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Cost and Benefit Analysis of Different Buildings Through Reuse of Treated Greywater

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Abstract − The fact that the impacts of climate change cannot be prevented in the short term has increased the importance of climate change adaptation activities, and many national and international studies have been initiated in this regard. Greywater reuse (GWR) activities have become important methods recommended by the Intergovernmental Panel on Climate Change (IPCC) for adaptation to climate change. This study selects GWR from 3 different real typologies, a hotel, a residential building, and an industrial plant planned in Izmir Province of Türkiye, to design greywater systems followed by cost-benefit analyses. The applicability of GWR systems in these typologies has been analyzed, and comparisons have been made. GWR systems at the project design stage eliminate the need for installation modifications. Therefore, it is concluded that new buildings should be designed to integrate these alternative water resource systems. Recovered water through the installation of GWR systems is recommended to be used as flushing water, and the excess for garden irrigation, car washing and cleaning. The payback periods were calculated as 12 years for the hotel and industrial plant and 6 years for the residential building. The water savings were calculated as 46% for the hotel, 44% for the residential building, and 29% for the industrial plant. The results put forth the feasibility of this alternative water resource.

Keywords − *Alternative water resources, buildings, cost and benefit analysis, greywater reuse, water saving*

1. Introduction

In developing countries, rapid urbanization caused some complications over time. In the future, urbanization is expected to increase more with the effects of climate change, and this will require the rapid implementation of sustainable management strategies, especially in water use. The final declaration of the Climate Council organized by the Turkish Ministry of Environment, Urbanization and Climate Change (MoEUCC) [1] in February 2022 states the country's road map for combating climate change in which two issues related to water use were emphasized:

*i.*Legislation regarding water efficiency in buildings should be established, greywater reuse (GWR) should be encouraged, and the use of rainwater and the establishment of a zero-waste system should be made mandatory.

*ii.*Rainwater harvesting (RWH) and GWR should be disseminated, and guiding legislation should be developed for this purpose. Wastewater treated in wastewater treatment plants should be reused.

When we look at the components of domestic water use, it is observed that at least 34% of it (30% flushing water, 4% garden irrigation) does not require potable quality water. Moreover, greywater/rainwater can be preferred in laundries and cleaning works, which account for 16% of domestic water use, by ensuring the need

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for treatment and water quality [2]. In short, RWH and GWR are the possibilities to be used in buildings, especially for flushing toilets, garden irrigation, car washing, and laundries and are regarded as alternative water resources. As such, around 50% of tap water can be saved [3-4]. These alternative uses have become even more feasible and remarkable due to the negative effects of climate change on existing water resources, as emphasized by [5-6].

Greywater is a large volume of wastewater with high reuse potential and applicability. It is domestic wastewater from showers, hand washing sinks, laundries, and kitchen water, excluding toilet and food waste from garbage disposals, known as black water [7]. The source and composition of greywater depend on living standards, demographical status, social and cultural habits, number of people living in the household, chemicals used in the household, availability of water, and climatic conditions that differ from one country to another [8].

This study on cost and benefit analyses of different buildings through the reuse of greywater was realized in real cases that have provided comprehensive examples to be followed by other scientists and practitioners interested in similar water reuse efforts in different parts of the world. Three building typologies are selected from the Izmir Province of the country: a hotel, a residential area (housing), and an industrial plant. All these buildings are in the planning stage. Calculations based on these real cases' design criteria and installation plans enabled detailed preparation of investment and operating costs along with depreciation periods.

Characteristics of greywater: Greywater contains easily degradable organic matter with less suspended solids (SS) and nitrogen (N) and more phosphorus (P) than typical domestic wastewater. Ammonia and total kjeldahl nitrogen (TKN) concentrations are approximately 10 times lower than in municipal wastewater. The metal and organic contaminant content in greywater is generally low, with lower levels of zinc and mercury than in mixed wastewater, and the rate of pathogens is relatively low [10-11]. The contaminants that cause pollution in greywater result from used personal hygiene products, detergents, dirty clothes, and body dirt. While greywater from showers and sinks contains low concentrations of bacteria and chemicals, wastewater from kitchen sinks and laundries contains high concentrations of bacteria, solids, chemicals, and oils [12]. For this reason, greywater sources are divided into low-load sources (bathtubs, showers, and hand sinks) and high-load sources (laundry rooms and kitchens). Pollutants that vary according to the different sources of greywater are given in Table 1.

