Rainwater Harvesting at Universities. Case study: Valle de las Palmas

Alicia Ravelo-García *, Maria Cristina Castañon-Bautista and Juan Antonio Pitones-Rubio

Facultad de Ciencias de la Ingenieria y Tecnología, UABC, Tijuana, Baja California.
* Corresponding author: alicia.ravelo@uabc.edu.mx

Received: April 27, 2023 Accepted: August 31, 2023 Published: September 4, 2023
DOI: https://doi.org/10.56845/rebs.v5i2.82

Abstract: Rainwater harvesting systems have become a necessary strategy at universities to reduce water consumption, particularly in semi-arid areas. Therefore, these systems are ideal and innovative for sustainable water management. Nevertheless, it is critical to make sure the implementation of such systems is properly planned and cost-effective as well as compliant with the needs of a specific college campus. The Faculty of Engineering and Technology Sciences (FCITEC by its acronym in Spanish) is located in the municipality of Tijuana, Baja California; on a zone considered semi-arid with winter rainfall of less than 500 mm per year. The main water supply in the state of Baja California comes from the Colorado River which represents 80% of the state's water supply while the remaining 20% comes from underground aquifiers, many of them operating with deficit as well as saline intrusions. Scarce rainfall has become a main problem for the Colorado River's basin, decreasing significantly the river's surface water levels, thus affecting the municipality of Tijuana in recent years, forcing the state operator of public services to implement tandem systems to distribute water in the city, provoking several neighborhoods to run out of water service, including the previously mentioned university academic unit. This paper proposes the calculation of a rainwater harvesting system to be applied at the FCITEC Academic Unit, in order to collect the rainwater and use it to irrigate landscape areas, for which the precipitation data from the in-site weather station was considered. Two buildings´ roof areas were selected for rainwater harvesting, applying a methodology to calculate a total volume of nearly 5,000 $m^3$of collected rainwater. We found that, at certain universities that have implemented this practice, there is evidence of significant savings and decreased demand for water in the municipal hydraulic network, as it was the case of the Federal University of Pará (Japan), and the Federal University of Viçosa (Brazil).

Keywords: rainwater harvesting systems, semi-arid areas, college facilities, sustainable water management

Introduction

The scenario for the management of water resources is limited, especially at places with a semi-arid climate where this issue has been related to health problems, limitations for economic and social development (Vargas-Parra *et al*., 2013), it also has become a public safety problem (Gebru *et al*., 2021), thus all these conditions, together with the accelerated growth of the population in cities (Rahman *et al*., 2020) has led to the expansion of urban areas, with a higher demand of water resources and, in consequence, exerting pressure on water supplies, therefore affecting the hydrological cycle in cities (Teston *et al*., 2018).

The United Nations Environmental Program estimates that by 2050, more than two billion people will live in a condition of high water stress, and this will limit the development of countries around the world (Ammar *et al*., 2016).

The Arid and Semi-arid Regions (ASARs) are zones which are characterized by short rainfall periods during the season in which they occur (Tamagnone *et al*., 2020), these regions represent 35% of the Earth's surface, which equals about 50 million square kilometers (Ammar *et al*., 2016) and, due to climate change. Márquez *et al*. (2021), point out that the frequency and intensity of droughts in ASARs restricts the availability and the usage of water resources (Ammar *et al*., 2016), therefore there is international interest in the implementation of sustainable measures for optimal water management, which can generally be categorized into actions such as: Re-use of treated wastewater (Dos Santos & de Farias, 2017), desalination (Imteaz *et al*., 2013), reduction in water consumption, and use of alternative means of supply, such as rainwater harvesting (Almeida *et al*., 2021), the latter being a topic that has received attention since 1980 (Ammar *et al*., 2016).

It is precisely in the ASARs where rain harvesting is used to optimize water supply sources (Bitterman *et al*., 2016), an alternate and decentralized option that contributes to the resilience of urban systems (Silva *et al*., 2022) since some authors point to it as a specific strategy to combat climate change (Youn *et al*., 2012), as it is considered as low-impact (Guo & Guo, 2018) and also known as a green infrastructure practice (Li *et al*., 2021) with the potential to reduce greenhouse gas emissions from storage tanks and water treatment processes which contribute to climate change.

(Aladenola & Adeboye, 2010; Imteaz *et al*., 2012) in addition they help to reduce the volume of water runoff as well as becoming a flood prevention measure (Sepehri *et al*., 2018).

Sangave *et al*., (2019) define the concept of rainwater harvesting (RWH) as the natural collection and storage of rainwater in order to increase its availability for human consumption, either being for domestic, industrial and commercial use (Sangave *et al*., 2019). Other authors integrate into this concept its use in agriculture, for the ecosystem's conservation (Gebru *et al*., 2021), as well as being used for the maintenance of landscape areas (Nop *et al*., 2021).

It has been estimated that with the implementation of water harvesting strategies, savings between 12% and 100% can be generated (Şahin & Manioğlu, 2019), since reports show that, for residential buildings, the savings range between 41% and 100% in countries such as Brazil and China, while the save ranges from 38% to 69% when the use of harvested rainwater is for toilets, laundry and irrigation of a housing unit (Rahman *et al*., 2020), thus the savings potential will depend on the amount of precipitation, catchment area, size of the container for its harvest and the demand for drinking water for domestic use (Teston *et al*., 2018).

