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Household model of rainwater harvesting system in Mexican urban zones

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Abstract: This paper describes a household model of the rainwater harvesting system in residential development of Tlaquepaque, Jalisco, Mexico. Harvested rainwater is estimated for designing a rainwater catchment system which reflects the maximum water supply to a household. Based on the estimation of the harvested rainwater, the total water demand is calculated in order to explore the possible uses of rainwater. Major components in the rainwater catchment system are as follows: catchment area; downspout (roof drain pipe) and first flush tank; cistern; infiltration well; pumping station and filtering system; and ultraviolet (UV) water treatment. The rainwater harvesting system is designed to operate as the part of the central water supply system. This paper exposes the process of design and construction and its cost. In this way, it aims to establish a technical and conceptual reference, which enables the citizens to design their rainwater systems and their construction. This model will produce an important experience that can help to improve the systems in a Mexican context. It can be also useful for the international community.

Key words: rainwater harvesting system; water supply; water demand; catchment area; cistern

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More than a half of the world's population lives in a metropolitan zone. This human concentration is provoking enormous and complex challenges, such as water supply and flood mitigations during rainy seasons. In the last few years, the rainwater catchment systems have been increasing as an alternative of partial water supply and as a way to diminish the floods in urban zones. In this way, many countries around the world have been implementing this technology in human settlements, and inspiring other nations[1]. Since the founding of Mexico City, the Aztecs and Mays implemented some systems in their architectures; however, after the Spanish conquest in Mexico this kind of technology was abandoned[2-3]. Nowadays the University of Guadalajara along with the International Rainwater Catchment Systems Association, Mexico Region has enhanced the implementation of many prototypes in order to generate new information that aims at more efficient rainwater harvesting systems[4].

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1 Studied Zone

Guadalajara's Metropolitan Zone is located in Jalisco, in west Mexico. It is divided into four municipalities: Guadalajara, Zapopan, Tlaquepaque and Tonala within three basins: Valle de Atemajac, Ahogado, and Rio Blanco. Our study zone is located in a housing area at the south of metropolitan zone, at the Ahogado basin in "Parques del Bosque" in Tlaquepaque, Jalisco, México (see Fig. 1). Our study zone is in Tlaquepaque at the south of Jalisco in the Ahogado basin. It is indicated by the circle in the Ahogado basin.

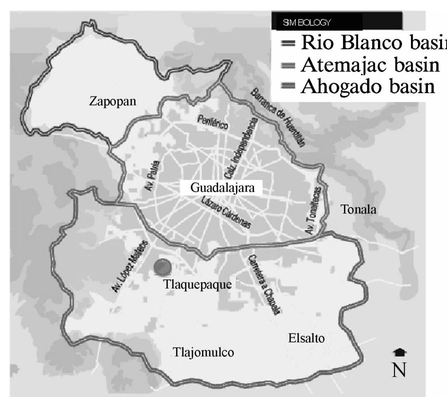
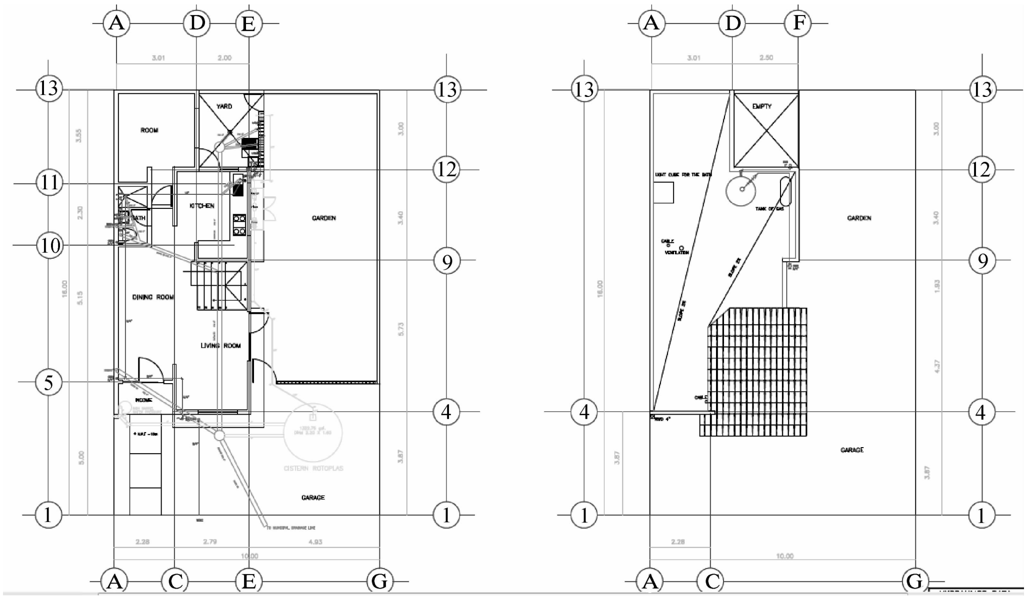