Table 1. Sources of greywater and polluting parameters [12]

Source of greywater	Polluting parameters
Washing machine	SS, organic matter, oil/grease, salinity, sodium, nitrate, P (from detergents), bleach
Dishwasher	SS, organic matter, oil/grease, increasing salinity, bacteria and detergent
Bathtub-Shower	Bacteria, hair, SS, organic matter, oil/grease, soap, shampoo residues
Sink (including kitchen)	Bacteria, SS, organic matter, oil/grease, soap, shampoo residues

Typical greywater volume varies between 60 L-120 L/person/day, depending on user behavior, demographics, traditions and habits, plumbing, and water availability [13]. Method of using treated greywater includes indoor reuse, such as flush toilets, and outdoor reuse, such as garden watering, car washing, and cleaning. Treated greywater may also be used as agricultural irrigation water when it meets the required health and environmental standards [14]. When we look at the European Union (EU) regulations, we see that there is currently no directive regulating water reuse. The European Plan for the Protection of Water Resources stated in 2012, emphasizes the importance of water reuse in irrigation and industry in line with the Water Framework Directive (WFD). Still, there is no clear directive [15]. EU tools on water reuse were prepared in 2016 [16], and the main idea behind these statements and efforts underlined the sustainable management of water, as water resources become scarce over time due to the effects of climate change. Water Reuse in EU Member States was proposed by the Commission on Environment, Climate Change, and Energy in 2018; however, this recommendation was mainly based on the reuse of treated wastewater for irrigation within the scope of river basin management plans [17].

On the other hand, water recycling is increasingly being incorporated into the policy framework and development of guidelines to help alleviate demand for drinking water in a water-stressed country, Australia. Implementation rules for GWR were established in 2010. Various states in the United States of America (USA) offer various incentives to users of GWR systems. However, as with RWH, this practice varies from country to country, state to state, and city to city [18].

Greywater treatment requirement for reuse and applicable technologies: When determining the collected greywater's quality and intended use after treatment, the required treatment level should be considered. While greywater can be used after being treated, it also has sample applications where it is reused without being treated. There are some practices where it is used directly in the garden and directly in toilet reservoirs [19]. In such applications as the greywater transfer system in Australia and the USA, greywater from sinks, washing machines, and dishwashers is used as flushing water in toilet reservoirs without being treated. In addition to the water savings achieved in both applications, storage problems are eliminated, and cost is low. However, untreated greywater in toilets leaves tints on the toilet bowl and requires sensitivity when flushing. Using untreated greywater in garden irrigation can accumulate salts, surfactants, oil, and grease in the soil in the long term. Therefore, when determining the need to treat greywater in its area of use, its environmental impacts should be considered.

Types of treatment may include one or more of the following substeps [12, 20]:

i. Physical treatment: sedimentation/flotation via sedimentation tanks, large particle filtration by sieving, mechanical fine filtration by membrane filtration,

ii. Biological treatment: such as constructed wetland (CW), rotating biological contactor (RBC), sequential batch reactor (SBR), membrane bioreactor (MBR) technologies,

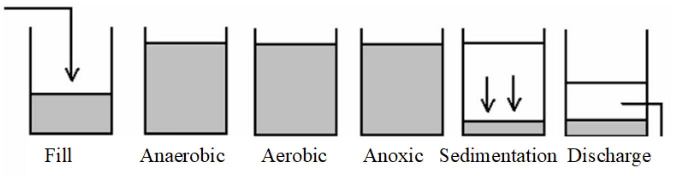
iii. Chemical treatment: such as precipitation, electrocoagulation, photocatalytic oxidation, ion exchangers and granular activated carbon,

iv. Disinfection: such as ultraviolet (UV) radiation chlorination.