Universities are institutions that also can join these strategies to contribute significantly to reduce water resources demand, with estimated savings between 10% and 100% (see Table 1), due to the potential use of water collection from the roofs of buildings (Anchan & Prasad, 2021). Cardoso *et al*., (2020) point out that, in Japan, 30% of schools have facilities for water harvesting. In this regard, Almeida *et al*. (2021) show that, in the case of schools, there is variability in water consumption patterns because university buildings have demand profiles that will be dependant on the periods of use, type of consumer, teaching activities, and school periods; likewise, the practice of sustainability in higher education institutions can contribute to the efficient use of water, reduce its management costs, and its implementation can have an investment return by 4.8 years (Teston *et al*., 2018). Furthermore, few studies have analyzed the feasibility of RWH systems for university buildings and, consequently, there is still a knowledge gap regarding the performance of RWH systems applied to this type of building.

Table 1. RWH (rainwater harvesting) systems for assorted Universities

Country	Educational Institution	Savings potential (%)	Authors
Indonesia	Diponegoro University	10	(Budihardjo *et al*., 2022)
Pakistan	University of Faisalabad	25	(Husnain *et al*., 2022)
Brazil	Federal University of Viçosa	48	(da Silva *et al*., 2019)
Brazil	Universidad Federal de Uberlândia	18 – 53	(Salla *et al*., 2013)
India	South India University	27	(Anchan & Prasad, 2021)
Japan	Federal University of Pará	80-87	(Cardoso *et al*., 2020)
Indonesia	Institut Teknologi Kalimantan	24-100	(Mamangkey & Sukmara, 2021)

Regarding the quality of rainwater, it is considered mostly clean, although its final quality will depend on the environmental context, catchment area size and rain season details (Almeida *et al*., 2021).

Materials and Methods

Location of the study area

The study area is the Faculty of Engineering and Technology Sciences (FCITEC by its acronym in Spanish), an Academic Unit of the Autonomous University of Baja California (UABC by its acronym in Spanish), located in the area known as Valle de las Palmas, southeast of the municipality of Tijuana, Baja California, Mexico, and it is an area with a climate classified as BSKs Arid, Temperate, with an average annual temperature between 12º C and 18º C, with average rainfall of 237.1 mm during winter, concentrated between the months of January and March (XIX Ayuntamiento de Tijuana, 2008) and a precipitation range between 150 to 400 mm. The site's topography features mountain formations such as

Cerro Yuma, *El Carmelo* and *El Macho*, with an altitude between 900 and 1000 meters above sea level (XIX Ayuntamiento de Tijuana, 2008).

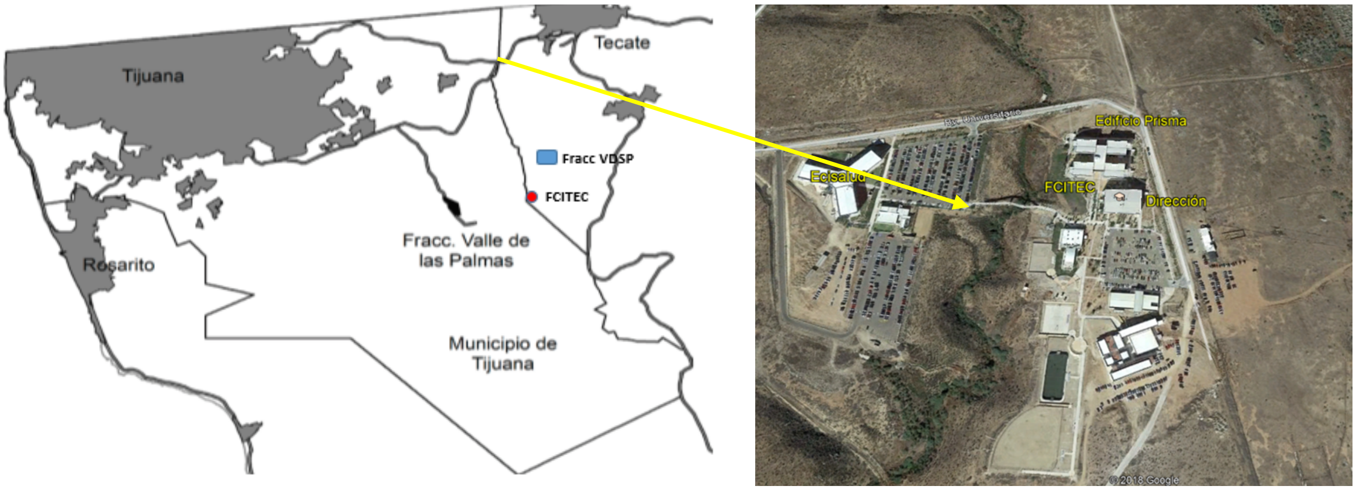

Figure 1. Location map and detailed view of the study area: the FCITEC Academic Unit of the Autonomous University of Baja California, located in the area known as Valle de las Palmas, southeast of the municipality of Tijuana (Google Earth, 2023).

