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Applied Article

An Analysis of Rainwater Harvesting Methods in Landscape Design in Identical Hypothetical Sites in Three Climate Zones in Iran

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Abstract | The concept of rainwater harvesting systems has been a very popular trend in recent years, and while water scarcity is a common issue, and will likely become an environmental crisis shortly due to climate change and global warming, the significance of these systems mostly remains in theory books and articles and many landscape architects are unaware of how to put them into practice, especially in hot and dry areas such as Iran, where rainfall patterns have changed more and All or most of the annual rainfall may occur in a short period, and there are periodic protracted droughts and brief, seasonal floods the necessity of rainwater harvesting by landscape architects has not yet been considered as made a permanent part of the design process. In this article, firstly initial guidelines and steps for creating an effective system for collecting rainwater in landscape architecture projects are explained, and then by designing a single hypothetical site in three different climates in Iran, the practical components, calculations, and proposed approaches suitable for each climate are provided.

Keywords | *Rainwater harvesting, active harvesting system, passive harvesting system, Xeriscaping, Microclimate, Rain Garden.*

Introduction| The process of harvesting and storing rainwater is not an innovative phenomenon. Indigenous water management methods worldwide, including Iran, go back thousands of years. Despite the development of new technologies, these old methods are still effective in different areas. People from various watersheds worldwide are constructing traditional structures using stones and soil to manage floods, sedimentation, and erosion, and utilize seasonal water flow effectively relying on local knowledge. Gathering, preserving, and utilizing rainwater has been practiced for a long time in regions such as Mesopotamia, Iran, Rome, and China. The residents of these regions are well-acquainted with this technology for storing and conserving valuable water during the rainy season to utilize during the dry season (Beckers et al., 2013, 145-164). This technique effectively changes rainwater, as a potential threat that can cause floods, erosion, and landslides, into a valuable resource and each site can be utilized to fulfill water requirements, leading to environmental advantages, cost reduction decreased flooding and erosion risks, and minimized reliance on alternative water sources like wells or municipal water and finally, this concept is explored (Issar, 1999) through a hypothetical case study in Iran, focusing on designing an autonomous rainwater harvesting system and addressing associated queries.

Iran in most parts has an arid and semi-arid climate, and noticeable climate changes have occurred in the country in the past few decades. Between 2015 and 2018, approximately six significant floods happened in surprising locations in the country's arid and semi-arid regions, and the pattern of destructive floods is still ongoing. According to a forecast published in Nature magazine in 2019, it is anticipated that Iran will undergo a temperature increase ranging from 1.1 to 2.75 degrees Celsius by the century's conclusion. Additionally, another model indicates a notable rise in temperature of 2 to 2.75 degrees Celsius across various country regions (Vaghefi et al., 2019). The diverse climate of Iran requires implementing different strategies specifically designed for individual regions, taking into account the preferred weather conditions. In this article, three distinct locations in Iran with varying climates were chosen to demonstrate rainwater harvesting methods, along with corresponding strategies designed for each climate.

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Initial Steps of Designing A Rainwater Harvesting System (RWHS)

Step one – The first phase involves conducting an analysis related to the capacity for rainwater harvesting and evaluating different techniques for rainwater collection to identify the most appropriate method. It is essential to take into account various factors, including site characteristics such as the volume of precipitation, the potential for rainwater extraction and distribution, the topography of the site, the existing vegetation and their water requirements, the type and depth of the soil, as well as budget considerations (Minnesota Pollution ..., 2022) (Fig. 1).

Step two - The efficiency of the harvesting system must be determined by taking into account factors such as evaporation, surface absorption, pipe leakage, and flow rate in the catchment area where rainwater may be lost. The efficiency of our system is determined by the formula below:

System efficiency is calculated by dividing the total amount of rain that has fallen by the volume of water that can be extracted.

System efficiency = the total volume of annual fall ÷ the volume of extractable water

Step three - The third step in choosing a rainwater collection system involves considering the two main types of rainwater harvesting systems that are available. Active and Passive systems, the definition of these two systems is briefly discussed below (ibid.).

Passive rainwater harvesting involves shaping the soil to optimize water collection and infiltration while reducing runoff. In this approach, constructions composed of soil and stone, including terraces, sand channels, and various other constructions, are established to facilitate water movement from the upstream regions of these structures to the downstream areas, utilizing the force of gravity (Fig. 2).

An active rainwater harvesting system involves utilizing a system of pipes and tanks to collect and store rainwater in tanks, followed by a distribution network to transport water to the point of use. This system enables the storage of rainwater to prolong its usability beyond just when it falls from the sky. As a result, this system tends to be both more intricate and costly. This typically includes a water storage tank in either surface or underground form, chosen based on the site's area, budget, and average yearly temperature (Murkute & Kekalekar, 2021, 12-20) (Fig. 3).

The choice between an active or passive system relies on different factors like precipitation trends, water needs, space availability, and budget. Passive systems may be adequate in high rainfall, low water demand areas, while active systems with extra components may be necessary in low rainfall, high water demand areas.

Step four - The final stage following the selection of the system involves assessing the expenses associated with the construction and installation of the system. This aspect is crucial, as water rates in certain municipalities can be quite low, making the implementation of a rainwater harvesting system on our property potentially uneconomical. To determine the overall cost-effectiveness, one must calculate the anticipated water savings over a ten-year period, based on the chosen system, and then compare the monetary value of these water savings with the costs incurred in establishing the system. This analysis will help evaluate the economic viability of the initiative.