The most important greywater treatment technologies mentioned by Üstün and Tırpancı (2015) are given in Figure 1a-d [21-23].

a b

Figure 1. Greywater treatment technologies: a) Constructed wetland [21], b) Rotary biological reactors [12], c) Sequential batch reactors [22], and d) Membrane bioreactors [23]



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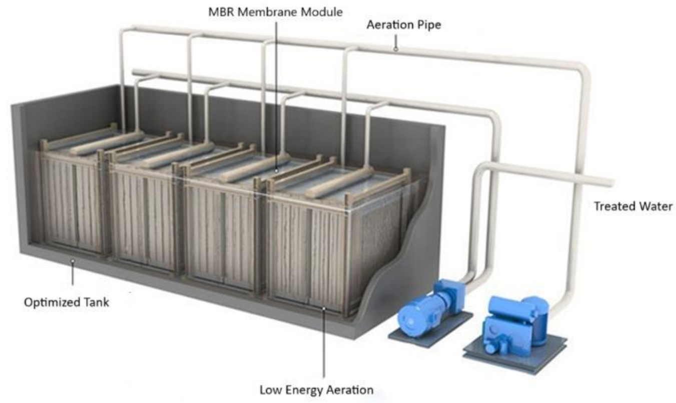

d

Figure 1. (Continued) Greywater treatment technologies: a) Constructed wetland [21]: b) Rotary biological reactors [12], c) Sequential batch reactors [22], and d) Membrane bioreactors [23]

National legislation: Although there is no statement in our country's legislation that requires the implementation of GWR systems, there are some encouraging principles. Regulation on Amendments to the Water Pollution Control Regulation prepared by MoEUCC put into force through publication in the Official Gazette dated 17.12.2022 and numbered 32046. With Article 4 under the title of Principles on Water Protection of the Regulation, the phrases "*Encouraging recycling and reuse in wastewater management in accordance with circular economy principles"* and "*Establishing an infrastructure suitable for the reuse of greywater"* are dictated. In Article 28, under the title of Reuse of Treated Wastewater of the same regulation, the phrase "*It is essential to evaluate the reuse opportunities of greywater and rainwater"* was added. In addition, within the scope of Article 28, *"In regions where irrigation water is scarce and has economic value, wastewater treated up to the irrigation water quality criteria given in the Communiqué on Wastewater Treatment Facilities Technical Procedures published in the Official Gazette dated 20.03.2010 and numbered 27527 should be used as agricultural irrigation water*". These phrases encourage the public the use alternative water resources. The Communiqué on Technical Procedures for Wastewater Treatment Facilities, which came into force after being published in the Official Gazette dated 20.03.2010 and numbered 27257, covers the technology selection of wastewater treatment plants related to the treatment of wastewater originating from settlements, design criteria, disinfection of treated wastewater, reuse and treatment options with deep sea discharge. It was prepared by the repealed Ministry of Environment and Forestry to regulate the basic technical procedures and practices to be used to dispose of the sludge generated during the process. In the 7th section of the Communiqué on Technical Procedures for Wastewater Treatment Facilities, regulations have been made regarding the areas of use of treated wastewater, location of the wastewater recovery facility, storage of treated wastewater, technology selection for wastewater recovery and irrigation water use criteria of treated wastewater.

Later, the Communiqué on Amendments to the Technical Procedures Communiqué on Wastewater Treatment Facilities was published in the Official Gazette dated 25.10.2022 and numbered 31994. In this context, by referring to Article 22/C added to the Communiqué after Article 22, Criteria and explanations regarding reusing greywater as urinals and flush water with closed circuit systems are given under the heading 7.4 in Annex 7. Accordingly, *"In the reuse of greywater as closed-circuit urinals and flush water, disinfection and removal of microorganisms and suspended solids are sufficient"* has been added. The debate on the need to treat greywater for use as flush water has been answered through the phrase added to the legislation.

