023 can cover the initial cost, scenario 2 in April 2024, whereas scenario 1 in November 2023.

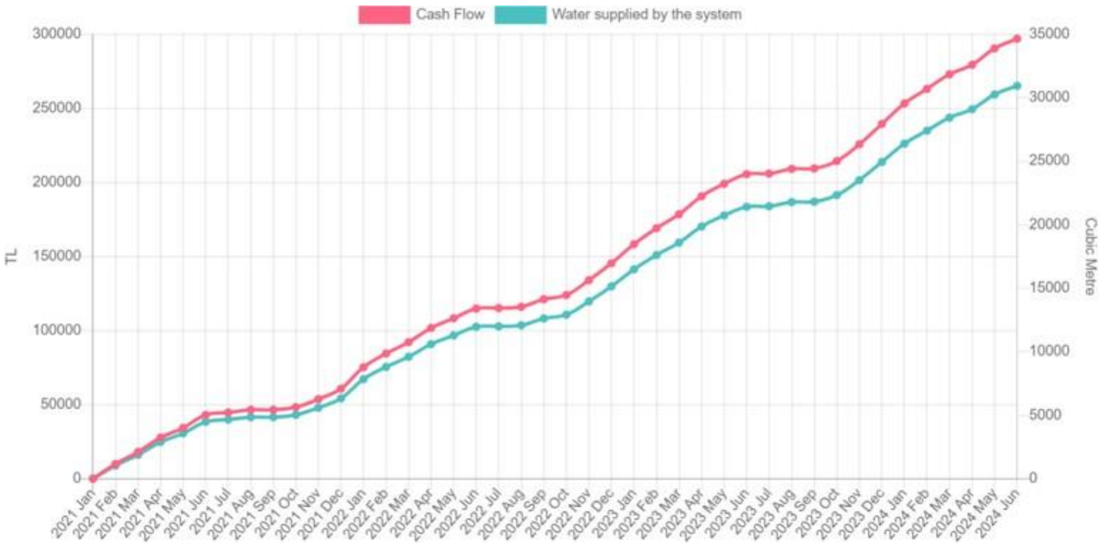

Figure 5.17 Cash flow chart of case 5

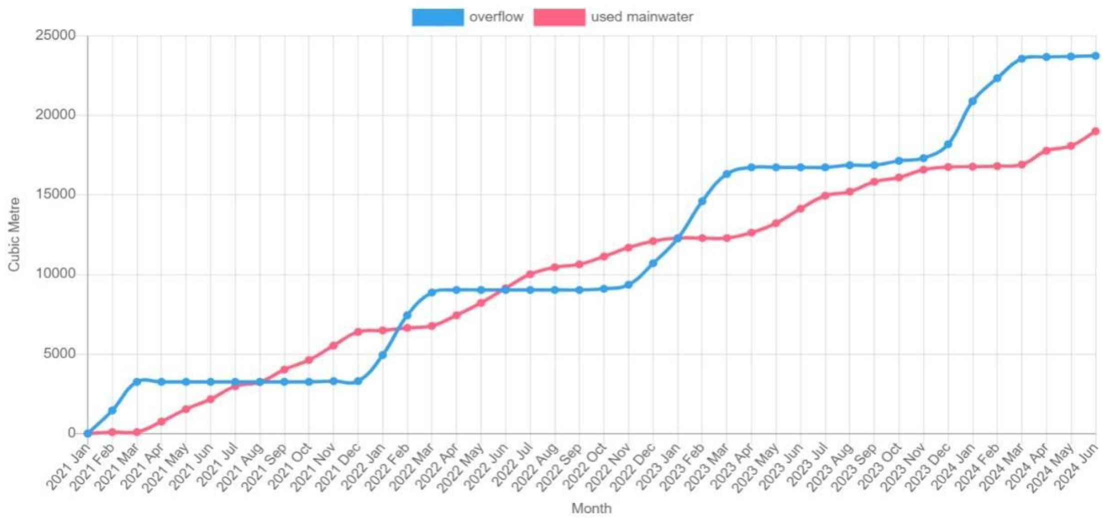

