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Full Length Research paper

Alternative water sources for residential irrigation systems: A case study from Istanbul

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Water is the primary life-giving resource and hence requires careful preservation. Choosing an irrigation system, which uses an alternative water source such as graywater or harvested rainwater will help this preservation. The intent of this study is to compare residential irrigation system designs that draw their water source from graywater, harvested rainwater or municipal water. For realizing this comparison, the following criteria were evaluated: Availability of water, system components, cost and maintenance. In conclusion, this study found that municipal water is still an economically feasible source for residential system in Istanbul, despite the fact that graywater and harvested rainwater are the preferred sources in terms of sustainability.

Key words: Sustainable irrigation, graywater, harvested rainwater.

INTRODUCTION

Landscape irrigation systems are typically designed to draw their water source from the municipal water and these systems consume 30 - 50% of municipal water in many areas. If summer months are drier and warmer than usual, this percentage can reach 75% or more (Groesbeck and Striefel, 1997). In addition to these issues, landscapes are considered as ornamental and when drought or supply problems arise, everybody targets landscape irrigation before agriculture or industry use. These facts do not seem to be sufficient in terms of sustainable design processes, but with careful design, planning and management, landscape irrigation systems can be more efficient.

Landscape designers have the opportunity to explore and encourage the use of more sustainable irrigation technologies such as drip irrigation and the use of recycled water sources such as graywater or harvested rainwater.

Graywater refers to the reuse of water drained from baths, showers, washing machines, and sinks (household wastewater excluding toilet wastes) for irrigation and other water conservation applications. Filtered graywater is most suitably used for subsurface irrigation of non-edible landscape plants (Thompson and Sorvig, 2008).

Not only does its use on landscapes conserve treated tap water, but graywater may also benefit plants because it often contains nutrients such as nitrogen or phosphorus (Waskom and Kallenberger, 2009).

Rainwater harvesting is the practice of capturing and storing rain to provide water for human use. Rainwater harvesting systems most frequently collect water from building roofs and store it in tanks, called cisterns.

Exploring these alternative water sources is important because implementing their use in irrigation system designs results in more sustainable technologies that will help to preserve the supplies of potable water and reduce the amount of storm water run off that enters municipal storm sewer systems. It is the aim of the study to determine and to discuss the feasibility of alternative water sources for a residential irrigation system in Istanbul.

Abbreviations: AHR, Amount of harvested rainwater; **NID,** number of irrigation days; **WD,** water demand; **TAW,** total amount of graywater and harvested rainwater.

MATERIALS AND METHODS

This research will seek the use of graywater and harvested rainwater from the roof, as alternative water sources for irrigation;

and compare the benefits and drawbacks of these alternatives with the that of the municipal water.

For this comparison, the availability of water, system components and cost and maintenance were selected as the criteria for the assessment. Each criterion will be evaluated for the three water sources. For this evaluation, an irrigation system was designed for a specific site in Umraniye, Istanbul. The irrigation system has two methods of water application. One is drip irrigation to supply the planting beds and the other is sprinkler irrigation for the turf areas.

The site: Eralp residence in Umraniye, Istanbul

The residence is located on a rectangular shaped lot that measures 15 m by 35 m with a minimal sloping of 0 - 5%, in a gated community in Istanbul.

Istanbul has a temperate climate, but due to its size, topography and maritime influences, Istanbul exhibits a multitude of distinct microclimates. Summer is generally hot and humid. The average temperature in summer ranges between 21.5 and 23.8°C. Winter is cold, wet and often snowy, averaging between 5.9 and 8°C. Spring and autumn are usually mild and the average temperature range from 7.7 - 16.7°C (URL-1) (2010). The humidity of the city is constantly high which intensify the harshness of the air than the actual temperatures. The city has an average annual humidity of 72%. Average annual precipitation is 678.3 mm. Istanbul has an average annual of 152 days of precipitation (URL-2) (2010) . Peak rainfall occurs in December with 101.3 kg/m^2 and the driest month is July with 24.7 kg/m^2 (URL-1) (2010). The city is also quite windy, having an average wind speed of 18 km/h (URL-3) (2010).

The site's soil type is heavy clay. Actually, heavy clay soil is a nightmare for many designers depending on its poor drainage and tendency to compact. They have little pore space, low permeability rates and store a great deal of water (Weinburg and Roberts, 1988). According to the climate conditions in this site, this type of soil would be wet in winter, spring and fall, but can be drier during periods of low rainfall from the beginning of May to end of September. So, landscape irrigation will be needed for the site, especially in summer.