Fig. 1 Study zone

2 Housing Characteristics

The housing area is in a residential development with more than 2 000 other houses. And until now, there has not been any other rainwater catchment system in the zone. Only two people are living in this house; however, it has a maximum capacity of seven. The water supply system comes directly from the central system with good pressure. And the sanitary system combines wastewater with rainwater. It is a two-floor house of 10 m × 16 m. It has a dining room, a living room, four bedrooms, three bathrooms, a kitchen and a service yard. Fig. 2 shows an aerial view of the house. On the first floor there are the kitchen, dining room, service room, study room, back yard, and bathroom. On the second floor there are three bedrooms, three bathrooms and a TV room.



First floor Second floor

Fig. 2 Aerial view of the house

3 Rainwater Catchment System Design

First, the calculation of the harvested rainwater was estimated by a formula. The result reflected the maximum supply of the house. Then, the total demand was calculated in order to explore the possible rainwater uses.

3.1 Defining the harvested water

In this case, the first step is to estimate the amount of water that can be harvested in a given area; for this, the following essential variables need to be determined: 1) The size of the catchment area, which is the site from which the rainfall will be collected, such as a roof; 2) The amount of local rainfall; 3) Runoff coefficient. These variables interpretation will directly affect the estimation.

The harvested water can be calculated by

$$\text{Harvested water} = \text{catchment area} \times \text{rainfall depth} \times 0.001 \times \text{runoff coefficient} \quad (1)$$

This formula allows a simple estimation in m^3 or L that can be harvested from a given catchment area during a rainfall event. To calculate the liters harvested, the catchment area (m^2) is multiplied by the depth of a rainfall in mm, by a conversion factor and then by a runoff coefficient.

The texture and material of the catchment surface affect the amount of water that can be harvested. A rough and/or absorptive surface conveys less rainwater than a smooth surface does. The coefficient reduces the estimated amount of water collected from a rainfall event. Using a coefficient of 0.75 rather than 0.95 reduces the estimate by 20%. Tab. 1 lists the runoff coefficients for specific catchment surface materials. Use the numbers in the high column when the surface is the smoothest; use the low coefficient only when the surface is rough. For instance, the coefficient of 0.95 would best represent a catchment surface made of concrete with a smooth, slick finish.

Tab. 1 High and low runoff coefficients for various catchment surfaces

Surface	Character of surface	Runoff coefficient	
		Middle	Low
Roof	Metal, gravel, asphalt shingle	0.95	0.75
Paving	Concrete, asphalt	0.95	0.70
	Brick	0.85	0.70
	Gravel	0.70	0.25
Soil	Flat (2% or less), bare	0.75	0.20
	Plano (2% or less), with vegetation	0.60	0.10
Lawn sandy soil	Flat (2% or less)	0.10	0.05
	Average (2% to 7%)	0.15	0.10
Lawn heavy soil	Flat (2% or less)	0.17	0.13
	Average (2% to 7%)	0.22	0.18

It is important to mention that the catchment area of this house will be superior since it shares one downspout with the near housing due to the fact that the neighbor is not interested in such kind of systems. The data are given as

$$\text{Catchment area} = 43\ m^2/\text{house} \times 2\ \text{houses} = 86\ m^2$$
$$\text{Rainfall depth} = 897\ \text{mm/year}$$
$$\text{Runoff coefficient} = 0.75$$

The following calculation will estimate the harvested water:

$$\text{Harvested water} = \text{catchment area} \times \text{rainfall depth} \times 0.001 \times \text{runoff coefficient} = 86\ m^2 \times 897\ \text{mm} \times 0.001 \times 0.75 = 57.85\ m^3 = 57\,850\ \text{L} \quad (2)$$

According to Eq. (2), the maximum harvested water is 57 850 L. However, the total water demands need also to be estimated, and the pre-determined demand according to the possible uses and space available.