Process of RWHS System Design

For this purpose, a singular hypothetical site has been examined across three distinct areas, each possessing unique characteristics. Consequently, in a single site with fixed aspects, the only variable of this research is the different climates of these three sites, and the appropriate approaches for these three climates have been investigated (Table 1).

The site plan that is shown in Fig. 4 represents our theoretical site measuring 1800 square meters, and incorporating four sections each distinguished by unique textures.

Rainwater harvesting is practiced in sections 1, 2, and 3 of the catchment basins, while zones 4 are designated for irrigation purposes. Hence, the total area for designing the landscape equals 1023 square meters. First, the design of the RWH system at site A has been examined.

• **Site A**

Our first location is the city of Yazd, situated in the heart of one of the most arid and hottest deserts in the world. According to Kopen's climate classification, Yazd experiences a hot, desert

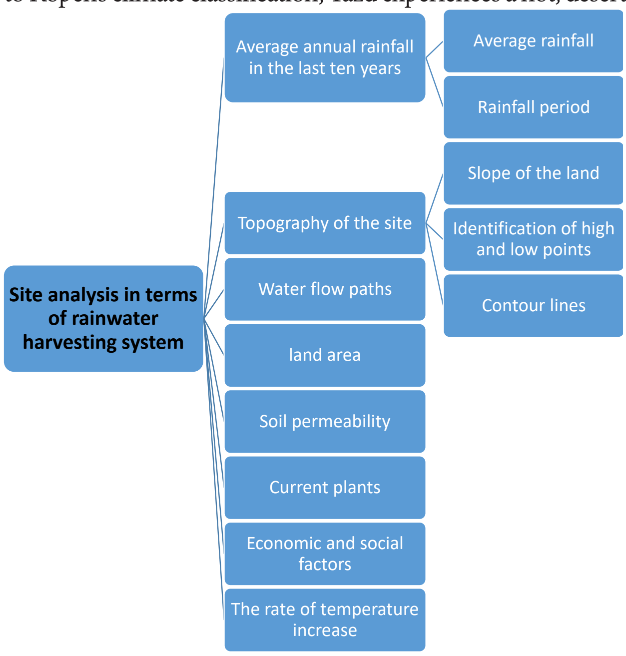

Fig. 1. Site analysis in terms of rainwater harvesting system. Source: Author.

Fig. 2. Components of passive rainwater harvesting system. Source: Author.

climate, with an annual precipitation of 60 mm and just 23 days of rain. Summer temperatures frequently exceed 40 degrees Celsius with strong sunlight and very low humidity. Establishing a garden under these conditions presents a considerable challenge; however, examining the extensive past of architecture and landscape architecture in this area shows us that it can be achieved. The inhabitants of this area were among the pioneers in developing the aqueduct system for carrying water from faraway mountains to irrigate their fields, gardens, and urban areas (Monshizade, 2008, 1-9).

- Calculations for Site A

The equation that is typically employed to determine the amount of water that can be gathered from a surface by incorporating area measurements, average yearly rainfall, and surface runoff coefficient is as follows (Son & Kwon, 2022):

C×I×A=Q

C: Coefficient C is the flow rate of water in the catchment area

I: Amount of annual rainfall (in millimeters)

A: Catchment area (in square meters)

Q: Quantity of water that can be harvested (litter)

Hence, The available volume of the system can be calculated by multiplying the catchment area (1023 sqm) by the rainfall amount (60 mm) and the collection efficiency.

The extractable volume of rainwater (RWH):

C×I×A=Q

0.8×60×777=37,296 litters

Therefore, it is evident from site A that the annual capacity for water collection from the roof and floor catchment areas of the building yard is 37,296 liters per year. This volume is insufficient for the intended purposes and does not adequately satisfy the water requirements of the planting sector, so The entire yard and area should be added to the water catchment area. Then the main problems of the site should be identified to find practical solutions that match the needs of the site.

- Site A's analysis

Issue number one: The primary issue is the limited yearly precipitation in places like Yazd, where water is highly evaluated. Hence, it could make financial sense to invest in a costly rainwater harvesting system.

Solution: Increase the catchment area to its maximum capacity

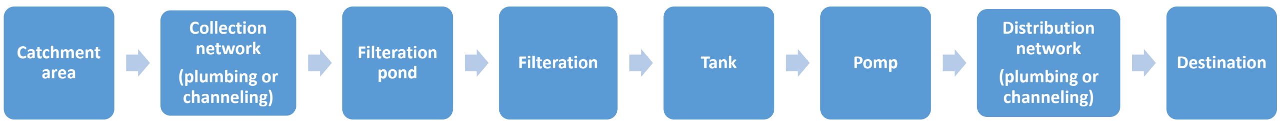

Fig. 3. Components of active rainwater harvesting system. Source: Author.

Table 1. Characteristics of the three studied sites. Source: NCEI (National Centers for Environmental Information).