Information on the study area and inventory of fixed assets

The FCITEC is an Academic Unit which belongs to the Tijuana campus of the Autonomous University of Baja California. It opened on August 15, 2009 as a Center for Engineering and Technology, and by 2015 it was established as the School of Engineering and Technology Sciences. By 2019 it becomes the current FCITEC (Faculty of Engineering Sciences and Technology). It currently has 2,851 students and an academic staff of 75 full-time professors, 160 subject teachers, and 10 academic technicians, in addition to administrative staff of 22 people. The FCITEC offers bachelor programs in Architecture and Design, as well as nine Engineering programs and graduate studies in Architecture, Design and Urban Studies, as well as a Master Degree in Technologies for Organizational Learning.

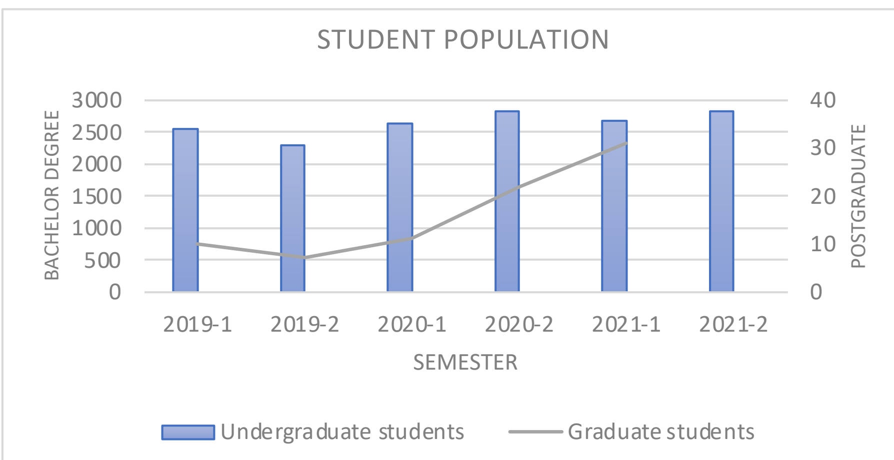

Figure 2. Student population since the opening of the academic unit up to the 2021 Fall semester (FCITEC's 2021 Statistical Report).

FCITEC's existing infrastructure

1. "*Prisma*" (Spanish for "prism"), is the main building divided into 4 blocks (buildings "A", "B", "C", and "D"), each of these has three levels and a ground floor, it has 68 classrooms, 20 cubicles for teachers, 17 laboratories, and it has 54 restrooms.

2. Administrative building, besides Dean's office, teachers' room, meeting room, cubicles and two small conference rooms on the ground floor, the first floor has the library and the second floor includes five computer labs, and a main hall for conferences, the whole building has a total of 10 restrooms.
3. Cafeteria building, it also includes university's sweepstakes administrative offices, sports office, and the whole building has 8 restrooms.
4. Workshop Building for Civil Engineering, Renewable Energies Engineering and Mechanical Engineering laboratories, it has a total of 6 restrooms.
5. Buildings "E", "F" and "G", with a total of 22 classrooms, 3 computer laboratories, 15 cubicles for teachers, a meeting room, and 10 restrooms.
6. Sports fields and courts.
1. FCITEC also has 2 parking lots, a waste warehouse and a drinking water storage cistern with a capacity of 650 cubic meters, which is fed from the municipal's water network. The hydraulic and sanitary systems at the academic unit work based on a pressure driven supply system.

Figure 3. Components of FCITEC Academic Unit: 1- Main building (or "prisma"). 2- Administrative building. 3- Cafeteria building. 4- Workshop building. 5- Buildings "E", "F", "G". 6- Sports Fields. FACISALUD refers to the adjacent Faculty of Health Sciences (Google Earth, 2023).

Project Engineering

The potential for the use of rainwater will be evaluated by means of a mathematical model and the initial process will support the subsequent stages of development, such as the storage capacity and the demand for water to be used for a rainwater harvesting system. In this sense, the Storm Water Management Model (SWMM, EPA, USA) was developed for the planning, analysis and design of stormwater runoff, and reduce rain water infiltration and, as well as to simulate hydrology and water quality in agriculture and urban areas (Li *et al*., 2021; Ammar *et al*., 2016).

Rainwater collection and use technique is understood as the practice (work or technical procedure) capable of, individually or combined with others, increasing the availability of water on the farm, for domestic, animal or vegetable use. Generally speaking, they are improved soil and water management techniques, crop management and animal handling, as well as the construction and operation of hydraulic works that allow collecting, diverting, conducting, storing and/or distributing rainwater. According to Siegert, the classification of rainwater harvesting techniques can be grouped into the following (FAO, 2013).