The Turkish Standard titled TS EN 16941-2 Onsite non-potable water systems - Part 2: Systems for the use of treated greywater (sink wastewater), published by the Turkish Standards Institute (TSE) in February 2021, is one of the important steps taken in the implementation of GWR systems. TS 16941-2 Standard covers greywater systems' design, sizing, installation, commissioning, and maintenance principles for onsite use [20].

2. Materials and Methods

2.1. Calculating the Amount of Greywater to be Recycled

Reference values used to calculate the amount of greywater that can be recovered in the greywater systems designed within the scope of this study are given in Tables 2, 3, and 4 [20]. The values reflect the average, and it is recommended to check the model standards of the vitrified fixtures used for each building of concern.

Equation 2.1 calculates the amount of greywater from sinks, showers, and bathtubs.

$$Amount\ of\ greywater\,\frac{lt}{day} = Flow\ rate\,\frac{lt}{min} * \text{Flow time}, min * \text{times of use}\ \frac{\text{times. person}}{\text{day}} * number\ of\ people \qquad (2.1)$$

Table 2. Typical average daily greywater yield and demand [20]

Fullness	Efficiency[a] (L/day)	Demand (L/day)		
		Toilets	Laundry	Other non-potable uses[c]
1 person	60	35	15	10

a) Efficiency from showers, baths, or sinks.
b) These figures are based on average daily demand. It should be noted that a washing machine usually uses 30 - 60 L per cycle.
c) For example, garden irrigation.

Table 3. Reference value ranges for water use [20]

Water Use	Range	Unit
The volumetric flow of the shower	5-15	L/min
Water volume per tub use	70-200	L
Sink	5-10	L/min
Water volume for washing machine per operating cycle	30-60	L/cycle
Water volume for dishwasher per operating cycle	10-20	L/cycle

Table 4. Flow times of bathroom fixtures [20]

Water Use	Value	Unit
Shower	5	minute
Sink	15	second
Bathtub	15	minute

2.2. Components of Greywater System

Greywater should be collected in a separate wastewater drainage pipe and allowed to flow by gravity from collection devices to the greywater system. The use of greywater for flush water, green area irrigation water, car washing, and cleaning purposes was evaluated for the buildings studied. While the system was being set up, it was accepted that only greywater from the sink, shower, and bathtub would come to the treatment plant. Various methods can be used to meet the need for treatment in selected use areas. The recovery of weak greywater (sinks, showers, and bathtubs) was evaluated in the studied cases.

Many studies cited in the literature indicate that biological treatment is needed to treat mixed and strong greywater. It has been stated that treatment systems that include combinations of physical or chemical treatment processes will be sufficient to treat weak greywater [24-26]. Direct membrane filtration alternative is considered convenient, consisting of pre-chlorination, sand filter, active carbon filter, ultrafiltration and disinfection-chlorination units [27]. In order to determine the components and costs of the greywater treatment system in this study, local companies were contacted, and local market prices of highly applicable systems were obtained. The greywater treatment system selected within this study consists of the following units: greywater collection tank, system feeding booster, stainless steel bag filter, fully automatic multilayer sand filter, fully automatic active carbon filter, filtered water tank, filtration system backwash booster, greywater package ultrafiltration system, automatic chlorine dosing unit, and treated water tank.

Prior to the cost-benefit analysis, the necessary data regarding the structure where the systems will be applied and the area where the system is located were obtained. In this context, the current situation of Izmir in terms of population, land use, water unit price, water supply and demand, and seasonal norms was examined, and its impact on the applicability of the systems was evaluated. Floor plans and plumbing projects were also discussed, necessary information was obtained, and calculations were made. The amount of recoverable greywater in selected areas, water needed in alternative use areas, potential water savings, and economic gain if the systems are implemented, were calculated. Since the selected buildings are in the planning phase and construction has not started, actual water consumption amounts were unavailable. As such, the amount of water needed was calculated by making certain assumptions for values, such as the number of people/visitors using the building and the number of days the building was used. Using the membrane filtration method in the greywater treatment system was preferred. Only greywater from the sinks and showers of the buildings will be collected, and wastewater produced from any areas other than these will not mix with the system.