Site	Similar cities in terms of climate	City Name	The type of weather	Average annual rainfall	Type of Soil
A	Karachi-Pakistan, Tucson-Arizona, USA	Yazd	Hot and Arid	60 mm	The combination of sand and clay, very little organic matter, Low ability of water absorption
B	Ankara - Türkiye, Yuma - USA	North of Tehran	Semi-Arid, Semi - Mediterranean	423 mm	Sedimentary and volcanic and low organic matter
C	Mumbai - India, Guangzhou - China	Rasht	Humid summers, and cold, wet winters	1323 mm	The combination of clay, silt, and sand along with many organic materials

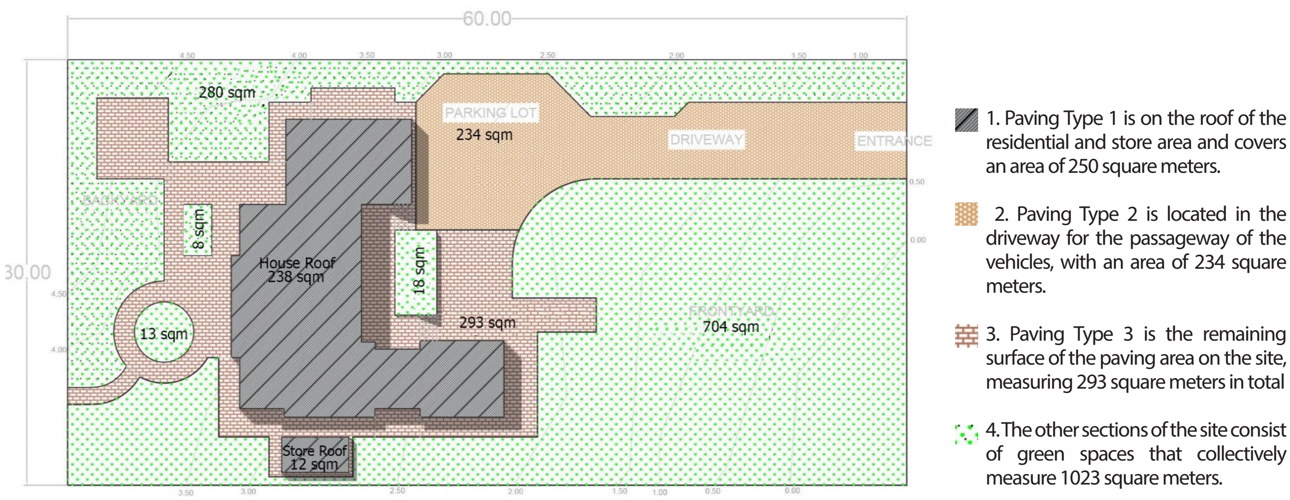

Fig. 4. Site plan of the hypothetical site. Source: Author.

and reduce the water requirement, as elaborated in the design elements segment.

Issue number two: intense heat (from April to November) and water loss caused by high evaporation.

Solution: To address this issue, we can explore the option of placing all rainwater collection facilities below ground. The ancient city of Yazd has long utilized aqueduct (Qanat) technology to implement a solution where the irrigation and water storage system is kept entirely underground, from source to destination, to protect the valuable water from the intense heat of the sun (Kalantari et al., 2017, 2-7).

Issue number three: Soil composition: The soil in Yazd is mainly a blend of clay and sand, with a water flow coefficient of 0.2.

Solution: A suitable method may involve compacting the subsoil layer to enhance effectiveness and decrease permeability. Another option is to use mulch or crushed stone to cover the planting area and surface soil layers, or to incorporate organic matter to increase soil moisture.

Issue number four: the quantity of water gathered at the location falls below the irrigation requirements of the planting zone.

Possible solutions: For addressing this, there are several options. 1. In this specific location experiencing water scarcity, it is essential to implement a specialized approach to enhance the amount of water harvested. Consequently, it is imperative to optimize the collection surface or catchment area/ 2. Another option is to utilize correct irrigation methods that can reduce water loss from evaporation or inefficiency. Drip irrigation is a method that delivers water straight to plant roots, minimizing water loss from evaporation and promoting efficient water utilization. Other methods within the local area, like jug irrigation, can enhance the effectiveness of irrigation (Tang, 2010, 1-4)/ 3. Planting indigenous trees and shrubs with strong resistance to drought and minimal water requirements./ 4. Xeriscaping design (Malekinejad et al., 2020)/ 5. Avoid planting grass/ 6. Determine the water requirement of the total vegetation of the site and try to equate it with the amount of water that potentially is collected annually/ 7. Designing a backyard area with shade trees, drought-tolerant trees, and water features with a closed-loop water system, to create a microclimate and boost humidity during the hot summer months/ 8. Construction of sidewalks in the area with concrete or mosaic with the ability to collect 90% of collected rainwater. based on the site analysis, the plan outlined Fig. 5, appears to be an appropriate system considering the attributes of site A. The chosen system is an active one, featuring underground reservoirs that minimize the cultivated area and substitute it with Xeriscaping components.

- **Elements of design at Site A**

a. The site is divided into two zones, each with a catchment area for rainwater collection (Fig. 6); The first zone comprises the roof and backyard, as well as an underground tank to prevent water loss from heat and evaporation. The second zone is the garden and yard located in front of the building and its surroundings, as well as a second underground well dug in the corner of the yard.

b. The main idea for the front yard involves designing a staircase composed of uniform rhombus shapes, each differing in height by 50 cm, in accordance with the existing terrain and slope.

c. Decreasing the planting space while expanding the collection area and soil through layering to increase rainwater collection efficiency, ensuring all water is directed to an underground well and pumped for drip irrigation to plants.