The designed irrigation system

Based on the nature of the heavy clay soils found on this site, the drip irrigation is the most efficient water irrigation system. In drip irrigation, the slow rate of application will not exceed the soil infiltration rate and the water will be directly added to the plants' root system. Since the drip irrigation is not recommended for turf areas, sprinkler irrigation is also used in the site, despite its incompatibility to use graywater as a water source. Therefore, the sprinkler system is designed for either municipal water or harvested rainwater, while the drip system is designed to draw its water source from either graywater or harvested rainwater. The irrigation system is divided into 7 zones (Figure 1). One of these zones is drip, while the other are sprinkler.

All system components are almost the same for either water source – graywater or harvested rainwater. House plumbing to the cistern for graywater and gutter routing and leaf screens for harvested rainwater were the only components which are not common for both system.

A 3-m^3 polyethylene tank will store the water, which will be pumped to irrigation pipes via a centrifugal pump. The actual system pressure will be set to 3.6 bars, because of friction loss through the pipes and the control valves. In this way, the last sprinkler will receive an operating pressure of at least 1.7 bars. Low flow, pop-up spray sprinklers from the Hunter PS Spray Nozzles were chosen for the turf areas. The drip system comprised of 200 m 20 drip irrigation pipe with 2 l/h drippers. The space between each two drippers is 40 cm.

Each zone is controlled by a 1" Hunter PGV-100GB Solenoid Valve and the controller will be located in the entrance hall of the residence for easy access and protection from the weather. The controller will be shared by both the sprinkler and drip systems.

DISCUSSION

Evaluation by criteria

Available water

As mentioned before, three water sources were considered for the irrigation design. They are; water from the city main, and two alternative sources – graywater and harvested rainwater. For the alternative water sources, it is necessary to determine if they are capable of meeting the water demands of the irrigation system.

Various studies have indicated that the amount of graywater generated per person per day varies from 96 - 172 L, or 384 - 688 L/day for a typical family of four (Gerba et al., 1995; Jenkins, 2005) and from these data, 500 L graywater per day can be accepted as an average value for this case.

The available water from a harvested rainwater system is calculated based on the square footage of the residence's footprint and the amount of average annual rainfall. In practice, some rainwater is lost to first flush, evaporation, splash out or overshoot from the gutters in hard rains, and possibly leaks from pipes (Bucklin, 1993). These inherent inefficiencies of the system need to be factored into the water supply calculation. Most installers assume an efficiency of 75 - 90% (Texas Water Development Board, 2005). In this case, 85% is accepted as collection efficiency.

As mentioned before, average annual precipitation is 678.3 mm in Istanbul. But to calculate the water supply, which is going to be used for irrigation in a correct way, the average amount of precipitation and the number of rainy days in dry season are needed, due to the fact that landscape irrigation will be realized in this site during that period. Monthly rainfall and rainy days data for the months of May to September, which was observed between the years of 1975 and 2008, are presented in Table 1.

Based on the data in Table 1, the amount of harvested rainwater (AHR) can be calculated:

AHR = Catchment area × Seasonal rainfall × Collection efficiency.

$AHR = 160\ m^2 \times 0.1483\ m \times 0.85$

$AHR = 20.1688\ m^3 = 20169\ L.$

AHR per day = 20169 L/ 30.5 days = 661.74 L/day.

So, the system will collect averagely, 650 L water per rainy days in dry season.

Table 1 also gives an idea about the number of irrigation days (NID):