In the selected cases, the location of the systems and the connection lengths for the installation floor column have been determined. The Bill of quantities was shaped by removing all investment cost items required to implement the systems, and unit costs for all necessary equipment and fittings were calculated according to local market prices. Average unit prices were reached by taking offers from companies close to Izmir. Regarding operating costs, electricity, and maintenance-repair costs were considered. The electricity cost was calculated using the unit prices per kWh of the distribution companies in the province based on the energy consumption of the pump operating in the system. The average prices suggested by maintenance service and system supply companies are the basis for maintenance repair costs. The repayment periods were calculated after calculating the benefits that the systems can provide and the investment and operating costs required.

In the benefit part, the savings on water bills using greywater instead of tap water were taken as the basis. Accordingly, the economic feasibility of the systems was determined based on the calculated payback periods. The payback period calculated within the benefit-cost analysis scope is an important criterion in evaluating the investment. The net Present Value (NPV) criterion was used to calculate the payback period and analyze the profitability of the GWR system to be implemented. NPV refers to the difference obtained by deducting investment expenses from the present value of the return provided by the GWR system investment throughout its economic life. The present value is calculated based on a certain capital cost discount. The discount rate was taken as 5%. The system's payback period was calculated by finding the annual net benefits. The payback period shows how many years it takes to recoup the investment made for the GWR system. The year in which NPV is positive was determined as the payback period [27].

Table 5 presents the water tariffs per subscriber in Izmir. These values were used in the selected typologies' cost calculations of GWR systems.

Table 5. İzmir Metropolitan Municipality 2023 water tariffs

Subscriber Types	Stages (m^3/month)	Water Price (TL/m^3)	Wastewater Price (TL/m^3)	Total (TL/m^3)
Housing	0~10	22.09	11.04	33.13
Housing	11~20	28.25	14.12	42.37
Housing	21~Above	52.89	26.44	79.33
Non-Residential	0~10	44.18	22.08	66.26
Non-Residential	11~20	56.50	28.24	84.74
Non-Residential	21~Above	105.78	52.88	158.66
Government offices	stepless	33.13	16.56	49.69
Park and Cemetery	stepless	32.71		32.71
Organized Industry	stepless	41,15	20,57	61.72
NATO and Embassy	stepless	62,22	31,10	93.32

2.3. Designing GWR Systems

The methodology followed in the design is explained through the Izmir Hotel example. It is accepted that 23 personnel work in the hotel, which serves as a tourist facility. The maximum number of guests (staying) is 60 people, and the number of visitors (participating in the various activities) is 455. The amount of greywater that could be recycled in the hotel's bedrooms and living room floors was calculatedthrough investigating the possible water usage habits. By means of inspecting the hotel's floor plans, all water usage areas resulting from greywater were analyzed and the number of existing fixtures was determined (Table 6). In the hotel, which also has washing machines and dishwashers, it was predicted that greywater from bathtubs and sinks will be collected, as the pollution load is thought to be lower than others. Greywater from bathtubs and sinks will be treated and fed to 53 toilets. In calculating the amount of greywater that can be collected, the water consumption of the people in the building and the reference values of the fixtures were considered (Table 7).

Table 6. Fixture types and quantity

Fixture type	Total number
Number of Tubs	53
Number of Sinks	67
Number of Toilet Bowls	53

Table 7. Amount of greywater that can be collected in the Hotel

Amount of Collectable Greywater		
Sinks		
Flow time	1	minute
flow rate	2.5	L/min
Number of guest usages	5	times/day
Number of personnel usage	10	times/day
Number of visitor usage	1	times/day
Sinks greywater flow rate	2.46	m^3/day
Bathtubs		
Flow time	15	minute
flow rate	10	L/min
Number of guest usages	0,5	times/day
Number of personnel usage	0.1	times/day
Number of visitor usage*	0.5	times/day
Bathtub greywater flow rate	6.72	m^3/day
Total amount of greywater from sinks and bathtubs	**9.18**	**m^3/day**

*Only visitors to the gym are allowed.