By utilizing the information provided in Fig. 7, the water flow coefficient in zone 2 (front yard) increases to 0.8, resulting in a higher capacity for the water collection system as calculated below:

$C \times I \times A = Q$

$0.8 \times 60 \times 1023 = 49{,}104$ litters

Therefore, the overall quantity of the yearly harvesting amount will be as follows:

$49{,}104 + 37{,}296 = 86{,}400$ litters

This amount of water is not sufficient for all the yearly water requirements, however, given that this area is situated in one of the most arid cities globally, this method remains financially reasonable due to the expensive water prices in the area and environmental benefits.

d. Concrete pavement is installed for its effectiveness in collecting water.

e. Utilizing the French pit technique along the sidewalks to gather rainwater as described in Fig. 8.

f. Xeriscaping and planting indigenous, drought-tolerant trees in the green areas.

z. Create a microclimate by planting shade trees and water features in the backyard

- **Site B**

This site is now believed to be situated in the northern region of Tehran, where the average annual precipitation is recorded at 423 mm. The climate of Tehran exhibits considerable variation; the southern part of the city experiences hot and arid winds originating from the central desert of Iran. In contrast, the northern area, positioned at the base of the Alborz Mountains, enjoys a more temperate and rainier climate. but it is still in a semi-arid climate without rain or with very little rain in the months of June to October.

- **Calculations for Site B**

The volume of rainwater harvesting is determined by the area of the catchment surface, the amount of precipitation, and the efficiency of the collection system.

$C \times I \times A = Q$

Volume of RWH = 777×423 mm $\times 0.8 = 262{,}936.8$ Litters

- **Site B's analysis**

Issue number one: Hot summers and cold winters.

Solution: Establish a microclimate in the backyard by planting shade trees installing a pond to lower the temperature during hot summers, and using antifreeze concrete on the sidewalks.

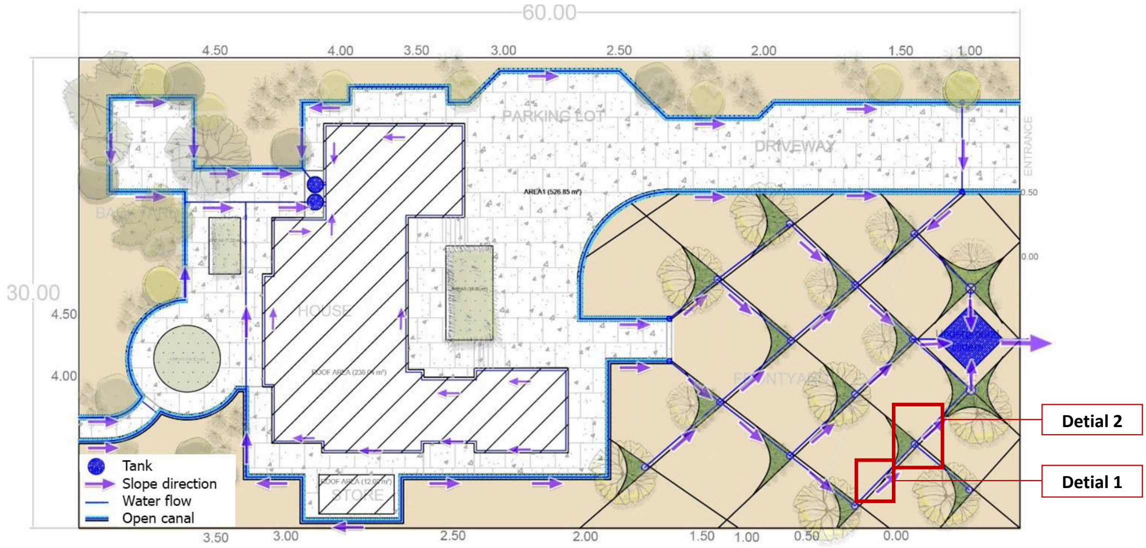

Fig. 5. The proposed plan for Site A. Source: Author.

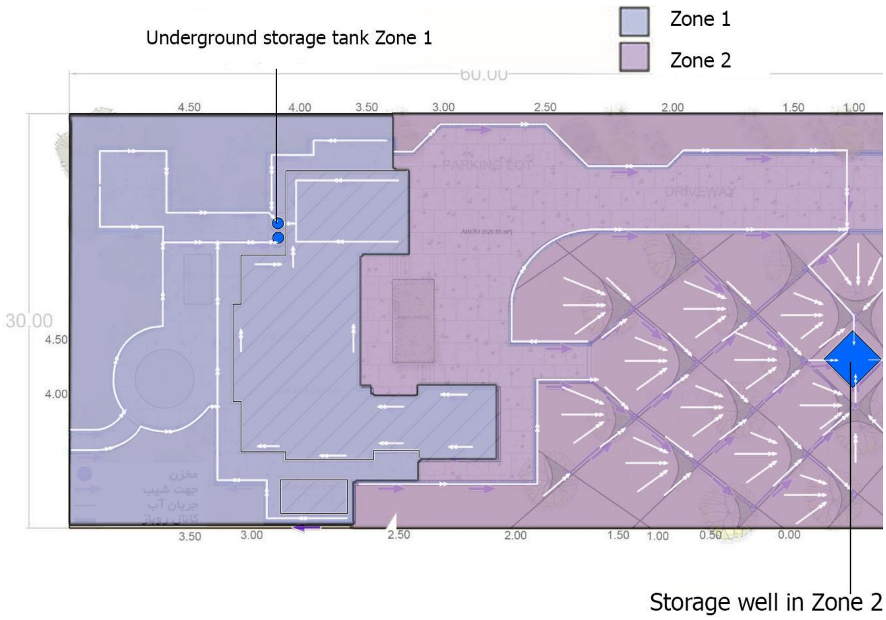

Fig. 6. Site A water collection route. Source: Author.