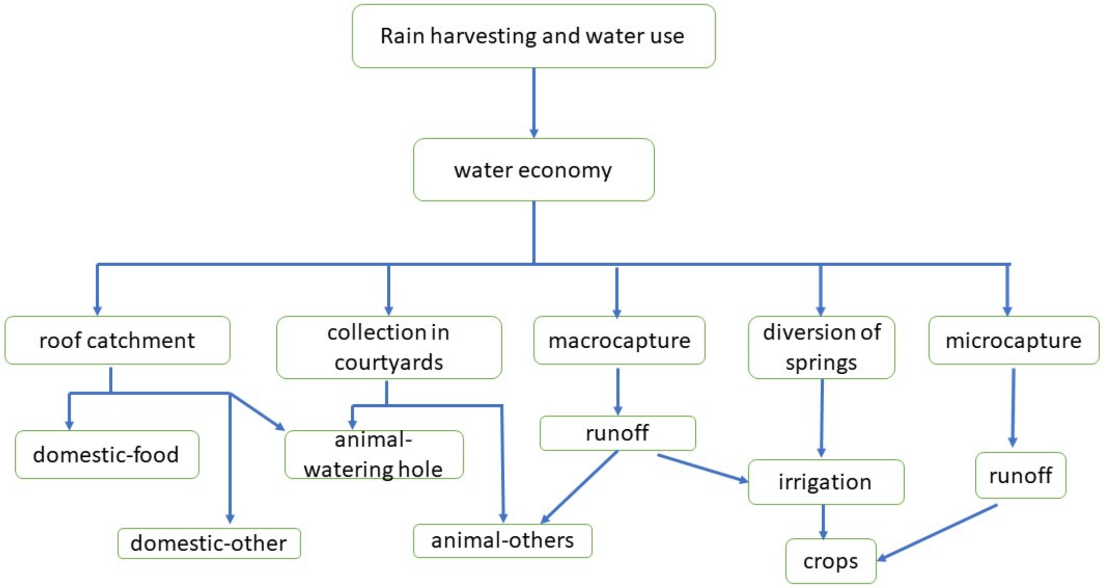

Figure 4. Modalities of water collection according to the purpose of use (Critchley *et al*., 2013).

The calculation elements for the harvesting of rainfall events can be classified into: floor and roofs (Dos Santos & de Farias, 2017) in this study, the method based on the roof catchment will be used, which depends on the surface, depth of the rainfall, storage and runoff coefficient. To calculate the amount of water that can be used, the World Meteorological Organization recommends having a database of precipitation records for 30 or at least 25 years, regardless of the method used for the calculation (Geraldi & Ghisi, 2017), however, studies such as Mitchell's (Mitchell, 2007) that the use of 10-year periods can be representative of a long-term precipitation pattern. For the purpose of this study, the sustainable methodology is used to capture rainwater in buildings.

The elements that set up a rainwater harvesting system are those that can be seen in the following figure:

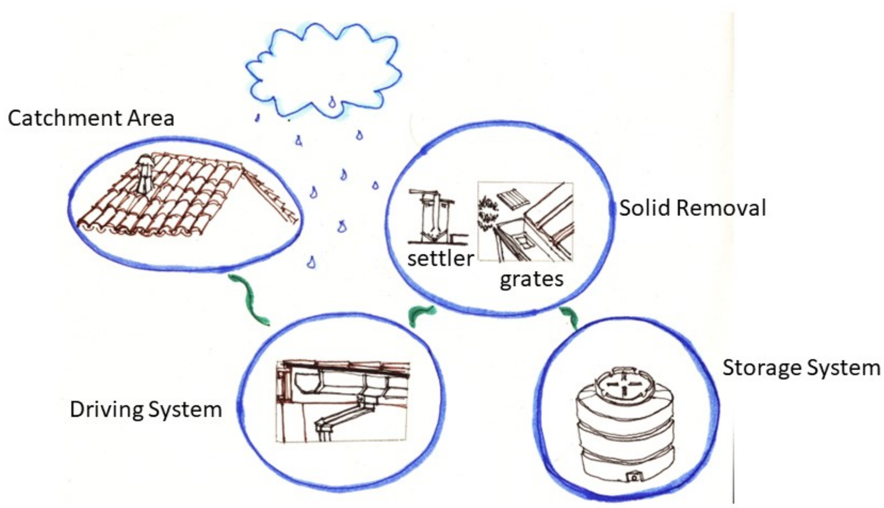

Figure 5. Elements that integrate a rainwater harvesting system (Anaya-Garduño, 2017).

Potential catchment area

In this study, two potential catchment areas at FCITEC are considered, being those the *Prisma* building with an area of 3,244.60 m² and the Administrative building, with 1,624.63 m².

Figure 6. Rooftop rainwater harvesting potential, building 1 (*Prisma*) and building 2 (Administrative) of FCITEC (Google Earth, 2023).

The demand or endowment per person is the amount of water that a person needs daily to fulfill the physical and biological functions of his/her body and it also considers the number of inhabitants to be benefited and domestic use.