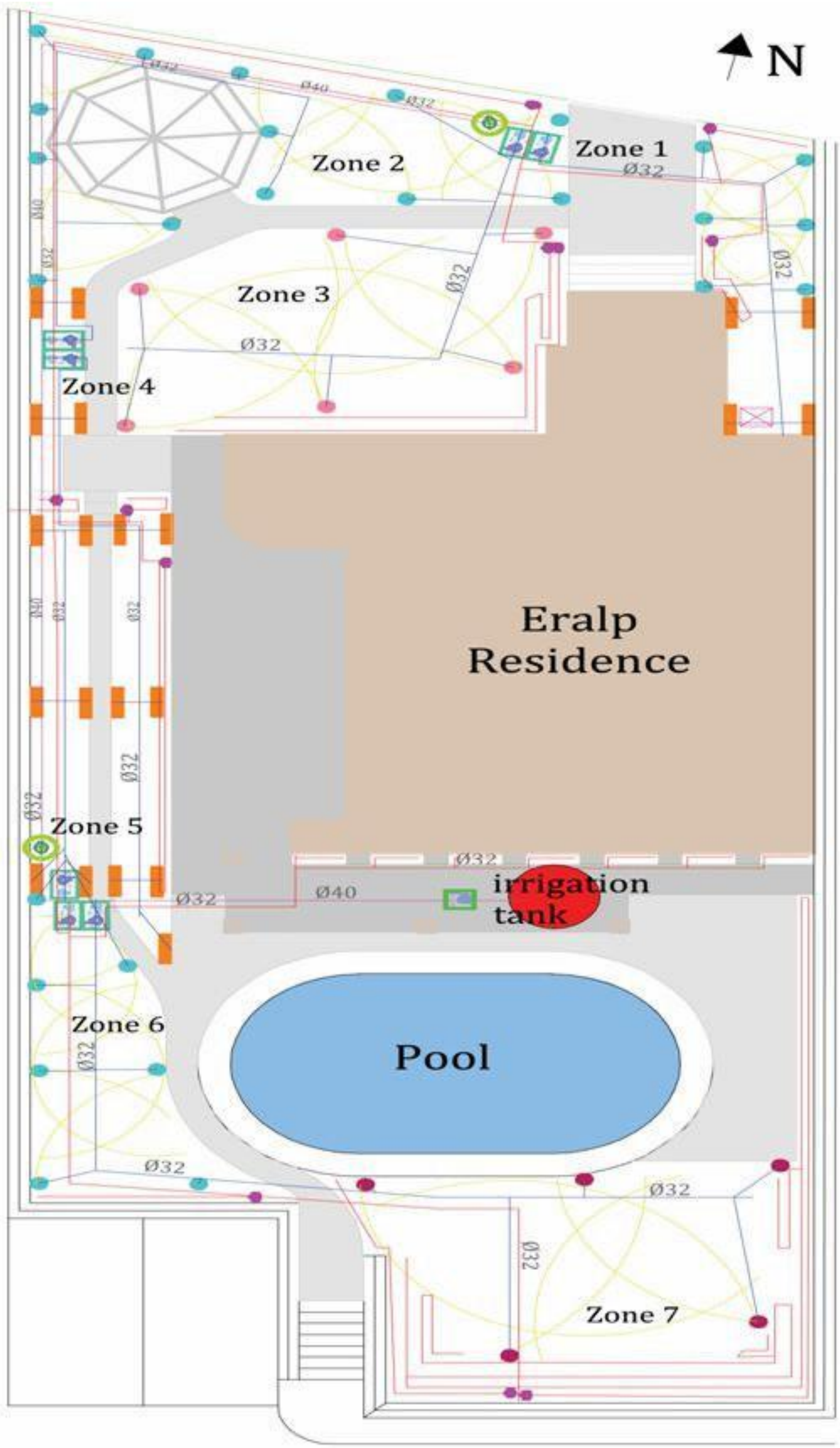

Figure 1. Site irrigation plan.

Table 1. The number of rainy days and the amount of precipitation in dry season (URL-1).

	May	June	July	August	September	Total
Number of rainy days (days)	7.6	6.4	3.9	5.6	7.0	30.5
Amount of precipitation (mm)	30.2	25.7	24.7	31.8	35.9	148.3

NID = Total no. of days in dry season – No. of rainy days in dry season.
NID = 150 days - 30 days = 120 days need irrigation. Besides, daily water demand for irrigation is 1880 L for this garden. This amount was calculated using the data and steps as follows:

Total green area = 280 m^2 (240 m^2 of turf, 40 m^2 of shrub/ground cover)
Water demand (WD) for lawn grasses = 6-7 mm/day (Melby, 1995).
WD for shrubs and trees = 4-5 mm/day (Melby, 1995). WD for sprinkler irrigation = 240 x 0.007 = 1.68 m^3 = 1680 L/day.
WD for drip irrigation = 40 x 0.005 = 0.2 m^3 = 200 L/day.
Total WD = 1680 + 200 = 1880 liters/day x 120 days = 225600 L.