The monthly maximum collectible greywater amount was calculated by multiplying the hotel's monthly occupancy rates. A comparison was made between the amount of greywater that could be collected and the water needed in areas where the treated greywater could be reused. The entire flush water requirement (5.22 m^3/day) can be met by the amount of collectible greywater (9.18 m^3/day) at the maximum capacity of the Hotel. Laterion, excess water remains, and that amount can be used for garden irrigation, car washing, and cleaning purposes. Therefore, a greywater treatment system with a capacity of 10 m^3/day was chosen for the hotel. The selected booster system and pump features for the greywater system with a capacity of 10 m^3/day are given in Table 8. In order to find the electricity cost during the operation of the greywater system, the annual energy cost was calculated by taking into account the daily operating times of the feed booster and pumps in the system with electrical power (Table 9).

Table 8. Greywater booster system and pump features

Parameter	Value	Unit
Pump pressure operating range	65.63-80.63	mSS
Pump capacity	3.67	m^3/hr
Booster tank capacity	139	L

Table 9. Energy cost of the greywater treatment system under operation

Parameter	Value	Unit
Average daily operating time of the system	8	hour
Daily electricity consumption	14	kWhr
Electricity tariff fee	279	kr/ kWhr
Annual electricity operating cost	14.143	TL/year

Greywater systems require periodic maintenance and control. Thus, annual maintenance and repair costs were included in the operating cost. According to the prices received from the companies supplying the greywater system, 26.000 TL/year was taken for the greywater system with a capacity of 10 m³/day. Investment cost components of the GWR system are listed as piping, mechanical equipment, installation, and treatment. Investment costs, together with the operation costs of the system, are given in detail in Table 10.

Table 10. Cost items and fees of Izmir Hotel GWR system

Cost Items	Meter survey (m)	Unit cost (TL)	Total Cost (TL)
Pipe need			
DN15	198	17	3.366
DN25	198	50	9.900
DN32	100	67	6.700
PVC70	198	34	6.732
PVC100	198	50	9.900
PVC125	100	67	6.700
Mechanical equipment			
Shut-off valve	33	83	2.739
Collector	2	415	830
Package booster system	1	30.240	30.240
Booster tank	1	6.840	6.840
Installation			
DN15	198	9	1.782
DN25	198	25	4.950
DN32	100	34	3.400
PVC70	198	17	3.366
PVC100	198	25	4.950
PVC125	100	34	3.400
Shut-off valve	33	42	1.386
Collector	2	208	416
Installation cost (manometer, pressure	1	8.000	8.000
Treatment			
10 m³ greywater treatment system	1	507.000	507.000
Total Investment Cost			**622.597**
Operation cost (electricity)			**14.143**
Maintenance and Operation Cost			**26.000**

3. Results and Discussion

The methodology used is given in detail for the Izmir Hotel case. The amount of greywater that can be recycled in the hotel, open 365 days with a daily amount of 5.8 m³ greywater treatment, was calculated as 1.667,24 m³/year. It has been determined that the annual economic savings of 222.078 TL can be achieved in the Izmir province, where the water unit price was 66.26 TL/m³ for non-residential subscribers. The benefit-cost analysis for the Hotel performed with the NPV formula is given in Table 11.

Table 11. Cost and benefit analysis of the Izmir Hotel GWR system

Cost and Benefits	0. year (TL)	12th year calculated with NPV (TL)
Investment cost	622.597	592.950
Operation cost	40.143	355.795
Annual benefit	110.471	979.135
Annual net benefit	70.329	707

Based on this calculation, the investment cost of the GWR system in the hotel, where a 10 m³/day greywater system will be treated and reused, is paid back after 12 years. The same methodology was used for the two other typologies, housing and industrial plants, and the findings are summarized below.