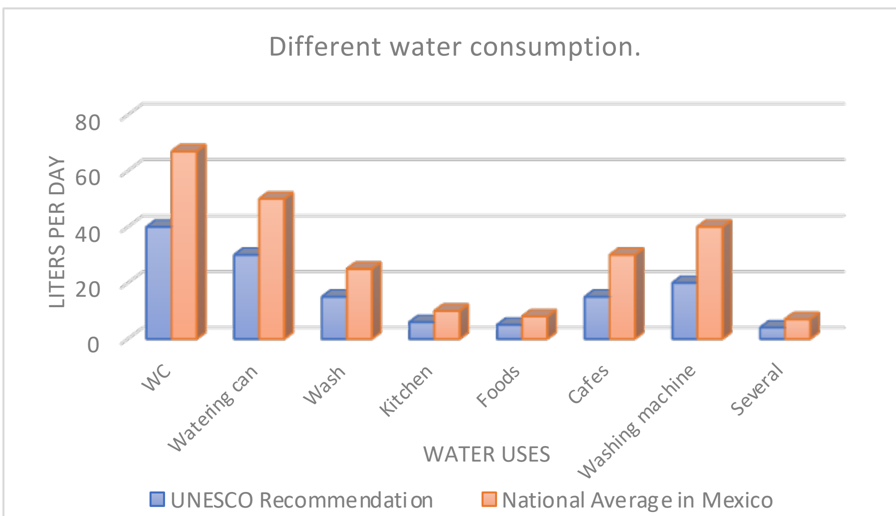

Figure 7. Demand for different water consumption, UNESCO data and national average in Mexico (UNESCO and CONAGUA, Mexico's National Water Commission).

To calculate the amount of rainwater to be captured on the roof of the building, we will use the following formula, which is total maximum rainfall.

$$TPpm = \frac{Ppm}{1000} \quad \textbf{(1)}$$

where: TPpm (m) is the total water from pluvial precipitation; and Ppm (mm) is the maximum rainfall of the rainfall record.

The maximum monthly precipitation was obtained from the Automatic Meteorological Station (EMA by its acronym in Spanish) at FCITEC, considering the rain data for the year 2019, a period with the heaviest rainfall since 2010. This year was selected since rain harvesting studies do not require analyzing such long periods of rain data as other types of research work like, for example, hydrological studies, which may need over 10 years of complete weather records. In Baja California the rainy season lasts 5.7 months, starting in October and ending in April, the average monthly precipitation for the year 2019 was 45 mm and the annual maximum is 291 mm, which occurred in the month of December. When the average monthly rainfall is less than 25 to 30 mm and of low intensity, it is not recommended to consider them and even if they are during dry months (Anaya-Garduño, 2017).

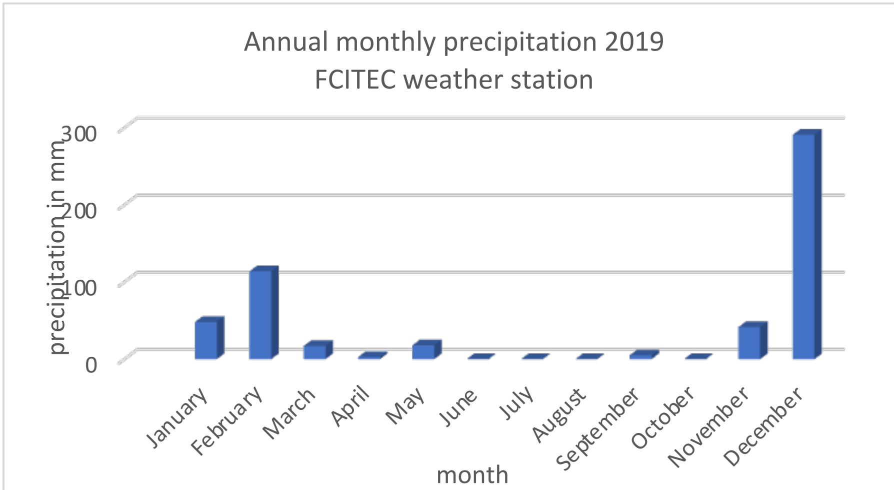

Figure 8. Average monthly precipitation (FCITEC's Automatic Weather Station).

To determine the total volume of rainwater collected on the roof.

$$\text{Vtpp} = TPpm * Az \tag{2}$$

where Vtpp (m^3) is the total volume of rainfall; and Az (m^2) is the surface area of the building's roof that will capture rainwater.

The following equation is used to calculate the actual total volume of water collected on the roof.

$$\text{Vr} = \text{Vtp}p * 0.85 \tag{3}$$

where Vr (m^3) is the actual volume of total rainwater harvested; and 0.85 is a constant for calculation to establish the actual stored volume of water equivalent to 85% of the total volume of water collected on the roof.

With the following equation, the number of rainwater downspouts is calculated from the actual total volume of water collected on the roof. The following equation is used, considering a 4¨ pipe when the area is less than 100 m^2 and, if it is greater than 150 m^2, then 6¨ pipes must be considered, in accordance with the Complementary Technical Standards for Architectural Projects (Tapia-Vargas, 2016).

$$\text{Bap} = \text{Az}/\text{Abap} \tag{4}$$

where Bap (pieces) is the number of downspouts needed; and Abap is the coverage area on the roof for each Bap installed.

The rainwater infiltration tank is determined with the following expression.

$$\text{Tf} = \left(\frac{\text{Vr}}{\text{Bap}}\right) * 0.95 \tag{5}$$

where Tf (m^3) is the actual volume of rainwater collected in the filter tank; and 0.95 is a calculation constant to determine the percentage of rainwater that is actually stored in the tank.

For the calculation of the design capacity of the filtration tank, the following equation is used.

$$\mathrm{Tff} = \mathrm{Tf} * \mathrm{D} \quad \textbf{(6)}$$

where Tff (m^3) is the design volume of the filtration tank in cubic meters; and D (days) is the water retention time inside the filtration tank, the recommendation is from 2 to 5 days.