Figure 5.18 Overflow chart of case 5

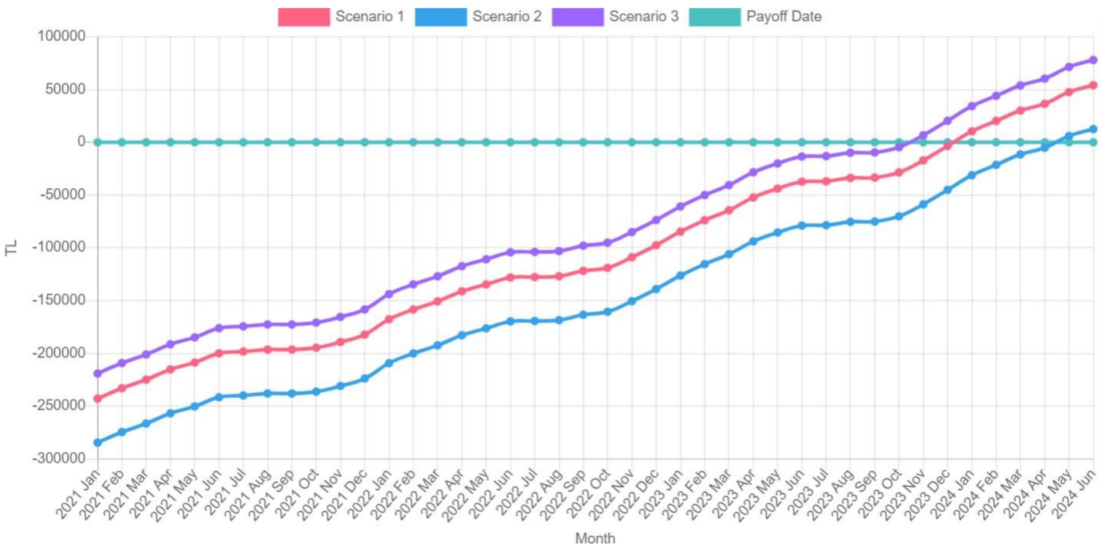

Figure 5.19 Payoff chart of case 5

<u>Case 6</u>: The random mode for a monthly period over 42 months of scenario 2 (Figures 5.20, 5.21).