According to these calculations, the amount of either graywater or harvested rainwater is enough for drip irrigation. However, even total amount of graywater and harvested rainwater (TAW) is insufficient to the entire irrigation system. Throughout the dry period, the graywater along with the rainwater can only provide 95000 L:

TAW = harvested rainwater (30 days) + graywater (150 days)
TAW = 20000 liters + 75000 liters = 95000 liters.
This is even less than the half of the total demand.

Furthermore, all of this amount could not be used in the system, because of health reasons. Municipal water and harvested rainwater are water sources for irrigation that do not pose a threat to human or plant health. However, graywater is different and it requires proper distribution to ensure that humans do not come in contact with the water. Therefore, it could only be applied to subsurface. So:

Total WD for drip system = 200 L/day × 120 days = 24000 L.
Total available water = harvested rainwater + graywater for drip irrigation.
Total available water = 20000 + 24000 L = 44000 L. Daily available water = 44000 L/120 days = 366.66 L/day. On an average, 365 L water per day is suitable for use in irrigation.

System components

Graywater systems generally contain a plumbing system to bring the graywater out of the house; a surge tank, filter to remove debris that might clog irrigation pipes and pump to move water from the surge tank to the irrigation field (Figure 2). Water pumping is one of the most efficiently used material during the generation of solar power and the pump used in this sustainable water collection system can be solar-powered, which is one of best ways of sustainable energy production.

Rainwater catchment systems comprised of a catchment area (roof), leaf screens to keep larger debris from entering the irrigation system, a storage tank and again a solar-powered pump to move water to the irrigation field (Figure 3) . As it is seen, both the graywater and the harvested rainwater are stored in tanks, apart from the main irrigation tank. These alternative water systems also need filters for each drip/sprinkler zone and the tank. Both systems are more complex systems than a system, which works with municipal water.

Cost

Additional system components, which are necessary for harvested rainwater and graywater systems, will increase the cost of application and maintenance. Table 2 lists the system components required for each type of water source with their current prices in Istanbul.

According to Table 2, the system that uses the municipal water is the least expensive one. If two other water sources are used together, along with municipal water, then total price will reach 4.098 $, which is 1.700 $ expensive than the municipal water system.

The money paid for irrigation water is another important issue. Upon current prices, using municipal water, it will cost: 3 $/$m^3$ x 1.9 m^3/day x 120 days = 684 $ per year If harvested rainwater and graywater are added to the system as alternative water sources, 1.5 m^3/day (1.9 - 0.4 m^3) will still have to be met by municipal water.

In this case, the cost of municipal water used for irrigation will decrease to:

3 $/$m^3$ × 1.5 m^3/day × 120 days = 540 $ per year.

And, total saving will be:

684 - 540 = 144 $ per year.

Thus, homeowner can gain back the money spent for the construction of irrigation system in 12 years, which is equal to economical lifetime of some components used in