3.1. Residential Building

The corresponding GWR system design and feasibility analysis results are given in Table 12. The water recovered with the GWR system designed for the residential building is predicted to be used as flush water. In this residential building where 450 people reside, 90% of the flush water need can be met by recycling 7.300 m³/year of greywater. Greywater treatment system capacity was determined as 20 m³/day. The subscriber tariff is lower than the other subscriber types and is determined as 33.13 TL/m³. Accordingly, the water bill had an annual economic saving of 241.849 TL. On the other hand, the initial investment cost was 853.540 TL. As a result of the benefit-cost analysis, the repayment period was found to be 6 years.

Table 12. Residential building greywater system

Parameters used	Values	Unit
Building typology	Housing	
Number of living people	450	person
Number of guests	45	person
Green areas	750	m²
Water tariff	33,13	TL/m³
Collected amount of greywater	7.300	m³/year
Capacity of the selected treatment system	20	m³/day
Demand for flushing	7.873	m³/month
Water saving potential	90	%
Economic saving (annual benefit)	241.849	TL/year
Investment cost	853.540	TL
Operation cost	53.973	TL/year
Annual net benefit	187.876	TL/year
Repayment period	**6**	**year**

3.2. Industrial Plant

The results of the industrial facility in Izmir, where the GWR system design and feasibility analysis were performed, are given in Table 13. Since there are no showers or bathtubs in the industrial facility with 400 personnel, only the amount of greywater resulting from the sinks was calculated. In the facility, where 5.25 m³ of greywater is produced from daily sink use, the greywater treatment system capacity is determined as 10 m³/day. By recycling 1.890 m³/year of greywater in the industrial facility, 42% of the flush water need can be met. The industrial facility subscriber tariff is higher than residential subscribers and is determined as 66.26 TL/m³. Accordingly, the water bill has an economic saving of 117.445 TL per year. As a result of the benefit-cost analysis of the system, whose initial investment cost was 611.514 TL and operating cost was 44.844 TL/year, the payback period was found as 12 years.

Table 13. Industrial facility greywater system

Parameters	Values	Unit
Building typology	Industrial plant	
Number of people	400	person
Number of guests	20	person
Green areas	500	m²
Water tariff	66,26	TL/m³
Collected amount of greywater	1.890	m³/year
Capacity of the selected treatment system	10	m³/day
Demand for flushing	4.356	m³/year
Water saving potential	42	%
Economic saving (annual benefit)	117.445	TL/year
Investment cost	611.513	TL
Operation cost	44.844	TL/year
Annual net benefit	72.600	TL/year
Repayment period	**12**	**year**

Table 14 summarizes the total water consumption in the analyzed buildings and water savings from the tap water that can be achieved with the GWR System. Water-saving rates were 46%, 44%, and 29% for the hotel, residential building, and industrial plant. These values show that utilizing alternative water resources like greywater reuse gains back a considerable amount of water. As mentioned previously, the selected typologies were in the planning stage. If these were already built and put into operation, installing a greywater system would require some demolition-production costs. The effect of such costs on the payback period of these buildings was also considered. Table 15 illustrates the effect of the demolition-production cost on the payback periods. The payback periods will, as expected, increase by 1 year in the case of the residential building and the industrial plant and 4 years in the hotel. However, such periods are considered acceptable and feasible compared to the benefits gained.

