Rainfall Study for the Design of a Rainwater Harvesting System: Case Study in the Community of Huapango Guanajuato.

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ABSTRACT

The difficulty of water constitutes one of the challenges of the 21st century. Nearly 1.2 billion people, almost one fifth of the planet, live in areas of physical scarcity of this resource, while 500 million people are going to this situation each time. In Mexico, 13 of the 32 states of the Republic have more than 80 percent of their territory with drought, due to this water problem suffered by certain regions, placing Mexico in 24th place out of 164 countries in the world with this problem. Water scarcity has strongly impacted the community of Huapango Guanajuato, a community of approximately 626 people, where sometimes drinking water is scarce for periods of a day to a week, to reduce this problem and to meet the basic needs of the people a rainwater harvesting system is proposed, where the largest amount of water is collected through the main streets, taking it to a point where it converges and storing it in a cistern of approximately 5,000 m3, making this project a viable proposal to meet the basic water needs of the people of the community of Huapango.

KEYWORDS

Stormwater, water harvesting system, storage, sustainability

1. INTRODUCTION

Water is one of the most important renewable natural resources for humans and other living beings on earth, as almost no activity can be carried out without it. Today society faces serious and complex water-related problems [1]. Today, many people continue to face supply problems due to continued population growth and movement from rural to urban environments, increased demand for food security and economic well-being, increased competition between users and uses, and the degree of pollution from industrial, municipal, and agricultural sources [2].

Currently, rainwater harvesting and use represents an option, as an alternative source, that can satisfy the demand for this resource for human use and consumption, in quantity, quality and on a continuous basis. Rainwater harvesting is a practice that promotes self-sufficiency and the rational use of this essential resource for various purposes. Rainwater harvesting systems and the use of rainwater have been, are, and will be the basis for the sustainable development of natural resources and the welfare of mankind. In addition, attention should be paid to the priorities of rural communities, mainly to the selfsufficiency of water for human consumption, food production (basic grains, fodder, vegetables and fruit trees) and the improvement of the ecological environment [3] Water is part of a cycle that science, technology, but mainly the awareness and sensitivity of its use, promote its reuse in various human activities. The process of rainwater harvesting consists of filtering the rainwater captured on a given surface to store it in a reservoir and then distribute it through pipelines to its destination [4]. Rainwater harvesting systems are capable of producing high quality water, but the harvesting process must be efficient to maintain the stored water and that it is of the best quality, so it is also necessary to perform correctly, from the design to the maintenance of the system, to maintain the quality and adequate quantity [5]. A typical rainwater harvesting and harvesting system (SCALL) implemented at the household level consists of the following sections: capture system or surface (roof, etc.), water collection or distribution system (gutters), rainwater diverter, and a water storage system or area (cistern, tank) [6].

The right to water requires the following conditions for its use. Availability refers to the fact that water must be an adequate and constant quantity so that each individual can satisfy his or her personal and general needs. Water must be of good quality, that is, it must be potable, free of microorganisms and chemical substances that endanger the health of individuals. And, finally, it must be accessible physically, economically, equitably and informatively [7]. The World Health Organization (WHO) recommends an amount of approximately 70 liters per day per person for basic hygiene and food needs. Despite the impressive achievements of the last decade, 748 million people lack access to improved drinking water sources and 2.5 billion lack access to improved sanitation. Investments in water and sanitation services result in substantial economic benefits Water in Mexico is used in a variety of ways in human activities, classified into four different uses [8]:

- Agricultural use, 76.6% (mainly crop irrigation).
- Public supply, 14.5% (delivery to domestic users).
- Electricity generation 4.9% (through thermoelectric power plants).
- Self-supplied industry, 4% (products and services).

Drinking water or using it for personal hygiene accounts for only four percent of people's water consumption. The products and services we commonly purchase account for an additional 96 percent. [8]. Figure 1 shows graphically the percentage of water use in the country.