To determine the total volume of rainwater in the cistern, we calculate it with the following expression.

$$\mathrm{Vt} = \mathrm{Tf} * \mathrm{Bap} * 5 \quad \textbf{(7)}$$

where Vt (m^3) is the total volume of water for the design cistern; and 5 is a calculation constant to store the volume of rainwater for 5 days.

Results and Discussion

Applying the previous equations and following the proposed methodology, we obtained the following results (see Table 2), as we present a summary of the calculations made for each building. In this case, building 1 (labeled as "*Prisma*"), and building 2 (named "Administrative"). In this study, two potential catchment areas are considered in the FCITEC, which are the *Prisma* building with a roof surface area of 3,244.60 m^2, and the Administrative building, with an area of 1,624.63 m^2. To start the calculations, it was established that the maximum annual precipitation value to be used would be 291 mm, according to data obtained from the Automatic Meteorological Station (EMA) located in-site at FCITEC. With the Academic Unit being founded on 2009, the EMA's records date back to 2010 and, after reviewing the precipitation data, the most complete and higher yearly records belonged to 2019.

Table 2. Summary of results obtained after applying the rainwater harvesting methodology on two FCITEC buildings.

	Variable / description	Prisma	Administrative	units
Ppm	maximum rainfall of the rainfall record in millimeters	291	291	mm
TPpm	total water from pluvial precipitation in meters	0.291	0.291	m
Az	roof surface area in square meters	3,245	1,625	m^2
Vtpp	total volume of pluvial precipitation of water in cubic meters	944	473	m^3
Vr	actual volume of total rainwater harvested in cubic meters	802	402	m^3
Bap	the number of downspouts required	5	3	6" downspout
Tf	actual volume of rainwater in the filter tank in cubic meters	143	143	m^3
Tff	design volume of the filtration tank in cubic meters	713	713	m^3
Vt	actual volume of rainwater collected in cubic meters	3,810	1,908	m^3

Table 2 shows that, over the course of a year, the *Prisma* building can capture up to 3,810 m^3 of rainwater, while the Administrative building could collect a volume of 1,908 m^3. The collection volume is a function of the roof surface area and the amount of rain that occurs during the year. It is important to acknowledge that, for the analysis of rain, there needs to be at least a minimum rainfall record of 10 continuous years to have reliable results for the calculations and sizing of the cistern. For rainwater drains, PVC pipes can be used, for this exercise they are proposed with a 6 inch diameter.

Standards Compliance.

In accordance with the NOM-127-SSA1-2021 standards, which establishes the permissible limits of quality and the purification treatments of water for human use and consumption, which must be met by public and private supply systems or any natural or legal person who may distribute it, throughout the Mexican national territory and NOM-12-SSA1-1994, which establishes the sanitary requirements that must be met by public and private water supply systems for human use and consumption to preserve its quality, rainwater that shall be captured, must be submitted to a disinfection process, to guarantee its bacteriological quality, ensuring the absence of pathogenic microorganisms; there are three classes of pathogenic microorganisms in water that could cause various diseases on human beings, such risks are viruses, bacteria and protozoa.

The disinfection can be carried out through different processes, such as the physical ones that include ultraviolet radiation, gamma radiation, X-rays, ultrasonic waves and direct application of thermal energy, while there are also chemical processes in which a variety of agents could be used such as chlorine, ozone, bromine, iodine, hydrogen peroxide, potassium permanganate and metal ions, such as silver and copper. Nevertheless, the most widely used disinfection method is chlorination due to its broad, low-cost germicidal spectrum.

Conclusions

Rainwater harvesting is a convenient way to obtain water for human consumption and/or use in areas where this liquid is scarce. Among the main advantages of using these systems there is the good quality of rainwater, the system's design scheme is independent, which is highly recommended for schools located in arid and semi-arid regions, especially useful at those which do not have potable water service available. Rainwater harvesting is an alternative, moreover due to the fact that this technique helps to avoid overexploitation of aquifers and, at the same time, prevents erosion and degradation of basins. However, it also has certain disadvantages, for example the economic aspects, such as the issue of depending on the project requirements, it can turn out to be expensive, and the fact that the amount of collected rainwater depends entirely on the precipitation pattern of the location and the available catchment area, which varies by region.

The purpose of this project is to implement such system at the FCITEC Academic Unit, since it is an area with a water deficit. Although it may not become a substitute for the current water supply system at the academic unit, it will help mitigate the site's water consumptions as well as achieving another goal sought with this project which is to promote the cultural value of rainwater harvesting at the community, starting on a municipal level and eventually reaching statewide relevance. Since the projected 5,718 m^3 total volume of rainwater collected from the two studied buildings is a yearly value that is highly dependent on the precipitation rates of the region, it is recommended to use this technique for the irrigation of landscape garden areas of the FCITEC, as an alternative to face the deficit of water in the vicinity area and the long term prospect to implement these systems at other campuses of the Autonomous University of Baja California.