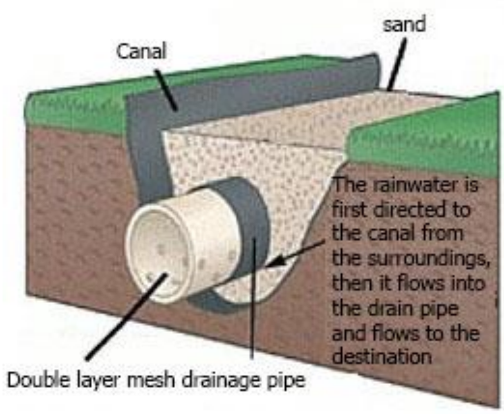

Fig. 7. Detial 1. www.usfabricsinc.com.

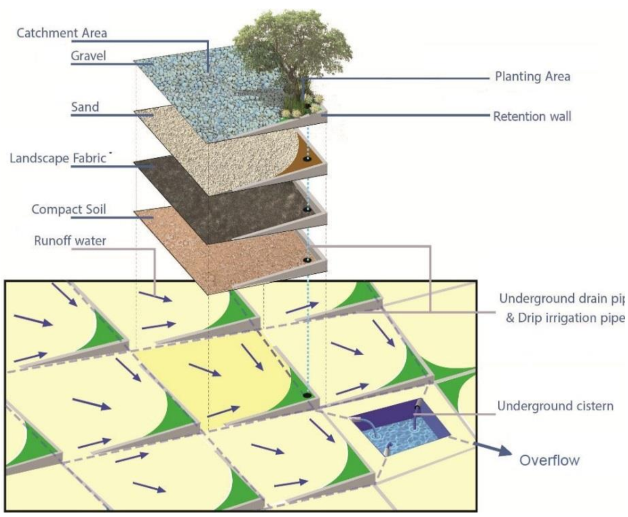

Fig. 8. Detail 2. Source: Author.

Issue number two: Limited annual rainfall amount.
Solution: Increase rainwater collection in the front yard by creating water flow paths on the sloped terrain leading to a dug well at the yard's lowest point. This particular number gets combined with the sum from the paved area collection, thus boosting our yearly total.
Volume of RWH = 1023 × 423 mm × 0.35 = 151,455.15 Litters
Hence, the overall amount of water extracted annually is:
262,936.8+151,455.15=414,391.95 litters
Issue number three: soil composition is a mix of sedimentary and volcanic soils with a low level of organic material.
Solution: Placing big rocks in the front yard can prevent erosion while adding leaf soil and organic matter boosts water absorption capacity.

- Elements of design on the B site
a. Just like site A, the site is split into two zones (Fig. 9), with an above-ground tank storing rainwater gathered from the roof and the paved section in the backyard, then pumping it back to the same area. In the second zone, a well is excavated at the yard's lowest spot for collecting rainwater and directing surface runoff into it. Additionally, implementing strategies such as planting shade trees and practicing low consumption, constructing a permanent fountain for hot summer days, and reducing the use of grass are appropriate methods for adapting to the local climate (Brad, 2022).
b. Decorating a catchment area with river rocks before the well can provide aesthetic enhancement while also serving to filter and stabilize the soil in the event of floods (Figs. 10, 11 & 13).