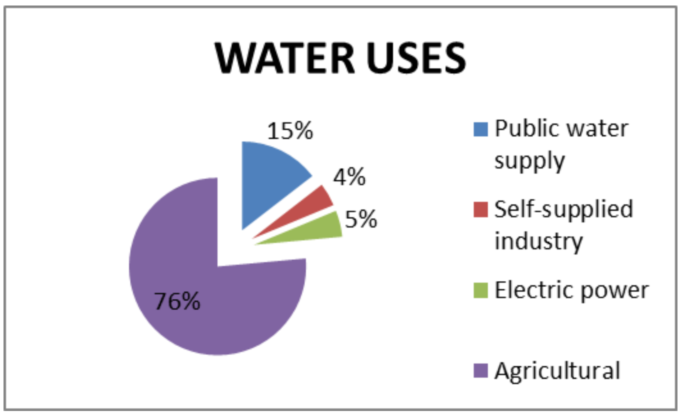


Figura 1. Water uses in México

Water harvesting systems for domestic use have been used for several centuries in Latin America, collecting water from roofs and floors. Currently, water is managed and stored in earthen dams, pots, jagüeyes and cisterns [9]. These are some of the cases where the development of rainwater harvesting systems has been implemented:

- In Brazil there are seasons of water drought in the semi-arid region of the country, so in 1983, the government of Sergipe launched a program to bring water to rural communities through small water collection tanks. The cistern model was built according to the materials of the area. Currently, rainwater harvesting has been incorporated into the educational program for sustainable living in the semiarid regions of the country [10].
- In June 2014, the Autonomous University of Mexico (UNAM) created the magazine "Impluvium", the first journal of the UNAM Water Network, which promotes the management of rainwater harvesting and rainwater harvesting systems at the national level in rural and urban areas [11].
- In Colombia specifically, the storage and use of rainwater has been implemented mainly in regions with drinking water supply problems for domestic consumption, such as La Bocana (Buenaventura), El Chocó, San Andrés; Puerto Carreño (Vichada), Cartagena; Cali, among others, most of which are empirical rural systems [12].
- CIDECALLI-CP has produced SCALL technologies for backyard agriculture, in environments such as greenhouses, for human and animal consumption and aquifer recharge. As part of the linkage exercise, the agency and FAO created a network of rainwater harvesting systems in the Dry Corridor and areas vulnerable to drought [13].

Huapango is located in the municipality of Tarimoro in the state of Guanajuato and is home to approximately 626 people. As a community that does not have its own well, it suffers from drinking water shortages on several occasions. The water that reaches the Huapango reservoir is pumped through a pipeline approximately 8.2 km long from the community of Cañada de Tirados in the municipality of Tarimoro. The main problem is the mechanical failure of the pumps, which over such a long distance get hot and fail constantly. Also, the various failures in the transport pipes cause the community to go without drinking water during the pump repair period, which sometimes lasts up to a week. This has a considerable impact on the people of the community since many families do not have cisterns or wells where they store water and only depend on the water in their water tanks, that is, when the water runs out in their tanks the people are completely deprived of the resource, some people opt to buy water pipes which is quite expensive, on average a pipe of 10,000 liters costs $1,007.00 pesos [14].

This is why the objective of the project is to perform a pluviometric analysis of the area, considering the study of rainfall and taking into account the available catchment area, which in this particular case we will take several streets of Huapango as a catchment area; and based on this we will design a rainwater catchment system that can help meet the basic needs of the people of the community in times of scarcity of this resource.

2. THEORETICAL CONSIDERATIONS

Rainwater harvesting systems are capable of producing high quality water, but the harvesting process must be sufficient so that the quality of the stored water is the best possible, as well as the use of rainwater reduces the consumption of potable water, thus reducing the costs of previous consumption, and using resources efficiently, so that those systems in which potable water is not necessary, can be supplied by rainwater.

Following the parameters established by [5] and [15], the definitions of the system components, the analysis of pluviometric information and the calculations performed for the design of the rainwater harvesting system are presented below.

2.1. Definition of the main components of the system.

A basic system consists of the following components

a. Capture
b. Collecting or driving
c. First water interceptor
d. Storage

For our proposed design we will go only as far as these first four components, but additionally the following can be integrated:

e. Filtration system
f. Treatment system
g. Water distribution network

2.1.1. Capture

Refers to the surface that will collect rainwater. It can be natural, such as rocks or artificial. In the latter case, the surfaces can be made of materials such as:

- Cement;
- Metal, plastic, glass fiber or asbestos sheeting, etc..;
- Clay, wood or plastic tiles;

These surfaces are generally used as roofs; due to their characteristics, some of them offer advantages over rainwater harvesting [16].