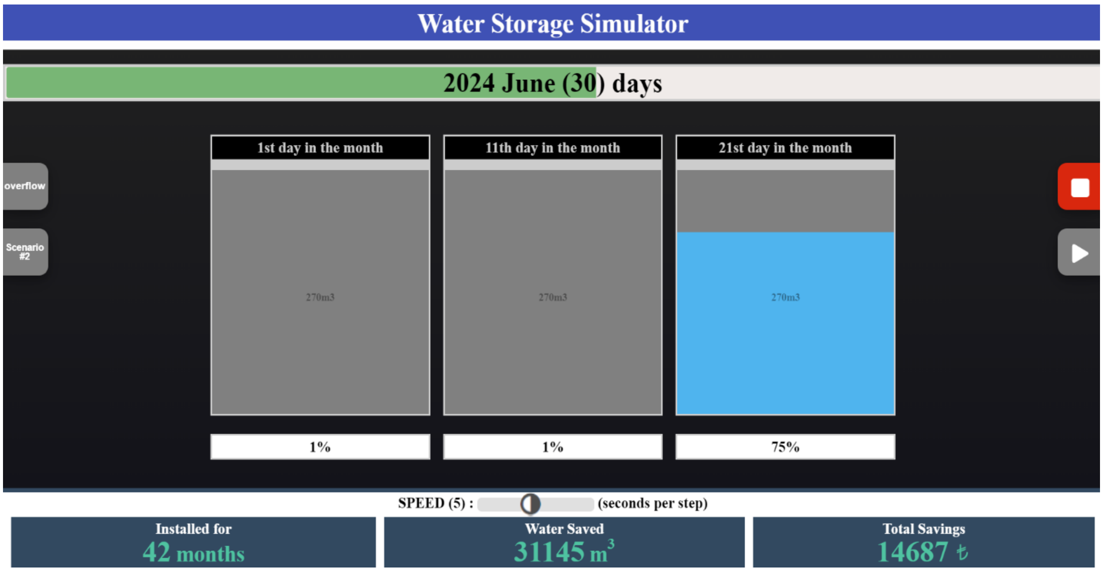

Figure 5.20 The water saved and total savings of case 6


RESULTS

Date	rainfall amount	water collected	water used	cash flow	accumulated savings
25 - 2023 January (31) days	139.31 mm	3254.33 m³	1127.756 m³	10826.46 tl	-115451.24 tl
26 - 2023 February (28) days	113.67 mm	2655.20 m³	913.760 m³	8772.10 tl	-106679.14 tl
27 - 2023 March (31) days	73.96 mm	1727.59 m³	1332.382 m³	12790.87 tl	-93888.27 tl
28 - 2023 April (30) days	34.94 mm	816.10 m³	872.108 m³	8372.24 tl	-85516.04 tl
29 - 2023 May (31) days	29.34 mm	685.36 m³	685.359 m³	6579.45 tl	-78936.59 tl
30 - 2023 June (30) days	5.27 mm	123.17 m³	36.110 m³	346.66 tl	-78589.94 tl
31 - 2023 July (31) days	16.40 mm	383.10 m³	334.998 m³	3215.98 tl	-75373.95 tl
32 - 2023 August (31) days	11.40 mm	266.30 m³	28.888 m³	277.32 tl	-75096.63 tl
33 - 2023 September (30) days	23.70 mm	553.62 m³	515.927 m³	4952.90 tl	-70143.73 tl
34 - 2023 October (31) days	57.81 mm	1350.53 m³	1184.393 m³	11370.17 tl	-58773.56 tl
35 - 2023 November (30) days	95.83 mm	2238.53 m³	1358.035 m³	13037.14 tl	-45736.42 tl
36 - 2023 December (31) days	191.65 mm	4476.81 m³	1511.532 m³	14510.71 tl	-31225.72 tl
37 - 2024 January (31) days	96.45 mm	2253.00 m³	1022.157 m³	9812.71 tl	-21413.01 tl
38 - 2024 February (29) days	94.72 mm	2212.66 m³	958.979 m³	9206.20 tl	-12206.81 tl
39 - 2024 March (31) days	32.87 mm	767.82 m³	723.317 m³	6943.85 tl	-5262.96 tl
40 - 2024 April (30) days	52.41 mm	1224.16 m³	1166.100 m³	11194.56 tl	5931.60 tl
41 - 2024 May (31) days	29.34 mm	685.36 m³	684.826 m³	6574.33 tl	12505.93 tl
42 - 2024 June (30) days	15.82 mm	369.50 m³	200.440 m³	1924.22 tl	14430.16 tl

Figure 5.21 The Simulation results table of case 6

In case 6, the random mode was used for a monthly period of scenario 2; the initial cost of scenario 2 is 284556 TL and decreased to 14687 TL, as seen in (Figure 5.20). The system, in 42 months has about 31145 m^3 of water saved. In the 40^{th} month, the initial cost was covered, and the profit started. The charts in this case as approximately the same in case 5.

Case 7: The uniform distribution mode for a monthly period over 42 months of scenario 1 (Figures 5.22, 5.23, 5.24, 5.25 and 5.26).