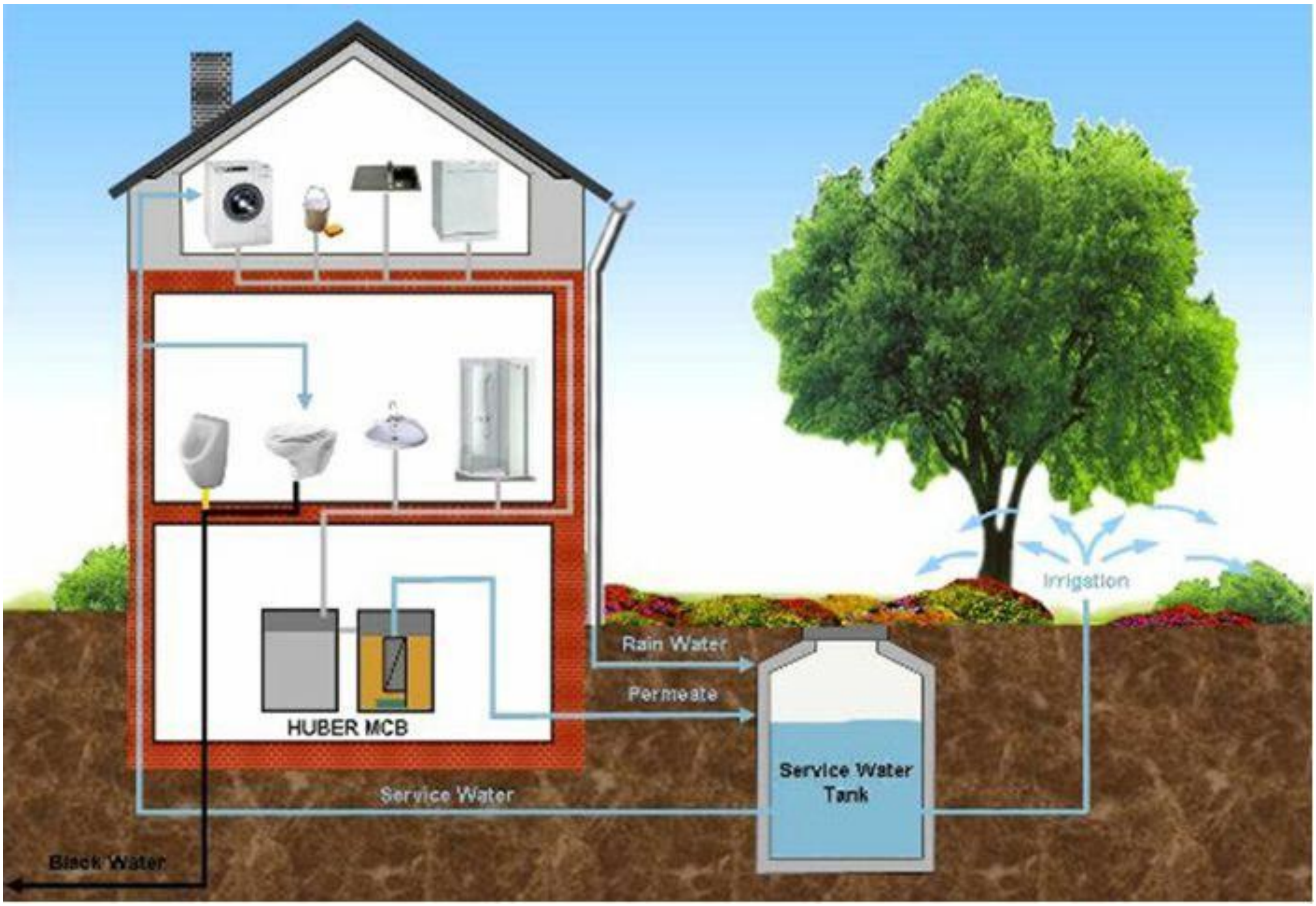

Figure 2. Graywater system components (URL-4).

the irrigation system. Moreover, the pumps, tanks and other additional system components of both the graywater and rainwater harvesting systems will have a negative impact on this saving (Ludwig, 1994). They will cause an increase the operation and maintenance expenses.

Maintenance

As mentioned before, alternative water sources, depending on their additional system components, will require additional system maintenance. For example, the gray-water system filters in the tank must be regularly cleaned and homeowners must regulate the types of cleaning products used in the household that will enter the gray-water system.

The pump must be monitored to ensure proper function with both the rainwater and graywater systems.

For the rainwater system, homeowners need to regularly monitor gutters to ensure that they are not clogged with debris. The leaf screens on the gutters should keep debris out of the gutters, but they should be checked seasonally (Leslie, 2001).

Conclusion

With two thirds of the earth's surface covered by water and the human body consisting of 75% of it, it is evidently clear that water is one of the prime elements responsible for life on earth. Despite this truth, demands are increasing every year for water while resources are becoming more and more limited. Therefore, as it is in all types of water use, landscapes and their irrigation systems also need to use water as efficiently as possible. As it is seen in this case, it is not hard to practice water conservation in a residential irrigation system, but there are difficulties to be handled.

The major issue is the cost of the system. The installation costs for alternative water sources is considerably higher than simply using the municipal water and without any dispute, municipal water is still the most preferable water source in terms of family budget. For example, a four household family living in a 160 m^2 residence in