2.1.2. Harvesting and driving

According to [16], the system requires elements for transporting the collected water to a place of use, treatment or storage, for which the following materials are commonly used: gutters or pipes:

- Plastics: polyvinyl chloride (PVC), high density polyethylene (HDPE) or polypropylene (PP).
- Metallic: galvanized steel sheet or zinc.
- Natural: wood and fibers.

2.1.3. Interceptor

It is the device designed to capture the first rainwater corresponding to the washing of the catchment area, in order to avoid the storage of water with a large amount of impurities. The design of the device must take into account the volume of water required to wash the roof, which is estimated at 1 liter per m2 of roof [17], it should be taken into account that the water collected by the interceptor can also be used for watering plants or gardens. The interceptor consists of a tank into which the water from the downspouts enters. This tank must have a float valve that allows it to be filled; when it reaches the desired level, the valve will prevent the water from passing into the interceptor and direct it to the storage tank. Additionally, the tank must have a purge valve at the bottom of the tank to drain it and perform the corresponding maintenance.

2.1.4. Storage

It is the deposit destined for the accumulation, conservation and supply of rainwater to the different uses. These tanks must comply with the following:

- Waterproof to prevent water loss by dripping or perspiration.
- Closed to prevent ingress of dust, insects and sunlight.
- Have a cover large enough to allow a person to enter for cleaning and repairs.
- To have devices for the removal of water and drainage.

The types of rainwater storage tanks to be used can be made of the following materials: Plastics: HDPE cans, tanks or cisterns (100 to 5000 L), ferro-cement and reinforced concrete for any type of volume.

2.2. Rainfall information

The design rainfall sheet may be calculated with climatological information from the nearest station or stations, applying any of the following procedures [8]: we will use the arithmetic method, since only data from a single station were used. It is calculated using the expression:

$$Pm = \frac{(P1 + P2 + P3 + ... + Pn)}{n} = \sum \frac{Pi}{n} \qquad (1)$$

Where:
Pi = the precipitation recorded in the period.
i = of the available register in mm.
n = the total number of records

2.3. Calculation model

The development of the calculations consists mainly of the determination of the water demand, the supply related to the precipitation of the area, the volume of rainwater storage, the interceptor of the area's wash water, the filter and treatment system and the rainwater distribution network.
For the calculation model of each of the components, we took as reference, THE TECHNICAL GUIDE FOR DESIGN: RAINWATER CAPTATION SYSTEM AT HOUSEHOLD LEVEL [5].

2.3.1. Monthly water demand

The water demand will be the amount of water that each person needs to satisfy his or her needs for each month of the year, calculated as follows:

$$V_{Dn} = \frac{C_a O_v D_{m_n}}{1000} \quad (2)$$

Where:
VDN: Volume of demand for month n, in m3.
Ca: Water consumption, in l/hab/day.
Ov: Housing occupancy, inhabitant/household. mn
D: Days of the month n

2.3.2. Water supply per month

Taking into account the monthly rainfall averages for all the years evaluated, the material of the streets and the runoff coefficient, we proceed to determine the amount of water captured for the total area of the streets and per month.

$$V_{C_n} = \frac{C_e * Ppi * A_C}{1000} \quad (3)$$

Where:
VC: Water supply per month n in m3
Ce: Runoff coefficient
Ppi: Average annual precipitation (L/ m2)
AC: Catchment area (m2)

2.3.3. Cumulative demand

It is determined according to the following expression:

$$V_{DAn} = V_{D_{(n-1)}} + V_{Dn} \quad (4)$$

Where:
VDAn : Accumulated demand at month "n" (m3).
VD(n- 1): Cumulative demand as of the previous month "n-1"(m3)
VDn : Demand for month "n" (m3)

2.3.4. Cumulative supply

It is determined according to the following expression:

$$V_{CAn} = V_{C_{(n-1)}} + V_{Cn} \quad (5)$$

Where:
VCAn : Cumulative supply at month "n" (m3).
VC(n-1): Cumulative supply to the previous month "n-1" (m3).
VCn : Bid for month "n" taking into account the losses (m3)