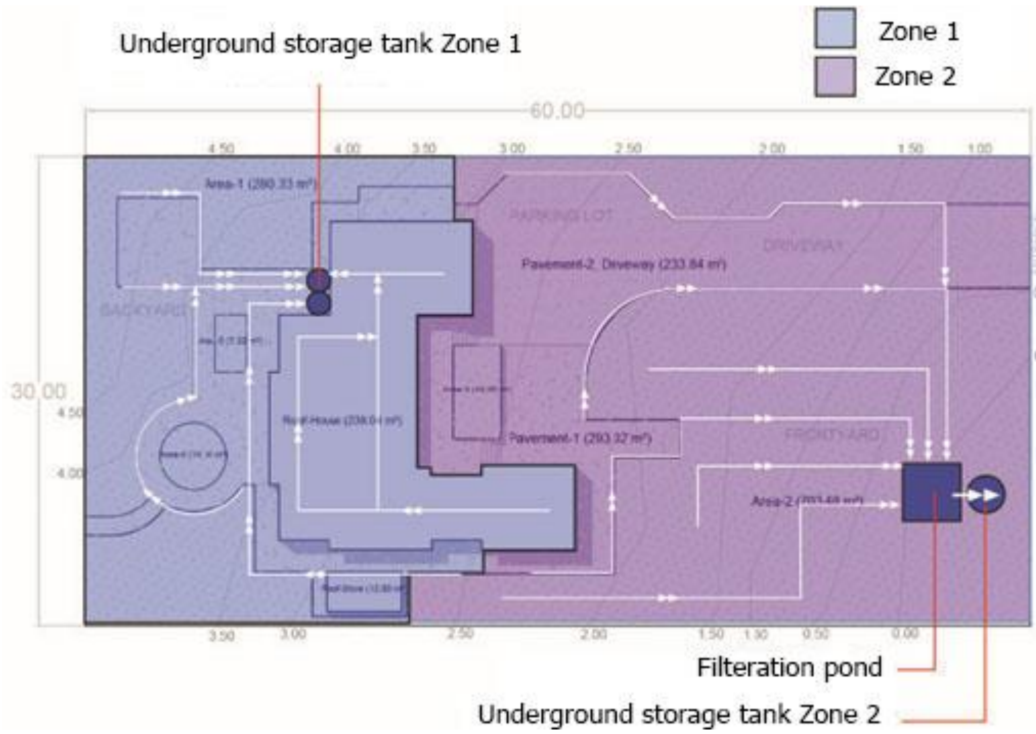

Fig. 9. Water collection path in site B. Source: Author.

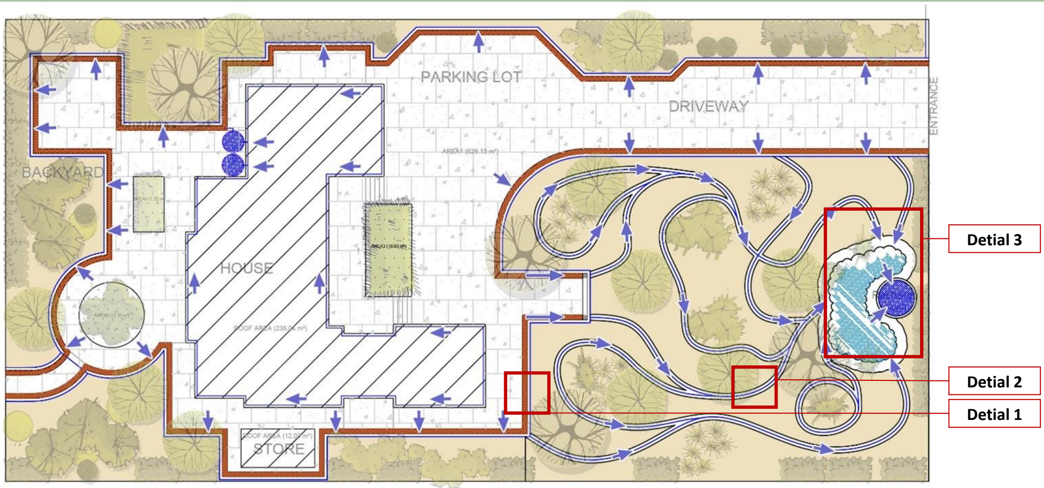

Fig. 10. The proposed plan for Site B. Source: Author.

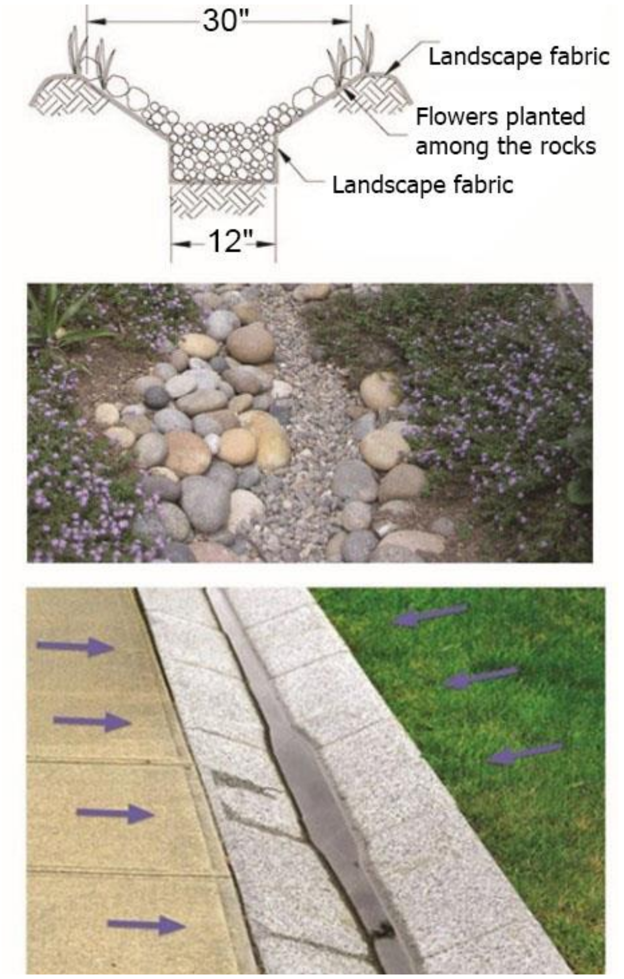

Fig. 11. Detail 1,2. Source: www.santacruz.watersavingplants.com.

