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/CONTENIDO/

ROOFTOP RAINWATER HARVESTING ACCEPTANCE IN THREE LOCALITIES OF GUANAJUATO, CENTRAL MEXICO

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SUMMARY

Rainwater harvesting (RWH) provides various social, environmental, and economic benefits. It is important to first consider individual preferences and willingness to use harvested water for different purposes in order to encourage a community to use RWH and establish strategies that allow for the introduction of an alternative water supply, and additionally foster water management through sustainable practices. This paper presents the willingness of individuals to use RWH in three localities (Guanajuato, Romita, and Silao) of the state of Guanajuato, Mexico, evaluated through the acceptance of using the collected rainwater found in the results of 504 questionnaires directly applied to owners and dwelling users in urban areas of the localities studied. Other aspects related with RWH were included in the study, such as some characteristics of the population and their dwellings.

Introduction

The increasing demand for water and subsequent strain on resources has propitiated the search for alternative sources, such as gray water, desalination and rainwater. Yet, in order to implement a new water supply scheme, it is very important to consult public opinion first. Public opinion will dictate the feasibility of introducing an alternative water supply and the best way of implementing it. Therefore, the perception and acceptance of the population towards alternative water sources has been studied in recent decades and related to aspects of individuals such as age, education, socioeconomic factors, and local policies, among others. These characteristics provide information to generate the necessary tools that allow communities to adapt to new water supply sources.

Rainwater harvesting (RWH) is an important means of optimizing water resource use that simultaneously promotes sustainable development (Ghisi *et al.*, 2009) and is strategically implemented in different regions to solve and reduce the strain on water resources. However, regardless of how RWH is implemented, it requires the acceptance and willingness of individuals to use the water collected (Barthwal *et al.*, 2013). RWH has the potential to provide a considerable volume of water to contribute to the water supply in a given area, while at the same time generating savings and reducing extraction from current supply sources. Hence, in order to promote RWH as a water management strategy in the localities of interest, it is necessary to know the level of RWH acceptance and willingness to use the water collected.

According to previous studies on barriers and acceptance towards using them, attitudes towards alternative water sources depend largely on the particular characteristics of the communities where they are intended to be introduced (Ward *et al.*, 2008, 2012; Domènech and Saurí, 2010; Parsons, *et al.*, 2010; White, 2010; Barthwal *et al.*, 2013). Limited information about current attitudes and perceptions towards RWH exists in Mexico. In the State of Guanajuato, there is no available information concerning this topic. This study is focused on roof RWH, an under-exploited resource in the location studied. RWH, can provide an important contribution to complement the current water supply, and could mitigate problems caused by intermittent service and water scarcity in the area.

Rainwater harvesting (RWH)

RWH is a technology used for collecting and storing rainwater from rooftops, land, roads, and rock surfaces (Abdulla and Al-Shareef, 2009; Helmreich and Horn, 2009). The components of rainwater harvesting systems (RWHS) depend on the final use of water. However, all harvesting processes imply a surface catchment, a delivery system, and a storage tank independent of the final use of the water (Abdulla and Al-Shareef, 2006). RWH provides different benefits, for instance, the collection and storage *in situ* has no cost related to distribution systems from centralized water sources and can be used for different purposes, taking into account the quantity and quality of the harvested water. Nowadays, rainwater is used at different levels around the

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ACEPTACIÓN DE LA CAPTACIÓN DEL AGUA DE LLUVIA EN TECHOS, EN TRES LOCALIDADES DE GUANAJUATO, MÉXICO

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RESUMEN

La captación de agua de lluvia (ALL) proporciona diferentes beneficios sociales, ambientales y económicos. Sin embargo, para promover el uso del ALL es importante considerar la disposición de la población a utilizarla y para qué propósitos, con el objeto de establecer estrategias que permitan la introducción de esa fuente alternativa de agua y fomentar el manejo del recurso a través de prácticas sostenibles. En este trabajo se presenta la disposición de la población hacia el uso del ALL en tres localidades (Guanajuato, Romita y Silao) del estado de Guanajuato, México, evaluada a través de la aplicación directa de 504 cuestionarios a propietarios y usuarios de las viviendas en las zonas urbanas de las localidades de estudio. Se incluyen otros aspectos relacionados con la captación del ALL, tales como algunas características de la población y las construcciones.