2.3.5. Storage volume

In order to know the necessary storage volume, the difference between the accumulated supply and the accumulated demand for each month must be found, so that the greater value of the difference will be the volume of the tank adopted. If the differences give negative values, it means that the catchment areas are not sufficient to meet the demand.

$$Vt = V_{CAn} - V_{DAn} \quad (6)$$

Where:
Vt: Initial tank volume
VCAn: Cumulative offer per month
VDAn Cumulative demand per month

2.3.6. First water interceptor

This element collects the first rainwater that falls and washes the roof; therefore, it is necessary to divert it so that it is not stored in the tank. Its design, according to the parameters established in the CEPIS methodology [6], establishes that one liter of rainwater is required to wash one square meter of the roof, i.e. the volume of the interceptor tank is calculated as follows:

$$V_{\text{int}} = \left(1\frac{L}{m^2} * A_c\right)/1000 \quad (7)$$

Where:
Vint: Interceptor volume (m3)
Ac: Area of the roof to be captured (m2)

3. METHODOLOGY

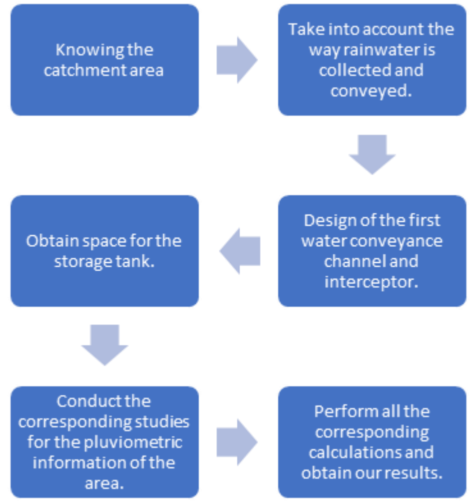
The community of Huapango Guanajuato was chosen as the main beneficiary for the development of the project, the community currently has 626 people including children, men and women. These streets were chosen because they converge at the same point and allow us to take more advantage of this resource. Figure 2 shows a map highlighting the streets of the community; the street sections highlighted in blue are the ones we will take into account for the analysis of our project:

Figure 2. Map of the streets of the community of Huapango Guanajuato.

The streets analyzed are listed below:

- Ignacio Zaragoza
- Vicente Guerrero
- Aldama
- Morelos
- Allende
- Galena
- Matamoros
- Hidalgo
- División del Norte
- San Miguel
- Av. Providencia
- Josefa Ortiz

In total, the streets have a catchment area of 26790.285 between all the streets. The following is a conceptual map of the methodology used for the project.



3.1. SYSTEM COMPONENT

The components used for the design of our system are described in the theoretical framework; however, the proposed design does not contemplate water for human consumption as the main use. In the channel that leads to the storage tank there will be a series of meshes that will serve as a filter, preventing the passage of large garbage, also this channel will be constantly cleaned to avoid contaminants, therefore the filter component will be omitted for our work, the water can be used for non-drinking use as sanitary discharges, watering plants, washing yards and cars, among other activities. If the water is to be used for human consumption in the future, it will be necessary to install a filtration system and an adequate treatment system to disinfect the water so that it can be consumed.

3.1.1. CAPTATION

The catchment was carried out in some streets of the community of Huapango, taking advantage of the fact that these streets converge at a single point and the surface facilitates the runoff of rainwater into the collection system. The streets that were chosen are completely made of concrete, due to their runoff coefficient they allow the water to flow in a faster way, however, it tends to drag solids that can affect our system, such as plastic bags, tree leaves, and more pollutants, and because of this the streets will be constantly swept.

3.1.2. COLLECTION AND HANDLING

Since the community of Huapango has no drainage system, the conduction will be through the streets themselves, which have a slope that makes the water from the streets studied reach the same place; a channel will be designed to conduct the water from the convergence point to the storage system. In addition, a section of meshes of different sizes will be installed in this channel to retain the coarser solids such as daughters, sticks, etc.