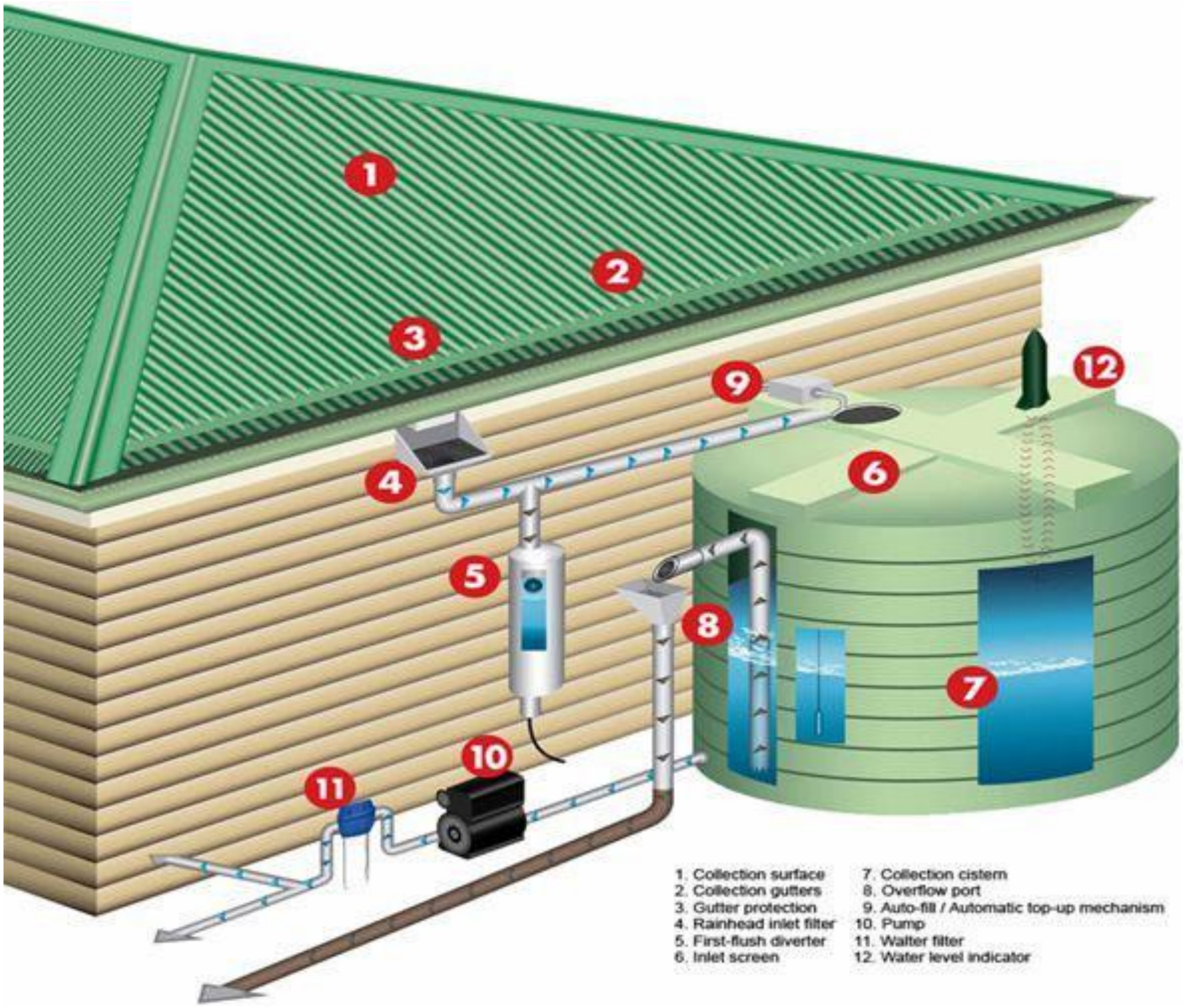

Figure 3. Rainwater catchment system (URL-5).

Table 2. System quotes for each type of water source.

No	System components	Quantity	Unit price	Municipal water ($)	Graywater ($)	Rainwater ($)
1	Ø40/10 PE 100 mainline	100 m	0.60	60.00	60.00	60.00
2	Ø32/10 PE 100 lateral	200 m	0.40	80.00	80.00	80.00
3	Ø40 x 1 ¼" male threaded adapter	2	0.75	1.50	1.50	1.50
4	Ø40 x 1" Tee	7	1.00	7.00	7.00	7.00
5	Ø40 x 3/4" tapping saddle	2	0.50	1.00	1.00	1.00
6	Ø40 coupling	2	1.40	2.80	2.80	2.80
7	Ø40 elbow	2	1.40	2.80	2.80	2.80
8	Ø40 end cap	1	0.70	0.70	0.70	0.70
9	Ø32 x 1" male threaded adapter	7	0.50	3.50	3.50	3.50
10	Q32 x 3/4" PE female threaded tee	11	0.60	6.60	6.60	6.60
11	Q32 x 1" PE female threaded adapter	2	0.60	1.20	1.20	1.20
12	Ø32 x 3/4" tapping saddle	58	0.40	23.20	23.20	23.20
13	Ø32 elbow	20	0.90	18.00	18.00	18.00
14	Ø32 tee	9	0.90	8.10	8.10	8.10
15	Ø32 coupling	3	0.90	2.70	2.70	2.70
16	Ø32 end cap	15	0.40	6.00	6.00	6.00

Table 2 Continued.