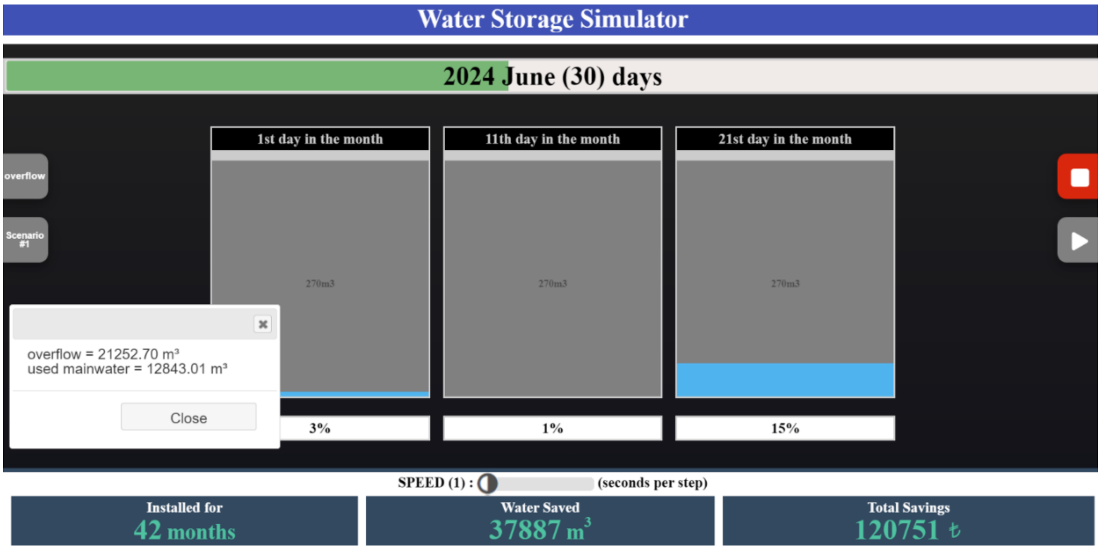

Figure 5.22 The water saved and total savings of case 7

RESULTS

Date	rainfall amount	water collected	water used	cash flow	accumulated savings
19 - 2022 July (31) days	4.10 mm	95.77 m³	166.251 m³	1596.01 tl	-83580.29 tl
20 - 2022 August (31) days	5.70 mm	133.15 m³	120.151 m³	1153.45 tl	-82426.84 tl
21 - 2022 September (30) days	15.80 mm	369.08 m³	382.079 m³	3667.95 tl	-78758.89 tl
22 - 2022 October (31) days	44.60 mm	1041.83 m³	1019.565 m³	9787.82 tl	-68971.06 tl
23 - 2022 November (30) days	93.70 mm	2188.79 m³	1598.192 m³	15342.64 tl	-53628.42 tl
24 - 2022 December (31) days	144.30 mm	3370.78 m³	1601.803 m³	15377.31 tl	-38251.11 tl
25 - 2023 January (31) days	136.10 mm	3179.23 m³	1127.756 m³	10826.46 tl	-27424.65 tl
26 - 2023 February (28) days	102.30 mm	2389.68 m³	913.760 m³	8772.10 tl	-18652.56 tl
27 - 2023 March (31) days	75.60 mm	1765.98 m³	1669.524 m³	16027.43 tl	-2625.13 tl
28 - 2023 April (30) days	46.00 mm	1074.54 m³	1151.331 m³	11052.78 tl	8427.65 tl
29 - 2023 May (31) days	31.10 mm	726.48 m³	790.894 m³	7592.58 tl	16020.24 tl
30 - 2023 June (30) days	11.60 mm	270.97 m³	195.071 m³	1872.69 tl	17892.92 tl
31 - 2023 July (31) days	4.10 mm	95.77 m³	171.673 m³	1648.06 tl	19540.98 tl
32 - 2023 August (31) days	5.70 mm	133.15 m³	119.466 m³	1146.88 tl	20687.86 tl
33 - 2023 September (30) days	15.80 mm	369.08 m³	374.071 m³	3591.08 tl	24278.94 tl
34 - 2023 October (31) days	44.60 mm	1041.83 m³	1050.525 m³	10085.04 tl	34363.99 tl
35 - 2023 November (30) days	93.70 mm	2188.79 m³	1598.192 m³	15342.64 tl	49706.63 tl
36 - 2023 December (31) days	144.30 mm	3370.78 m³	1534.082 m³	14727.19 tl	64433.82 tl

Figure 5.23 The Simulation results table of case 7

In the last case, the uniform distribution mode for a monthly period over 42 months of scenario 1 was considered. The system shows 37887 m^3 of water saved in addition to 21252.70 m^3 overflow volume, and in the 28th month, the initial cost was covered, and the profit started, as shown in (Figures 5.22, 5.23). Over 42 months, the initial cost decreased to 120751 TL. Cash flow and water supplied by the system always take close or equal values of each other, as seen shown in (Figure 5.24). Although the overflow is higher than the main water, there is a need to use the main water that is estimated at 12843.01 m^3. According to the payoff chart in (Figure 5.26), scenario 1 in April 2023 can cover the initial cost, scenario 2 in November 2023, whereas scenario 1 in February 2023.