Table 14. Total water consumption in the studied buildings and water saving rates that can be achieved with the GWR System

Building typology	Recovered greywater (m³/year)	Flushing water (m³/year)	Garden irrigation (m³/year)	Car washing (m³/year)	Cleaning (m³/year)	Water Use Reference Value (L/person.day)	Number of people	Total Water Consumption in the Building (m³/year)	Water Saving Rate (%)
Hotel	1.667	733	731	4.32	230	150	83	3.663	46
Housing	7.300	7.873		-	-	100	450	16.425	44
Industrial plant	1.890	4.536	1.218	432	115	45	400	6.570	29

Table 15. The effect of the demolition-production cost on the payback period in selected typologies

Building typologies	When Applied During the Project Phase		When Applied During the Use Phase	
	Investment cost (TL)	**Repayment period (year)**	**Investment cost (TL)**	**Repayment period (year)**
Hotel	622.597	12	749.797	16
Housing	853.540	6	973.540	7
Industrial plant	611.514	12	649.914	13

On a university campus in Northeastern Mexico, where GWR strategies were implemented coupled with RWH, the payback period was found to be 6 years [28]. India is experiencing a water shortage due to the demand brought by its rapidly growing population. Aybuga and Isildar [29] calculated the repayment period of both RWH and GWR systems in Ankara, Türkiye, as approximately 5 years at the household level. An applied case study was conducted on both systems in a single-family house in Durban, Kwa-Zulu Natal Province, South Africa, and the corresponding payback period was found to be 4.39 years [30]. Another interesting study on the cost-effectiveness of RWH and GWR systems was recently conducted in detached houses in 8 different countries. The results varied widely depending on access to fresh water, water price, water quality, climate change, and the city's precipitation regime. However, the general result of the study revealed the reality of the approach that such new technologies and their financial indicators will provide benefits in the long term, regardless of the location of the building [31]. According to the results of the surveys conducted in 8 different European cities within the scope of the same study, it is seen that RWH systems were relatively more preferred than GWR systems. This finding highlights a societal problem regarding the questionable hygienic conditions of GWR systems. This situation is consistent with [18], which underlines the need to provide some financial incentives to GWR systems to encourage the use of the GWR system. Finally, [32-33] summarized information on social acceptance of reuse practices. It offers a systematic perspective on general reuse experiments and social isolations for water reuse, considering water source, technology, and end-use elements. Therefore, taking inspiration from reuse practices is not just a technological and financial aspect; it also manages a socio-economic understanding that requires dissemination activities to be carried out across the country.

4. Conclusion

Cost and benefit analyses on installing GWR systems to 3 different building typologies in İzmir Province of Türkiye were the main intention of this study. These 3 buildings were real cases under planning. The investment and operation costs were calculated, and payback periods were determined. In addition to payback periods, it has been observed that the water savings achieved with GWR applications are significant in areas that do not require potable water quality, such as toilet flushing, irrigation, cleaning, and car washing. Since these systems generally require a treatment plant, they need more technical details than RWH systems. Nowadays, packaged membrane modules are supplied by manufacturers, and they also provide technical support during the entire system's operation. In addition, since greywater is produced continuously, there is no water flow problem, and it can be used safely to flush toilets after disinfection. As a result, using recovered water will provide undeniable water savings. Water savings will also protect receiving water resources and reduce the pollution load of wastewater treatment facilities. There will also be a financial benefit as water bills will be greatly reduce.

Savings in total water consumption through GWR were calculated as 46% for the hotel, 44% for the residential building, and 29% for the industrial plant. As seen from the water and economic savings values, high benefits can be achieved with these applications, and thus, freshwater resources can be used more effectively, especially in urbanized areas. Finally, raising public awareness and increasing interest in the great benefits provided by this alternative system is another issue that should be emphasized as much as the implementation by the government and local governments. Its practices could also be further encouraged by providing certain tax benefits similar to those undertaken by some countries as an important adaptation action against climate change.

Author Contributions

The third author directed the project and supervised this study's findings. The second and third authors devised the main conceptual ideas and developed the theoretical framework. The first and second authors performed the data analyses. The first author wrote the manuscript with support from the second, third, and fourth authors. The third author reviewed and edited the paper. All authors read and approved the final version of the paper. This paper is derived from the first author's master's thesis, supervised by the third author.

Conflicts of Interest

All the authors declare no conflict of interest.

Ethical Review and Approval

No approval from the Board of Ethics is required.

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