3.1.3. FIRST WATER PIPE AND INTERCEPTOR

The designed channel will help us to conduct the water from the streets to the interceptor once they reach the convergence point; the two streets that converge are Aldama and Hidalgo streets, which transfer all the water from the other streets. After the water is conducted through the channel, a series of stainless steel meshes with different openings will be installed to help us eliminate large, medium and small debris. Later they will arrive to an interceptor which will have a valve for its filling, as already mentioned in the theoretical framework, the interceptor will be of help to that the first waters do not arrive to the cistern but it is stored in this interceptor, this will serve to wash the streets in the first rains, once the interceptor arrives to the wished level the valve will prevent its passage of the water towards the interceptor and it will direct it towards the storage tank.

3.1.4. STORAGE

The storage tank will be rectangular in shape and made of reinforced concrete, taking advantage of the space on the ground, and the cistern will be waterproofed on the inside to ensure that there are no cracks that could affect its operation; the dimensions are specified in the results section, according to the volume of rainwater collected.

3.1.5. PLUVIOMETRIC INFORMATION

The precipitation data collected for Huapango Guanajuato was obtained from CONAGUA. The data analyzed corresponds to the last three years 2019, 2020, 2021, where the months of highest and lowest precipitation in those years were analyzed.

3.1.6. CALCULATION MODEL

The following data were used as parameters for the calculations corresponding to our project:

- Number of people in the community of Huapango Guanajuato (Ov)= 626 people.
- Type of material of the catchment area, in our case the streets are made of concrete.
- Runoff coefficient (Ce), for concrete corresponds to Ce=0.9.
- Endowment for each person, this refers to the water consumed by each person per day. (Dot)= 50 L/inhab/day.
- Catchment area (Ac)= 26790.285 m2 (this is the area of all the streets studied for our project).

4. RESULTS

Due to the availability of rainwater throughout the year in Huapango, Guanajuato, the adequate catchment areas and the space available to carry out the storage project, we present the results obtained from an average rainfall of the area for the last three years (2019, 2020, 2021), and the calculations for each of the components of the system according to the methodology and theoretical framework described above.

4.1. AVERAGE MONTHLY PRECIPITATION (Ppi)

The average monthly precipitation (without taking evaporation into account) is expressed in mm. To obtain the results, we add each of the monthly precipitations for the three years analyzed and divide by three to obtain the average, as shown in Table 1; we also graphically represent the average precipitation for each month, as shown in Figure 3.

YEAR	2019	2020	2021	Ppi
ENE	3.3	5.6	4.8	4.56
FEB	0.8	20.5	0.2	7.16
MAR	0.9	12.1	0.2	4.4
ABRIL	0.3	6.7	3.8	3.6
MAY	8.7	27.7	62	32.8
JUN	95.	104.5	137.3	112.03
JUL	136.4	111.1	148.6	132..03
AGO	137.1	109.9	170.3	139.1
SEP	191.2	69.9	201.8	154.3
OCT	63.2	4.7	47	38.3
NOV	9.4	1.2	1.8	4.13
DIC	6.6	1.7	2.6	3.63
			Ppi anual	636.57

Table 1. Average monthly precipitation values in (mm) for the 3 years analyzed (2019, 2020, 2021)

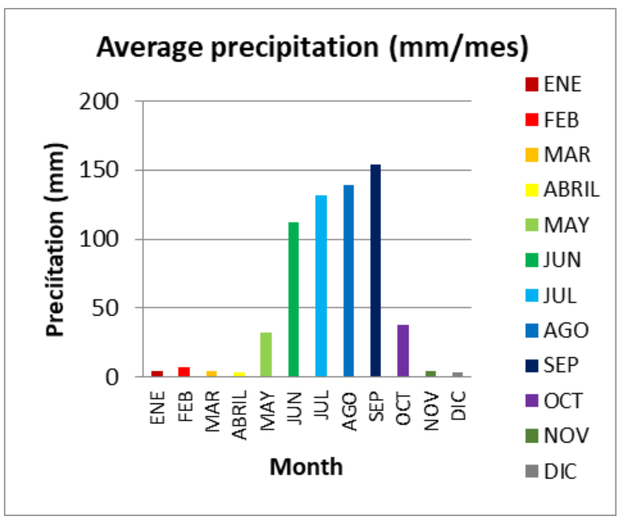


Figure 3. 3-year average monthly precipitation (without evaporation)

The data obtained show that on average, the rainiest months are from May to October, the rainiest month of the year is September, with an average value of 154.3 mm, and the driest month is April with an average of 3.6 mm. In order to determine the values of the parameters mentioned in the theoretical framework and to adequately obtain the volume of rainwater storage, the precipitation of the month with the highest rainfall during the 3 years evaluated must be distributed and the regular order of the following months is continued. The rainwater supply was calculated based on the catchment area of the streets studied, the areas were obtained street by street and their corresponding areas were added up to obtain a total area corresponding to 26790.285 m2 Table 2 shows the areas for each of the streets.