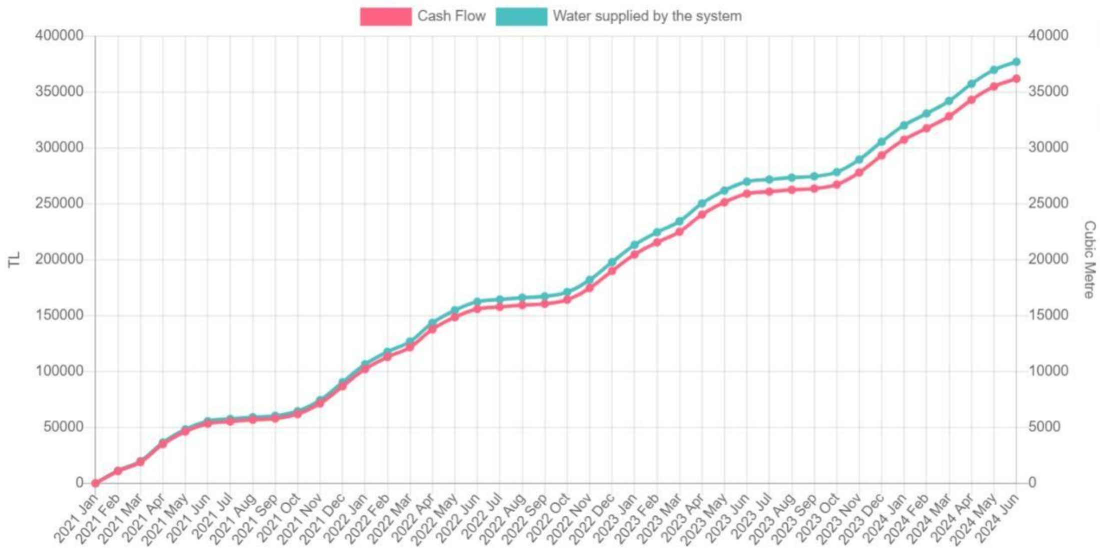

Figure 5.24 Cash flow chart of case 7

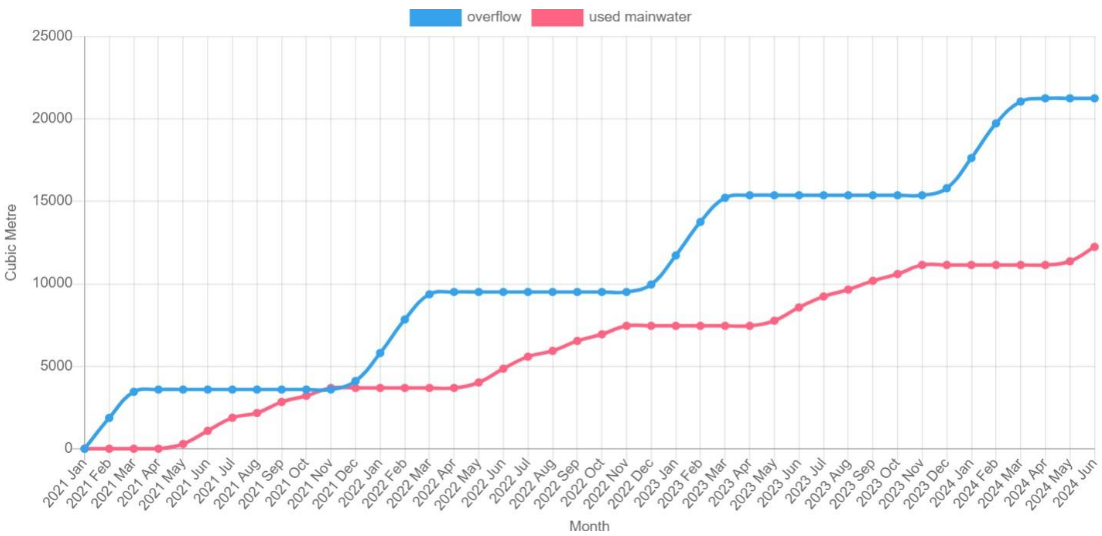

Figure 5.25 Overflow chart of case 7

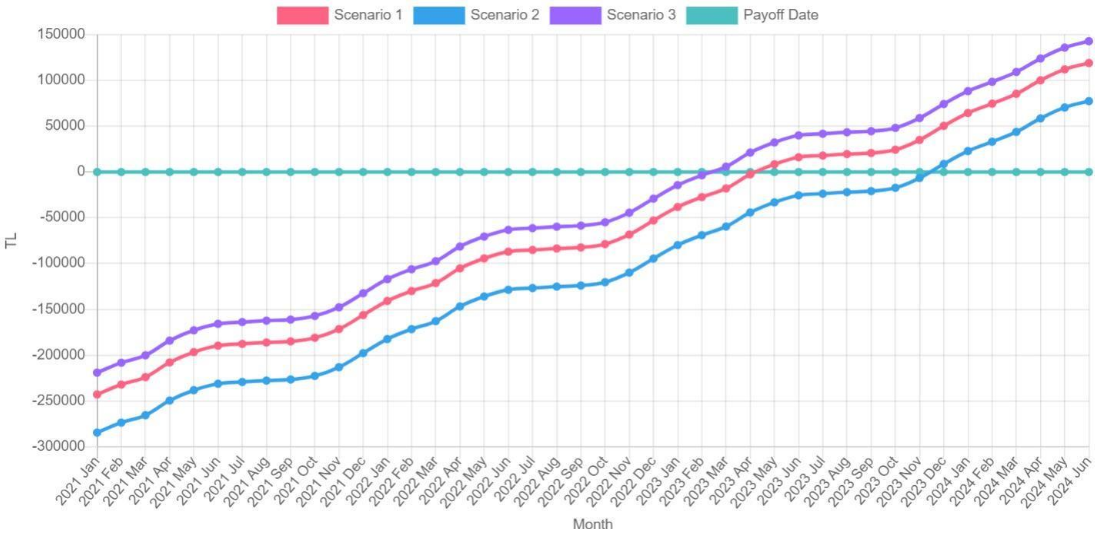

Figure 5.26 Payoff chart of case 7

6. RESULTS AND DISCUSSION

This thesis aims to study the economic analysis of water storage by rainwater harvesting technique in the main campus at Izmir Katip Celebi University. Determining the water supply volume requires evaluating the demand volume. Water demand data were obtained by installed flow meters on supply pipes for sinks and toilet-urinals of men's and women's toilets. On the other hand, the rainwater supply data were determined by calculating the catchment area and estimating the rainfall in Izmir city. The supply and demand water results show that 100% of the studied building demand is met; this is because of the adequate catchment area and the precipitation amounts in Izmir city. The excess annual amount of rainwater was estimated at 2861.45 m^3, as seen in (Table 6.1).

Table 6.1 Data for Water Supply and Demand.

Total number of male and female toilets	24 toilets
The catchment area (m^2)	25955.61 m^2
Average Annual precipitation In Izmir (mm)	711.1 mm
Total water demand (m^3/year)	13753.2 m^3/year
Total water supply (m^3/year)	16614.65 m^3/year
Excess rainwater (m^3/year)	2861.45 m^3/year

Cost estimating is one of the most critical economic analysis steps, but the cost estimation of a system may not be enough to determine if the project can be classified from successful projects. For this reason, some of the scenarios were done and proceed with an economic study. In the economic analysis of these scenarios, the maximum net benefit of project life and the minimum discounted payback period have been chosen as main