3.2 Defining total demand

The total demand is calculated according to per person consumption (L/capita)[5]. The estimate is

$$\text{Demand} = \text{number of person} \times 150\ \text{L/capita} = 2\ \text{persons} \times 150\ \text{L/capita} = 300\ \text{L/capita} \quad (3)$$

$$\text{Annual demand} = 300\ \text{L/capita} \times 365\ \text{d} = 109\ 500\ \text{L/a}$$

The estimation of the percentage of collaboration is

$$\text{Percentage} = \text{supply/demand} = 57\ 870/109\ 500 = 54.85\%$$

3.3 Pre-determined demand

Even when the harvested rainwater rate is high, the space available in the house is reduced. Due to this problem, it is necessary to determine the exact water demand depending on the most frequently water uses in the house: irrigation, car washing and drinking water.

1) Irrigation demand

$$\text{Irrigation demand} = \text{green area} \times \text{days for irrigation} \times \text{consumption} = 90\ \text{m}^2 \times 28\ \text{d} \times 5\ \text{L/m}^2 = 12\ 600\ \text{L} \quad (4)$$

2) Car washing

$$\text{Car washing} = \text{number of cars} \times \text{days for washing} \times \text{liter for car} = 2\ \text{cars} \times 48\ \text{d} \times 20\ \text{L} = 1\ 920\ \text{L} \quad (5)$$

3) Drinking water

$$\text{Drinking} = \text{numbers of persons} \times \text{consumption days for drinking} \times \text{liter per person} = 2\ \text{persons} \times 365\ \text{d} \times 2\ \text{L/person} = 1\ 460\ \text{L} \quad (6)$$

4) Total pre-determined demand

$$\text{Total demand} = \text{irrigation demand} + \text{car washing} + \text{drinking} = 12\ 600\ \text{L} + 1\ 920\ \text{L} + 1\ 460\ \text{L} = 15\ 380\ \text{L} \quad (7)$$

After knowing that the estimated harvested water covers the pre-determined demand of the house per year, the place for the system was defined. The designed model was made so the rainwater would come from the roof and then sent to a first flush tank. Afterwards the rainwater would be conducted to a 5 000 L underground tank, where it is stored to satisfy one third of the house demand.

3.4 Defining the system

As mentioned before, the system pretends to harvest and satisfy at least one third of the house water demand. This is why it was determined that the house should be connected to the central hydraulic system during the dry season, and connected to the rainwater harvesting system during the rainy season[6]. Rogers based the design on the models described by the OPS/CEPIS in 2004 and in 2006[7-8]. Therefore, the system was designed in the following way (see Fig. 3). The rainwater goes from the roof, down through the conveyance directly to the first flush tank. Then it is stored in an underground cistern. Later, a pumping system sends the water up to the roof into a water tank. The water tank distributes the water to the house. Finally, when the system is totally filled, the water is sent to the infiltration well.

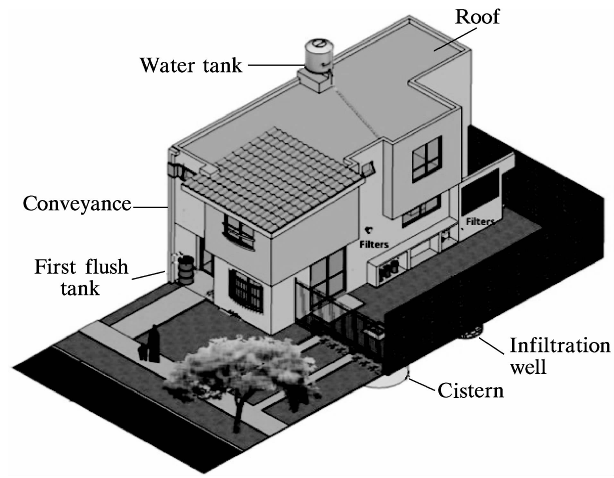


Fig. 3 Rainwater catchment system

4 System Components

4.1 Catchment area

Like most of the houses in Mexico, this flat concrete roof has only a 2% slope. Once the rainwater touches the surface, it flows into a downspout that conducts the water into a first flush tank (see Fig. 4). The roof with a 2% slope allows the water to flow directly to the downspout.