It should also be considered that this alternative will have the following impacts: (1) Economic impact: savings, return on investment, catchment surface area, contribution to energy savings in drinking water and sewage management systems, where it is estimated that the world's energy consumption for this concept is close to 3% (Teston *et al*., 2018); and (2) Environmental impact: reduction in the flow of water that runs off roads and sanitary drainage. Reduction in the use of potable water for non-potable uses (landscape area irrigation, sidewalk cleaning, car washing), as well as the conservation of water resources, the contribution to water safety and the promotion of environmentally sustainable actions.

Author contributions: A.R.-G. and M.C.C.-B.: Writing, analysis and interpretation of data, conceptualization, provide materials; J.A.P.-R.: Writing, translation, and editing.

References

Aladenola, O. O., & Adeboye, O. B. (2010). Assessing the potential for rainwater harvesting. *Water resources management*, *24*, 2129-2137. https://doi.org/10.1007/s11269-009-9542-y

Almeida, A. P., Liberalesso, T., Silva, C. M., & Sousa, V. (2021). Dynamic modelling of rainwater harvesting with green roofs in university buildings. *Journal of Cleaner Production*, *312*, 127655. https://doi.org/10.1016/j.jclepro.2021.127655

Ammar, A., Riksen, M., Ouessar, M., & Ritsema, C. (2016). Identification of suitable sites for rainwater harvesting structures in arid and semi-arid regions: A review. *International Soil and Water Conservation Research*, *4*(2), 108-120. https://doi.org/10.1016/j.iswcr.2016.03.001

Anaya-Garduño, M. (2017). *Aprovechamiento del agua de lluvia: calidad, cantidad y abastecimiento continuo para diversos usos.* Editorial del Colegio de Postgraduados, Colegio de Postgraduados.

Anchan, S. S., & Prasad, H. S. (2021). Feasibility of roof top rainwater harvesting potential-A case study of South Indian University. *Cleaner Engineering and Technology*, *4*, 100206. https://doi.org/10.1016/j.clet.2021.100206

Bitterman, P., Tate, E., Van Meter, K. J., & Basu, N. B. (2016). Water security and rainwater harvesting: A conceptual framework and candidate indicators. *Applied Geography*, *76*, 75-84. https://doi.org/10.1016/j.apgeog.2016.09.013

Budihardjo, M. A., Arumdani, I. S., Puspita, A. S., & Ambariyanto, A. (2022). Improving Water Conservation at Universitas Diponegoro, Indonesia. *Journal of Sustainability Perspectives*, *2*, 277-284. https://doi.org/10.14710/baf.%v.%i.%Y.106-116

Cardoso, R. N. C., Blanco, C. J. C., & Duarte, J. M. (2020). Technical and financial feasibility of rainwater harvesting systems in public buildings in Amazon, Brazil. *Journal of Cleaner Production*, *260*, 121054. https://doi.org/10.1016/j.jclepro.2020.121054

Critchley, W., Siegert, K., Chapman, C., & Finket, M. (2013). *Water harvesting: A manual for the design and construction of water harvesting schemes for plant production*. Scientific Publishers.

da Silva, L. C. C., Oliveira Filho, D., Silva, I. R., e Pinto, A. C. V., & Vaz, P. N. (2019). Water sustainability potential in a university building–case study. *Sustainable Cities and Society*, *47*, 101489. https://doi.org/10.1016/j.scs.2019.101489

Dos Santos, S. M., & de Farias, M. M. M. (2017). Potential for rainwater harvesting in a dry climate: Assessments in a semiarid region in northeast Brazil. *Journal of Cleaner Production*, *164*, 1007-1015. https://doi.org/10.1016/j.jclepro.2017.06.251

FAO. (2013). *Captación y almacenamiento de agua de lluvia. Opciones técnicas para la agricultura familiar en América Latina y el Caribe.* Santiago, Chile: FAO. https://www.fao.org/3/i3247s/i3247s.pdf

Gebru, T. A., Brhane, G. K., & Gebremedhin, Y. G. (2021). Contributions of water harvesting technologies intervention in arid and semi-arid regions of Ethiopia, in ensuring households' food security, Tigray in focus. *Journal of Arid Environments*, *185*, 104373. https://doi.org/10.1016/j.jaridenv.2020.104373

Geraldi, M. S., & Ghisi, E. (2017). Influence of the length of rainfall time series on rainwater harvesting systems: A case study in Berlin. *Resources, Conservation and Recycling*, *125*, 169-180. https://doi.org/10.1016/j.resconrec.2017.06.011

Guo, R., & Guo, Y. (2018). Stochastic modelling of the hydrologic operation of rainwater harvesting systems. *Journal of hydrology*, *562*, 30-39. https://doi.org/10.1016/j.jhydrol.2018.04.062

Husnain, S. A., Tariq, K. A., & Khan, N. (2022). Estimation of Rainwater Harvesting Potential in an Educational Institute of Faisalabad, Pakistan. *Journal of Sustainability Perspectives*, *2*. https://doi.org/10.14710/baf.%v.%i.%Y.117-129

Imteaz, M. A., Adeboye, O. B., Rayburg, S., & Shanableh, A. (2012). Rainwater harvesting potential for southwest Nigeria using daily water balance model. *Resources, conservation and recycling*, *62*, 51-55. https://doi.org/10.1016/j.resconrec.2012.02.007