criteria over 20 years. Scenario 1 assumes that the harvestable rainwater collection is coming from the total catchment area, then it will be stored in one tank or a series of tanks. In scenario 2, every location of toilets is related to one storage area. Scenario 3, every two locations have one storage area. In each scenario, the cost of purchasing required components such as tanks, sand filters, and pumps were determined, and the percentage distribution of the initial costs, as shown in (Figure 6.1).

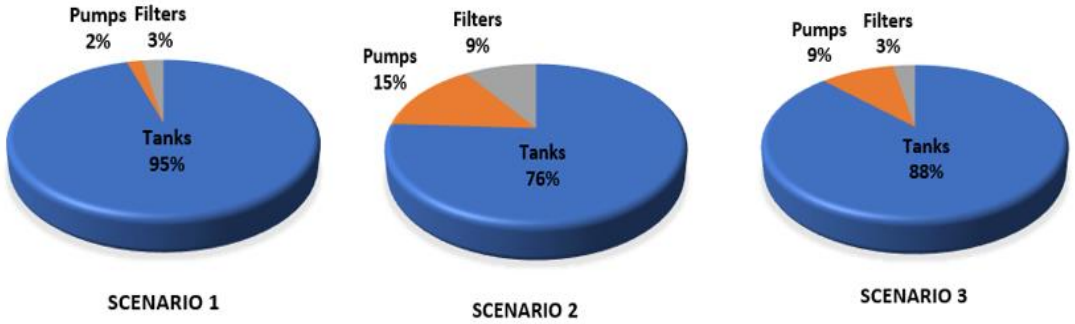

Figure 6.1 The percentage distribution of the initial costs

Then all the scenarios were evaluated by calculations of the payback period (PBP), the net present value (NPV), the discounted payback period (DPBP), the Return on Investment (ROI), and the Internal Rate of Return (IRR). The minimum payback period requires a minimum initial investment because the difference between scenarios depends on cash's outflow. A significant convergence was observed in the cash inflow over 20 years between the first and third scenarios, while scenario 2 recorded the largest cash outflow, as shown in (Figure 6.2). The rainwater harvesting system's profitability in all scenarios is very high, as presented in (Figure 6.3).

A decision related to the scenarios cannot be made based on only the cost estimations. There are advantages and disadvantage of each scenario should be taken into consideration. The water storage in scenario 1 requires fewer tanks than other scenarios, and the location of tanks outside offers easy access for inspections and maintenance. However, the tank will be more exposed to climate changes; and, its location outside is undesirable aesthetically. In case of any failure in the system, it will completely be out of service.