17	1" Nipple	7	0.10	0.70	0.70	0.70
18	PS series 10 A spray sprinkler	26	1.90	49.40	49.40	49.40
19	PS series 12 A spray sprinkler	6	1.90	11.40	11.40	11.40
20	PS series 17 A spray Sprinkler	5	1.90	9.50	9.50	9.50
21	PS ultra spray sprinkler and strip pattern nozzles	21	2.20	46.20	46.20	46.20
22	Ø20 x 3/4" PE male threaded elbow	58	0.30	17.40	17.40	17.40
23	Ø20 x 1/2" PE male threaded elbow	58	0.30	17.40	17.40	17.40
24	Ø20/6 PE Drip Line	200 m	0.30	60.00	60.00	60.00
25	PGV- 100 GB solenoid valves	7	11.40	79.80	79.80	79.80
26	6" valve box	2	2.50	5.00	5.00	5.00
27	10" valve box	8	4.00	32.00	32.00	32.00
28	Quick coupler	2	5.00	10.00	10.00	10.00
29	Backflow preventer	1	76.00	76.00	76.00	76.00
30	1" metallic filter	1	5.00	5.00	5.00	5.00
31	PRO-C controller	1	400.00	400.00	400.00	400.00
32	Teflon tape	35	0.10	3.50	3.50	3.50
33	Q16 x 3/4" globe valve	11	0.50	5.50	5.50	5.50
34	Pressure regulator	1	37.50	37.50	37.50	37.50
35	Ø16 pipe clamps	176	0.10	17.60	17.60	17.60
36	Ø16 tee	10	0.10	1.00	1.00	1.00
37	Ø16 elbow	50	0.10	5.00	5.00	5.00
38	Ø16 coupling	5	0.10	0.50	0.50	0.50
39	Ø16 end cap	25	0.10	2.50	2.50	2.50
40	Check valve	2	5.00	10.00	10.00	10.00
41	Drip stakes	400	0.10	40.00	40.00	40.00
42	Irrigation pump	1	700.00	700.00	700.00	700.00
43	Irrigation tank (3 m^3)	1	500.00	500.00	500.00	500.00
44	Rain sensor	1	50.00	50.00	50.00	50.00
45	Graywater connection to indoor plumbing	1	70.00	-	70.00	-
46	Additional parts for installing separate waterline to use drip irrigation with graywater	1	130.00	-	130.00	-
47	PE drum (1 m^3)	1-for each	150.00	-	150.00	150.00
48	Solar powered pump	1-for each	350.00	-	350.00	350.00
49	Leaf screens on gutter	100 m	5.00	-	-	500.00
Total				2.398,00	3.098,00	3.398,00

Istanbul has to wait at least 15 years to gain back the money spent for the construction of the irrigation system which can use alternative water sources.

Another issue is the availability of alternative water sources. Even though all amount of collected water from both sources can be used in the system, it is still not enough to meet all the demand of a residential irrigation system. It is needed to seek out and find other innovative water conservation solutions to install an irrigation system that gets its all water in sustainable ways.

Although there are economical difficulties and availability problems, alternative water systems are not seen from the potable water supply, which is so important for the future of civilization. Water reuse and conservation at the household level will also help to reduce stormwater runoff into municipal storm sewer systems, while preserving the potable water supply.

From the view of sustainability, water conservation should not be considered an option any longer. Although the cost of municipal water sourced irrigation system is less than the others, indirect costs and problems, change the equation significantly and makes the alternative water sources more preferable in the long run. As further research is conducted, the general public needs to be educated and informed, and sustainable technologies need implemented, it will be possible to see wider use and mainstream acceptance of these practices. More information about these practices will be provided by focusing on the studies, which are on the use of alternative water sources at other scales such as streets, neighborhoods or golf courses.

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