Fig. 4 Catchment area

4.2 Downspout

The original design of the house had a tube that conveyed the rainwater from the roof, directly to the front garden. For this project a new downspout was placed. Fig. 5 shows the adaptation of the old PVC4 tube to the new one PVC3, which sends the rainwater to the flush tank (see Fig. 5). The figure shows the adaptation made so that the water could be sent to the first flush tank.

Fig. 5 Downspout

4.3 First flush tank

Since the first rains may bring some of the air pollution and roof trash, it is necessary to retain this water to avoid the underground reservoir contamination. The first flush tank is a plastic device of 200 L storage capacity, which will receive the first rainwater. Once these rains are finished it is necessary to empty the device (see Fig. 6). This device retains the first water to prevent the underground reservoir contamination.

Fig. 6 First flush tank

4.4 Cistern

According to the system design, the plastic cistern is placed underground. For this procedure, after excavation, a 5 000 L reservoir is placed, and the system is adapted so the overflow will be conducted to an infiltration well (see Fig. 7). This device, which is placed underground, has a capacity of 5 000 L.

4.5 Infiltration well

This device has the purpose to infiltrate the overloaded rainwater directly to the aquifers. Fig. 8 shows the infiltration well of 1.20 m × 2.10 m lined with concrete bricks, which is connected to the cistern. The water enters by the inlet and then filters to the ground. The infiltration well of 2.10 m is connected to the cistern. After the cistern is filled to its capacity, the water is conducted to the infiltration well to be infiltrated to the aquifers.

Fig. 7 Cistern

As a result, the system avoids sending the rainwater to the drainages, contributing to reduce the floods as it helps in the aquifers restoration (see Fig. 8).

Fig. 8 Infiltration well

4.6 Pumping system

The rainwater stored in the cistern, passes through a pumping system of 1/2 HP, which drives the water into the filters, and then to another water tank placed on the roof. Finally from this place, the water is distributed along the house (see Fig. 9). This system provides enough pressure, so the water can be sent to the filters.

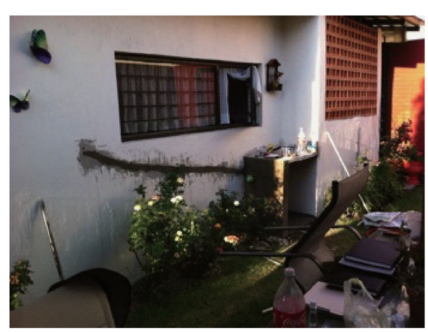


Fig. 9 Pumping system

4.7 Filtering system

The filter is purchased from Carbotecnia, (model Colomos). The size of the system is 37 cm × 27 cm × 15 cm. This device can remove clays, silts, iron, manganese and organic material. This procedure clarifies the water and makes UV disinfection more effective (see Fig. 10). This device removes most of the chemical pollutants before UV disinfection.

Fig. 10 Filtering system

4.8 Ultraviolet water treatment

As mention before, the UV radiation for water systems is not suitable in high levels of suspended solids, organic materials, turbidity or color. These conditions may cause the materials to react to UV radiation reducing the disinfection process. For this reason, the UV treatment system is placed after the filtering system and nearby the kitchen, so it can be easily used. The system is purchased from Carbotecnia (model Purificador Colomos UV) (see Fig. 11). Water receives UV treatment to eliminate odor, color and taste.

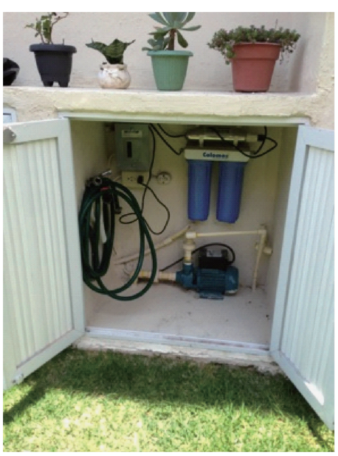


Fig. 11 Ultraviolet water treatment

5 System Operation

The rainwater harvesting system is designed to operate as part of the central water supply system. In this way, during dry season, water comes from the central water supply and as soon as the rain season starts, the valve from the central water supply is closed and the rainwater harvesting systems start to operate as follows:

The rainwater descends by the downspout to the first flush tank. Once the tank is full, the rainwater goes to the 5 000 L underground cistern. If the cistern is overfilled, the water overflows into the infiltration well. The stored water is pumped to the filters and then driven to a tank placed on the roof. Finally the rainwater is distributed along the hydraulic system (see Fig. 12). The figure shows the pipeline of the model. It is also suitable for the central water supply system.