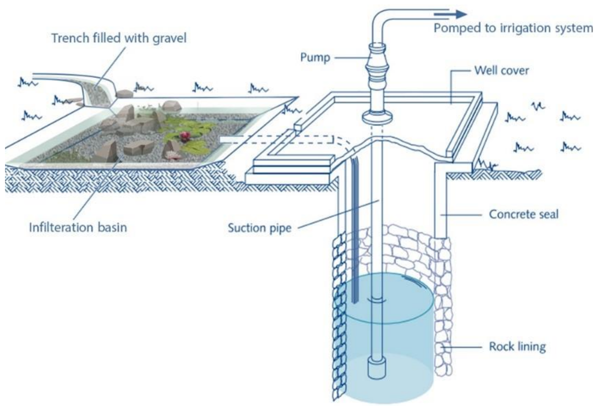

Fig. 12. Detail 3. Source:www.vardhmanenvirotech.com.

c. Planting indigenous trees and shrubs suitable for the climate and minimizing grass planting to only areas with specific purposes like a playground or picnic spot (Raes & Savolainen, 2021, 10-13).

• Site C

The third location is Rasht city in Gilan province near the Caspian Sea, which has an average annual rainfall of 1330 mm, a moderate climate, hot, humid summers, and cold, wet winters. Should a rainwater collection system be installed in this region? Certainly, the system can be utilized in various locations including tropical areas due to its ability to improve water efficiency.

- Calculations for Site C

Rainwater harvesting volume equals the area where water is collected multiplied by the amount of precipitation and the efficiency of water collection.

$C \times I \times A = Q$

Volume of RWH $= 777 \times 1323$ mm $\times 0.8 = 822{,}376.8$ Litters

This amount represents only the water gathered from the ground surface and could rise by extending our collection zone to the planted area, yet through a passive approach, this objective is available without needing a tank or pipes.

There is regular rainfall yearly, allowing for rainwater collection in an open pond. However, due to issues associated with mosquito breeding, fiberglass tanks are preferred for storing large amounts of water (with a capacity of over 40,000 liters) for irrigation purposes instead. The container must be kept at its full capacity, and any surplus water can be repurposed for various activities such as doing laundry and flushing the toilet.

- Site C's Analysis

Issue number one: The main issue is the steep slope in certain areas of the site, leading to faster water flow during floods and decreased rainwater storage capacity.

Solution: In a yard with a slope ranging from 10% to 12%, employing the design technique of aligning with the front contour lines proves to be advantageous. Retaining walls or ridges are constructed along these contour lines, spaced between 5 to 20 meters apart on this specific site. The initial 1 to 2 meters above the ridge are designated for cultivation, while the remaining area is utilized for the collection of rainwater. The effectiveness of this system hinges on the precise positioning of the ridges along the contours, which helps to mitigate the speed of runoff water during flood events.

Issue number two: The second issue is that the soil type at this location is fine clay, with low sand content and high organic matter content, causing a higher-than-normal level of suspended solid particles in the water.

Solution: There is a need to install a filtration system that can effectively remove any undesirable materials and solid particles from the water collected before storing it in tanks. This procedure enhances both water quality and the lifespan of storage tanks.

- Elements of design for site C

a. There is enough rainfall to meet the needs and you only need to determine the direction and cycle of the running water and minimize the speed of the water flow so that the soil has a chance to absorb the water needed by the plants. Therefore, the design of the "ridge counter" technique will be efficient (Figs. 13 & 14).

b. When creating a rain drainage system in a location with yearly precipitation of 1323 mm, it is important to take into account the water channel running alongside and across the sidewalks for rainwater absorption (Fig. 15).

c. The Rain Garden method is an appropriate strategy for this location, as it minimizes water wastage and is an effective way to replenish underground water levels (Chen, 2016, 5-6) (Fig. 16).

d. Permeable flooring: This type of paving is made with a surface that contains open pores on the top layer and a sand base on the bottom layer.

Conclusion

Each location has unique characteristics, and one can apply the methods discussed in this article (Table 2), a combination of these methods, or other approaches not mentioned here to adapt to various weather conditions