Street	Longitude (m)	Wide (m)	Área (m2)
Ignacio Zaragoza	60.5	6	363
Vicente Guerrero	207	7.5	1552.5
Aldama	847	6.44	5454.68
Morelos	780	6.2	4836
Allende	317	3.6	1141.2
Galeana	140	5.24	733.6
Matamoros	138	3.8	524.4
Hidalgo	872	5.4	4708.8
División del Norte	205	6.9	1414.5
San Miguel	445	5.7	2536.5
Av. Providencia	349	9.4	3280.6
Josefa Ortiz	61.9	3.95	244.505
		Total area	26790.29

Table 2. Area of the analyzed streets in the community of Huapango

The results are shown below.

Table 3 below shows the results of monthly average precipitation, monthly demand and supply, accumulated demand and supply, and storage volumes.

Monrh	Ppi (mm/m2)	Days of the month	Demanda Di	Dai (m3/mes)	Ofert Ai (m3/mes)	Aai (m3/mes)	Volume Vi (m3/mes)
SEP	154.30	30	1314.6	1314.6	3720.37	3720.37	2405.67
OCT	38.30	31	1358.4	2673.0	923.46	4643.7	1970.7
NOV	4.13	30	1314.6	3987.6	99.66	4743.3	755.77
DIC	3.63	31	1358.4	5346.0	87.60	4831.0	-515.04
ENE	4.57	31	1358.4	1358.4	110.11	4941.1	3582.6
FEB	7.17	28	1226.9	2585.4	172.80	5113.9	2528.5
MAR	4.40	31	1358.4	3943.8	106.09	5219.99	1276.19
ABRIL	3.60	30	1314.6	5258.4	86.80	5306.7	48.39
MAY	32.80	31	1358.4	6616.8	790.85	6097.6	-519.18
JUN	112.5	30	1314.6	7931.4	2713.3	8810.96	879.54
JUL	132.0	31	1358.4	9289.8	3183.4	11994.4	2704.6
AGO	139.1	31	1358.4	10648.3	3353.88	15348.33	4700.0

Table 3. Results of rainfall, demand and supply, and volumes.

4.2. STORAGE VOLUME

Figure 4 shows graphically the different volumes for each month of the year. The gray color indicates the month with the highest volume, which corresponds to the month of August, which was taken into account to design the size of the storage tank, the green colors represent the months with remaining volumes after collection and consumption, and finally the bright green color represents the months where the demand is greater than the rainwater collected

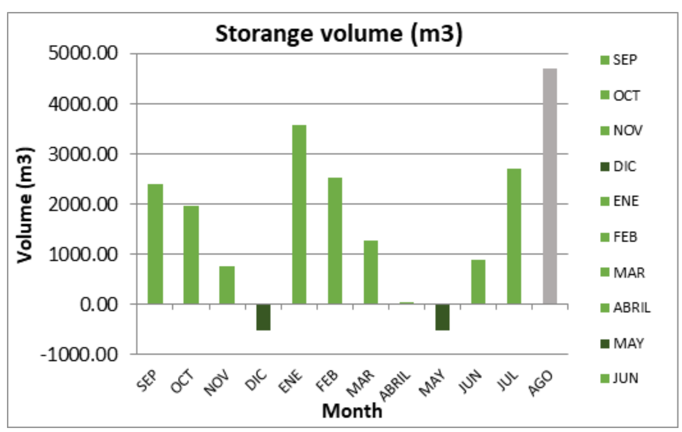


Figura 4. Monthly storage volume

According to the results of Table 3 and Figure 4, of the 12 months of the year, only 2 months the demand exceeds the accumulated supply, which are the months of December and May, so in those two months drinking water will be used; however, the remaining 10 months there is a supply greater than the demand, with this we prove that the project is viable to meet the needs of people, in addition to having a saving of drinking water.
Now, to obtain our storage volume, based on our parameters, it will be the largest value obtained from the accumulation of rainwater, the largest accumulated volume is equivalent to the month of August with a value of 4700.07 m3. This volume will allow us to supply the community of Huapango during 10 months of the year.