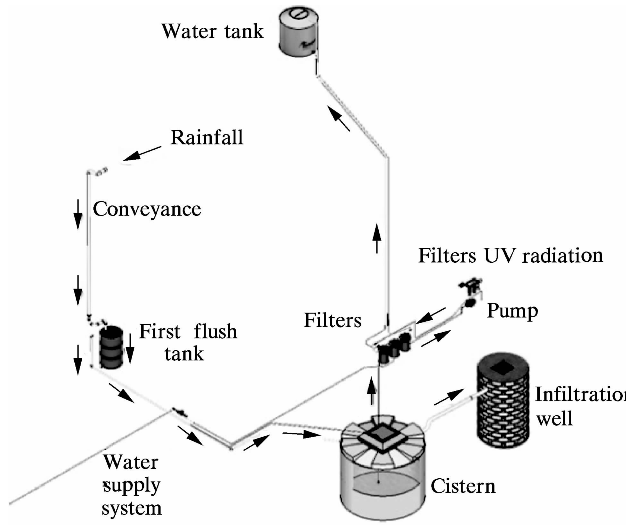


Fig. 12 Rainwater harvesting system isometric

6 Costs and Results

The cost of this project is more than 3 000 US dollars. The concepts and their cost percentages are given in Tab. 2. The rainwater harvesting system is installed at the beginning of June, and starts to operate as soon as the first rainfalls begin. The annual consumption is almost 109 500 L. The rainwater starts to work since June 26th and ends on October 15th; it is not necessary to use the water from the central system, which represents a saving of 36 500 L for fourth months. The economic saving is of about 50 US dollars during the rainfall season.

Tab. 2 Costs of the rainwater systems

Concept	Cost/(US dollars)	Percentage/%
Materials	630	21
Storage system	750	25
Purification system	420	14
Labor	1 200	40
Total	3 000	100

7 Discussions

The calculation for annual demand shows that it is difficult to meet through rainwater. At one point it is necessary to calculate the pre-determined demand for irrigation, car washing and drinking. Even when the pre-determined demand is estimated, the current water consumption registered by the central water supply shows higher data, which may be explained by a higher water demand needed for irrigation. However, when the system is installed, it demonstrates that the rainwater harvesting meets the total demand of the house during the rainy season.

The high cost of the model might represent a problem in encouraging people to install this system. However, most of the costs are raised because of the adaptations needed. This article also suggests creating new house designs that allow the installation of a rainwater harvesting system without doing any architectural modification. This would reduce the total cost, making rainwater harvesting more affordable.

Finally, it is important to mention that this household model is the first one in Jalisco. But still there are not many people interested on its implementation, mostly because of the lack of education about rainfall importance and its potential use. It is recommended to work along with social researchers who set strategies to educate people about natural resources and the benefits of creating suitable households.

8 Conclusion

This rainwater harvesting system is capable of satisfying the house water demand during the rainy season. It is also important to remark that even the rainwater that is not used for the house demand is sent to the infiltration well. After the end of the rainy season, the rainwater, which remains in the cistern, can be used for two weeks more. As mention before, the original sewage systems are used to send rainwater directly to the drain. This new harvesting model helps to reduce water consumption from the central supply system as it helps to reduce rainwater contamination by using the infiltration well. Finally, this system can represent a progress in reducing the drains saturation and as a consequence preventing future floods. This model is still under supervision in order to observe advances and problems during the process.

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墨西哥城区雨水收集系统的家庭模式

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摘要:详细介绍了墨西哥哈利斯科州特拉凯帕凯市住宅开发区雨水收集系统的一种家庭模式. 为了设计出一个可以为家庭提供最大水量的雨水收集系统,对雨水收集量进行了估算. 基于估算出的雨水收集量,对家庭总需水量进行了计算,以便探讨雨水的可能用途. 雨水收集系统的主要组成部分如下:集水区;落水管(屋顶排水管),第一冲洗水箱;水箱;渗井;泵站,过滤系统;紫外(UV)处理设备. 雨水收集系统被设计成中央供水系统的一部分. 介绍了雨水收集系统的设计和建设过程及其造价. 通过该方式,可提供一个技术参考,从而帮助市民来设计和建设他们的雨水系统. 该模式既可促进此系统在墨西哥的发展,也可为国际社会提供宝贵的经验.

关键词:雨水收集系统;供水;需水量;集水区;水箱

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