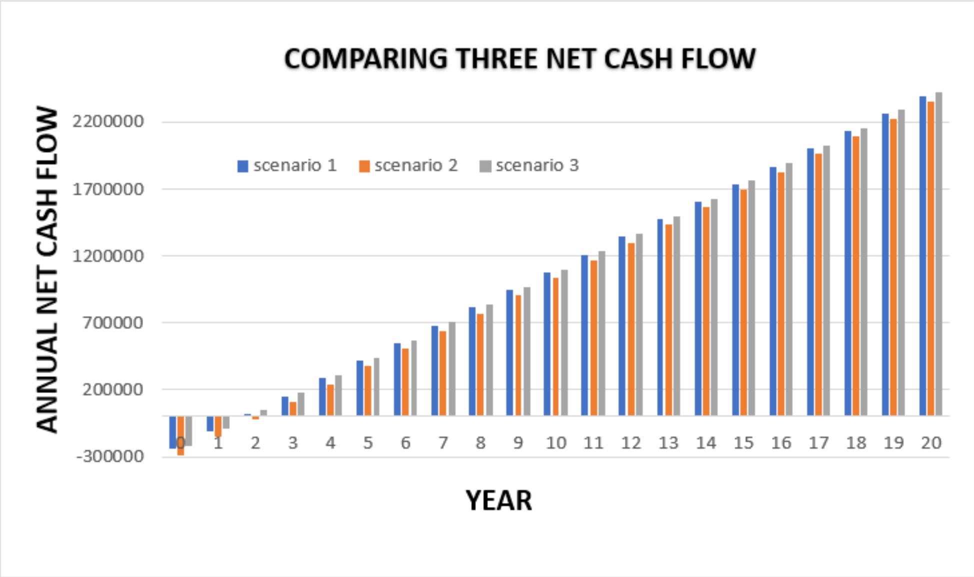

Figure 6.2 Comparing three net cash flow

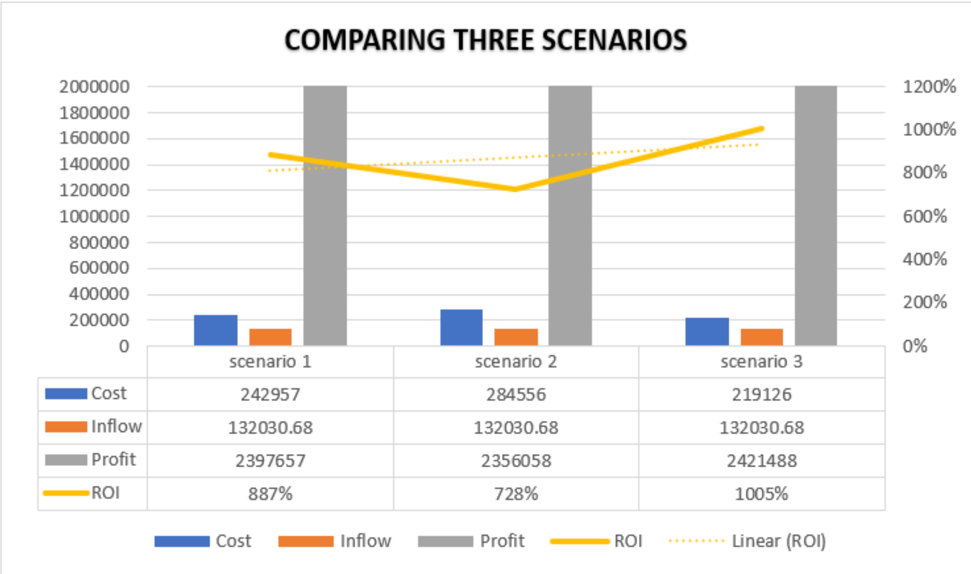

Figure 6.3 Comparing three scenarios

Scenario 2, the locations of the tanks are in the basement. For this reason, there are no risks of weather events and their implications on the system. Any failure in one location of the system does not affect the performance of other locations. On the other hand, water storage inside may make the floor wet if there are leakages or overflows; also, this scenario's maintenance process is difficult. There is no flexibility in choosing the sizes of the storage tanks; in this case, the system requires more tanks to meet the required storage volume. Scenario 3 is like Scenario 2 but has fewer tanks. The results of the economic analysis summarized as presented in (Table 6.2).

Table 6.2 Summary of Economic Analysis Results.