In order to store rainwater, the design of a 5000 m3 semiburied cistern in reinforced concrete is proposed. The cistern will be located at a distance of 23 m from the convergence point of the streets, as shown in Figure 5. The blue circle shows the convergence point, the green rectangle shows the first water interceptor, then the red rectangle shows the area for water storage and the yellow line corresponds to the distance between the convergence point and the storage area.

Figure 5. Location of the rainwater harvesting system in the community of Huapango.

In accordance with the aforementioned parameters, the the cistern will have the capacity to store 5,000 m3 of rainwater, a depth of 5m and rectangular dimensions of 20m wide x 50m long x 5m deep, the cistern will have a cover of 1m x 1m so that it can be entered for proper maintenance of the cistern. Figure 6 shows a plan view of the cistern and its components.

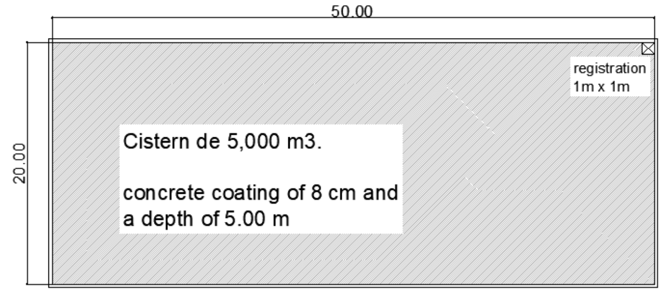


Figure 6. Plan view of the cistern

4.3. FIRST WATER CHANNEL AND INTERCEPTOR

The channel to be used to convey the water from the convergence point to the first water interceptor and then to the cistern will be a rectangular channel which must have adequate dimensions to transport the rainwater from one point to another. In addition, at the beginning of the channel there will be a network of stones of different diameters that will help the flow of water to be calmer and slower and to reach the interceptor in an adequate manner, Figure 7 shows an example of the network of stones that will be installed, In addition to a section of meshes of different openings that will help separate the debris that can be dragged by the water, these meshes will be frame types of the size of the channel which will be installed perpendicular to the channel, in figure 8 an example of mesh that will serve as a type of filter is shown.

Figure 7 Network of stones of different diameters.


Figure 8 Stainless steel mesh.

The first water interceptor was calculated according to the total catchment area and the volume of rainwater required for the washing of each square meter of streets, for an area of 26790.285 m2 The volume of rainwater that will not be stored in the cistern is 26.790285 m3 For this purpose, we propose the design of a sub-tank with the following dimensions: 3 m wide x 5 m long x 2 m deep, which is equivalent to 30 m3 of rainwater. In addition, a valve will be placed to prevent the passage of water when it reaches the desired volume, diverting the water into the cistern.

5. CONCLUSIONS

Based on the results obtained, it can be concluded that the project meets the proposed objective in that it is viable to make efficient use of water in the community of Huapango Guanajuato, since with the rainfall in the area and the available street space, it is possible to completely supply the 626 people in the town during 10 months of the year, the month with the highest volume is August with 4700 m3, it will only be necessary to use potable water for the remaining two months (December and May) according to Table 3.
However, the project requires a very high initial investment, so it is not a low-cost system, which makes it inaccessible at times if there is not adequate financing to carry out the project.

The system is designed for the hydraulic and meteorological conditions of the area, and the precipitation corresponding to the last three years (2019, 2020, 2021), so the design may vary if the conditions are different or do not resemble those presented above, and the volume captured may be higher or lower, depending on various factors.

Since this project consists solely of the conceptual engineering of a system to harness the energy of the details of the installation and construction of the system are not yet known. Therefore, for its implementation, field surveys are recommended for the precise quantification of the system components and their location.

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