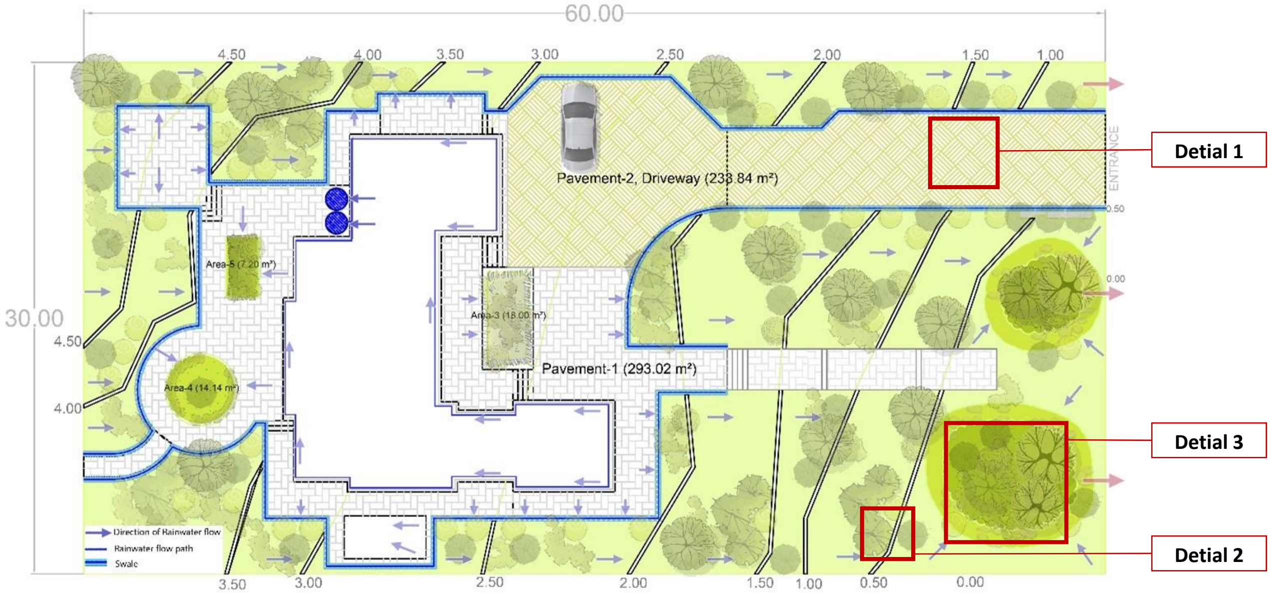

Fig. 13. The proposed plan for Site C . Source: Author.

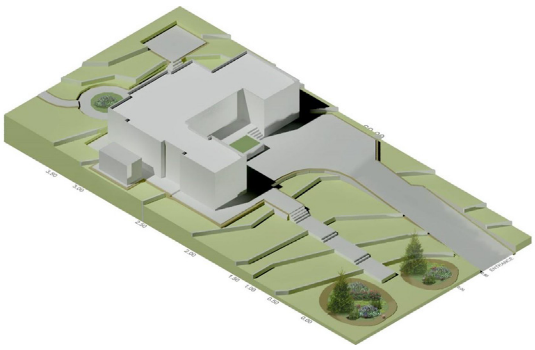

Fig. 14. Detail 2. Source: Author.

Fig. 15. Detail 1.Source: www.carousell.ph.

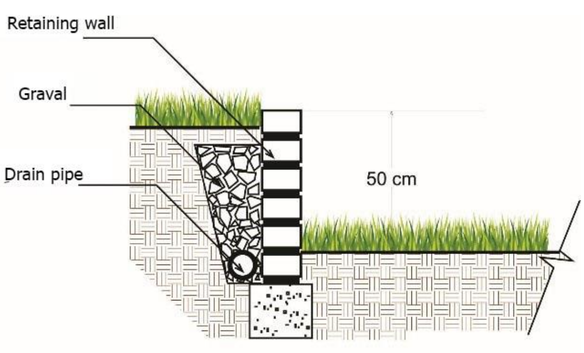

Fig. 16. Detail 2. Source: Author.

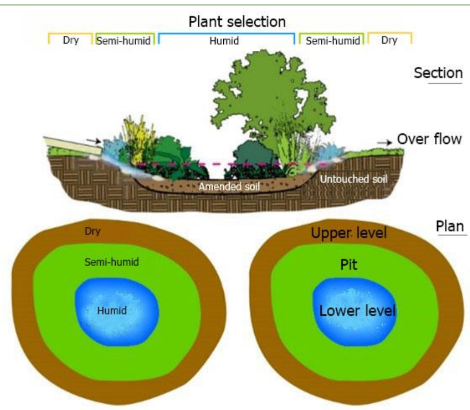

Fig. 17. Detail 3. Source: www.slideshare.net.

Table 2.Comparison table of components of three sites. Source: Author.

Location	RWHS System	Climate and annual Precipitation	Site Issues	Solutions and approaches	Annual volume of rainwater that can be harvested (lit)
Site A: Yazd	Active	Hot and arid 60mm	Low annual harvest - Extreme heat and water loss due to high evaporation - Soil type	Maximizing the catchment area, minimizing the water requirement, efficient irrigation techniques, moving the irrigation network and reservoir underground, compressing the subsoil layer, planting native trees and shrubs, landscaping, and creating a microclimate.	86,400
Site B: North of Tehran	Combination of active and passive systems	Semi-arid- Semi Mediterranean, 423mm	Hot summers and cold winters, insufficient amount of annual precipitation, soil type	Creating a microclimate in the backyard with shade trees and a water feature, implementing water flow paths along the slope of the land, placing large stones in the front yard to prevent erosion, and adding mulch.	392,414
Site C: Rasht	Passive	Mild and humid, 1323mm	Relatively high slope and high speed of flowing water during floods, suspended particles in water, soil type	soil type, Design matched with the contour lines, efficient filtration system, Rain Garden, Porous and permeable pavement	822,378

based on the specific features of each site. By conducting a comprehensive analysis of the location, utilizing reliable data, and selecting appropriate techniques, landscape architects can create an effective rainwater harvesting system. Offering incentive measures like low-interest loans with extended repayment terms can be an effective way to motivate private individuals to implement such systems, particularly in countries facing the risks of floods and droughts (Zhong, 2022, 1-4).

Landscape architects should possess a comprehensive understanding of various factors during the pre-design and design phases of a landscape project. In addition to standard practices such as site inventory and analysis, functional diagrams, and design concepts, it is crucial for them to address the significant concern of utilizing renewable and sustainable rainwater as the primary source for water requirements. They should formulate an appropriate strategy that considers climatic conditions, enabling them to shift their focus from merely aesthetic and functional spaces to creating a sustainable environment that is resilient to future challenges.

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