	Scenario 1	**Scenario 2**	**Scenario 3**
Initial Investment ₺	242957	284556	219126
Cash Inflow ₺	132,030.68	132,030.68	132,030.68
PBP (Year)	1.84	2.16	1.66
DPBP (Year)	2.41	2.90	2.12
ROI%	887	728	1005
IRR%	54	46	60
Profit ₺	2,397,656.60	2,356,057.60	2,421,487.60

The higher initial cost of scenario 2 than the initial costs of other scenarios, the payback period (PBP) is 2.16 years, and the discounted payback period (DPBP) is 2.90 years. The profit over 20 years is estimated at 2,356,057.60 TL. The initial cost of scenario 1 is less than scenario 2, and therefore, the profit over 20 years higher, which is estimated at 2,397,656.60 TL. The (PBP) and (DPBP) values in scenario 1 are 1.84 and 2.41, respectively. Scenario 3 is the lower initial cost and higher profit, estimated at 2,421,487.60 TL comparing to the other scenarios. The (PBP) and (DPBP) values in scenario 3 are 1.66 and 2.12, respectively. Return on Investment (ROI) in all scenarios is perfect, but the higher one is 1005% of scenario 3. The higher value of the internal rate of return (IRR) is scenario 3, estimated at 60%. As a result, the scenario presented with the low initial cost, low payback period, and high profit is scenario 3.

On the other hand, the results of the water storage simulator are illustrated by the studied cases. The main difference between the scenarios is the initial cost. However, when the system is implemented, other factors besides the cost also play an important role in effective storage, and they should be taken into consideration.

In comparing the two cases 1 and 2, there are many water losses in the random mode because of the possibility of heavy rain days. Case 2 could save more water, and no need to main water over time. If the study is chosen daily, it is difficult to assess the volumes such as water used volume, saved water, overflow, and the value of profits. For this reason, the charts cannot show the results.

The random mode was used for a monthly period of scenarios 1 and 2 in cases 5 and 6; due to the first scenario's lower initial cost than the second scenario, the first scenario covered the initial cost in a shorter time.

All results indicate that within three years, the system can meet the initial cost besides the profits over time.

CONCLUSION

The water storage volume analysis is the main criterion in a rainwater harvesting technique since rainwater harvesting is a system where the drops of rain are collected and stored in a cistern to use later. The cost-sufficiency of rainwater harvesting system depends on its aim since there is a difference in the treatment process between potable and non-potable water. The majority of water demand in public facilities is non-potable water. In this thesis, the economic analysis of water storage by rainwater harvesting technique was evaluated at Izmir Katip Celebi University. Determining the water supply requires calculating the catchment area and the annual rainfall estimation; those are 25955.6 m^2 and 711.1 mm. Therefore, the water supply volume was calculated, it is about 16614.65m^3/year by considering the runoff coefficient. The water demand volume of the toilets flushing was evaluated by the flow meters installed on the supply pipes for sinks and toilet-urinals of men and women toilets that were estimated at 13753.2 m^3/year. The purchase costs of the tanks, sand filters, and pumps were assumed as the initial cost. According to the received results, 100% of the required water demand can be met in the studied building through the sufficient captured rainwater from the building's catchment area and the amount of precipitation in Izmir city.

Three scenarios were analyzed economically for the implementation of an appropriate rainwater harvesting system at the university. The scenario should reflect decisions about location, capacity, and material of optimal rainwater storage to maximize a system's efficiency. The main difference between the scenarios is the size of the tanks. The economic analysis results show that scenario 2 includes each location (male and female toilet) one storage area. So, scenario 2 needs a higher initial cost and higher value of (PBP) than other scenarios. Scenario 3 includes every two locations (male and female toilet) one storage area for that; this scenario needs a low initial cost. Thus, the low value of (PBP) compared to other scenarios. The comparisons show that the initial cost of scenario 3 was estimated at 219126 TL, and the total profit over 20 years was calculated at 2,421,487.60 TL. This system can pay back in around two years.

The present study shows the implementation of the rainwater harvesting technique in the building at Izmir Katip Celebi University relieves the present pressure on municipalities to supply enough water to the community. Besides contributing to reducing bill costs at IKCU. As seen in the results, all the scenarios are with a large percentage of return on investment (ROI); their values range from 728% to 1005%. About 2861.45 m^3/year is the value of excess rainwater that may be directed for irrigation purposes in university parks; thus, it would be an extra annual profit, which is estimated at 27469.96 TL for the university budget.

Through the study conducted in the simulation, the building can cover water demand and save the network water. The average duration of all studies and cases conducted is about three years to meet the initial cost besides profits. There are quantities of overflow water that can cover other needs if stored, but this requires large cisterns, so the initial costs will be higher than the current values.

As a result, the projects of renewable resources systems are with high returns on investments. Therefore, the rainwater harvesting system in public buildings is an excellent step to harvest rainwater for economic and environmental aspects.

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