Imteaz, M. A., Ahsan, A., & Shanableh, A. (2013). Reliability analysis of rainwater tanks using daily water balance model: Variations within a large city. *Resources, Conservation and Recycling*, *77*, 37-43. https://doi.org/10.1016/j.resconrec.2013.05.006

Li, S., Liu, Y., Her, Y., Chen, J., Guo, T., & Shao, G. (2021). Improvement of simulating sub-daily hydrological impacts of rainwater harvesting for landscape irrigation with rain barrels/cisterns in the SWAT model. *Science of The Total Environment*, *798*, 149336. https://doi.org/10.1016/j.scitotenv.2021.149336

Mamangkey, E. T., & Sukmara, R. B. (2021, November). Rainwater harvesting as an alternative of freshwater supply in Balikpapan city–a case study of Institut Teknologi Kalimantan. In *IOP Conference Series: Earth and Environmental Science* (Vol. 896, No. 1, p. 012040). IOP Publishing. https://doi.org/10.1088/1755-1315/896/1/012040

Márquez, J. D., Peña, L. E., Barrios, M., & Leal, J. (2021). Detection of rainwater harvesting ponds by matching terrain attributes with hydrologic response. *Journal of Cleaner Production*, *296*, 126520. https://doi.org/10.1016/j.jclepro.2021.126520

Mitchell, V. G. (2007). How important is the selection of computational analysis method to the accuracy of rainwater tank behaviour modelling?. *Hydrological Processes: An International Journal*, *21*(21), 2850-2861. https://doi.org/10.1002/hyp.6499

Nop, C., Fadhil, R. M., & Unami, K. (2021). A multi-state Markov chain model for rainfall to be used in optimal operation of rainwater harvesting systems. *Journal of Cleaner Production*, *285*, 124912. https://doi.org/10.1016/j.jclepro.2020.124912

Rahman, A., Snook, C., Haque, M. M., & Hajani, E. (2020). Use of design curves in the implementation of a rainwater harvesting system. *Journal of cleaner production*, *261*, 121292. https://doi.org/10.1016/j.jclepro.2020.121292

Şahin, N. İ., & Manioğlu, G. (2019). Water conservation through rainwater harvesting using different building forms in different climatic regions. *Sustainable Cities and Society*, *44*, 367-377. https://doi.org/10.1016/j.scs.2018.10.010

Salla, M. R., Lopes, G. B., Pereira, C. E., Moura Neto, J. D. C., & Pinheiro, A. M. (2013). Technical viability of implementation of the stormwater harvesting system for non-potable uses at a university. *Ambiente Construído*, *13*, 167-181. https://doi.org/10.1590/S1678-86212013000200013

Sangave, A. A., Mohite, S. J., Pawar, H. R., Kulkarni, V. V., & Abhangrao, C. R. (2019). Design & Estimation of Rain Water Harvesting System for a college campus in Solapur City. *Int. J. Eng. Adv. Technol*, *8*, 4629-4632. https://doi.org/10.35940/ijeat.F8909.088619

Sepehri, M., Malekinezhad, H., Ilderomi, A. R., Talebi, A., & Hosseini, S. Z. (2018). Studying the effect of rain water harvesting from roof surfaces on runoff and household consumption reduction. *Sustainable Cities and Society*, *43*, 317-324. https://doi.org/10.1016/j.scs.2018.09.005

Silva, M. B. M. D., Brandão, I. A. D. P., & Ribeiro, M. M. R. (2022). Feasibility, seasonality and reliability of rainwater harvesting in buildings of a university in Campina Grande, Paraíba. *RBRH*, *27*. https://doi.org/10.1590/2318-0331.272220210127

Tamagnone, P., Comino, E., & Rosso, M. (2020). Rainwater harvesting techniques as an adaptation strategy for flood mitigation. *Journal of Hydrology*, *586*, 124880. https://doi.org/10.1016/j.jhydrol.2020.124880

Tapia-Vargas, M. (2016). *Diseño de redes hidrosanitarias y de gas para arquitectura*. Gustavo A. Madero, Mexico: Instituto Politécnico Nacional

Teston, A., Geraldi, M. S., Colasio, B. M., & Ghisi, E. (2018). Rainwater harvesting in buildings in Brazil: A literature review. *Water*, *10*(4), 471. https://doi.org/10.3390/w10040471

Vargas-Parra, M. V., Villalba, G., & Gabarrell, X. (2013). Applying exergy analysis to rainwater harvesting systems to assess resource efficiency. *Resources, Conservation and Recycling*, *72*, 50-59. https://doi.org/10.1016/j.resconrec.2012.12.008

XIX Ayuntamiento de Tijuana. (20 de Noviembre de 2008). Instituto Metropolitano de Planeación de Tijuana. Recuperado el 20 de Septiembre de 2021, de Instituto Metropolitano de Planeación de Tijuana: https://implan.tijuana.gob.mx/

Youn, S. G., Chung, E. S., Kang, W. G., & Sung, J. H. (2012). Probabilistic estimation of the storage capacity of a rainwater harvesting system considering climate change. *Resources, Conservation and Recycling*, *65*, 136-144. https://doi.org/10.1016/j.resconrec.2012.05.005