ACEITAÇÃO DA CAPTAÇÃO DA ÁGUA DA CHUVA PELOS TELHADOS EM TRÊS CIDADES NO ESTADO DE GUANAJUATO, MÉXICO

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RESUMO

A captação de água da chuva (AC) fornece benefícios sociais, ambientais e econômicos. No entanto, para promover o uso da AC é importante considerar a vontade da população para sua utilização e para que propósitos, em ordem de estabelecer estratégias que permitam a introdução de uma nova fonte da água e promover a gestão da água de forma sustentável. Este artigo apresenta a vontade da população para usar a AC em três cidades (Guanajuato, Romita e Silao) no estado de Guanajuato, México. A aceitação foi avaliada através da aplicação direta de 504 questionários a proprietários e usuários das casas em áreas urbanas das localidades estudadas.

world to supply domestic or non-potable uses, promote water savings, efficient strategies for water management, and environmental conservation (Herrmann and Schimda, 1999; Ghisi, 2006; Chiu *et al*., 2009; Parsons *et al*., 2010; Mankad and Tapsuwan, 2011).

In Mexico, RWH was a common practice and was used throughout different ancient civilizations. The runoff from roofs and courtyards was delivered through storage structures inside and outside dwellings, using different materials in the process; the final uses were domestic supply and irrigation (CONAGUA, 2009). During the colonial period, with the arrival of religious orders, the design of convents and monasteries included rainwater collection and storage. Hence, in colonial cities of Mexico, such as Guanajuato, it is common to find structures for harvesting rainwater in old buildings, cisterns for domestic supply and water boxes for irrigation. Currently, this resource is used in some Mexican states, generally receiving support from social programs, but private initiatives are also present.

Study Area

The State of Guanajuato is located in central Mexico; it is comprised of 46 municipalities. Groundwater is the principal water supply source in the state and as a consequence the majority of aquifers in the area are overexploited, as is the case of the Silao-Romita aquifer in the center of the state. In this zone, the extraction of underground water has caused serious social, economic, and environmental impacts, such as the increasing cost of water extraction, high water salinity, and subsidence in some areas (Foster and Garduño, 2009). Recent demographic growth and agricultural and industrial development have resulted in increased pressure on the limited water resources to satisfy increasing demands. Thus, with decreasing water availability, it is highly relevant to generate the basis for establishing strategies that contribute to sustainable water management and provide alternatives to supply the needs of the population, according to individual characteristics.

This study is focused on the urban areas of Guanajuato, Silao and Romita. Guanajuato is a historical mining city; the northernmost region of the city is located in a transition zone between two physiographical provinces (Cerca-Martínez *et al*., 2000) causing variable weather which may include extreme events. There are records of floods since 1629 and droughts between 1710 and 1730 (Valles Septién *et al*., 1983; Miranda-Avilés *et al*., 2009). Thus, the population in this region has faced the kind of events that determine the hydraulic infrastructure of the city and may be why RWH became a common supply practice. Romita, the southernmost locality, is predominantly agricultural and faces regional pressure on water resources despite having the smaller population of the three localities; here, the use of rainwater is not documented. Silao is one of the most industrialized cities in the state and is experiencing an important increase in its population; as in the case of Romita, the use of RWH is not documented.

Materials and Methods

The study was conducted using a questionnaire directly applied to the owners or users of dwellings in the urban areas of the localities of interest in the months of April and May 2013. A total of 504 questionnaires were applied: 267 in Guanajuato, 146 in Romita and 91 in Silao. The questionnaire is comprised of six sections designed to establish perceptions about public water supply and RWH, and some aspects of the characteristics of dwellings. Most of the questionnaire consists of yes or no questions. Table I summarizes the questions included in sections 2 to 5 of the questionnaire.

The first section of the questionnaire is focused on the identifying data of the dwelling, such as location, gender of the respondent, characteristics of the house including size, construction material, and whether the resident is the homeowner or a tenant. The second section considers water use from the centralized supply; the objective of this part of the questionnaire is to recognize priorities in the use of water and possible endowments. The next section of questions assesses the perspective of the respondent towards the quality of water received from the current supply, if the respondents drink the piped water and whether or not they detect some odor or distinct color. The quantity of potable water used was also established.

The potential usage of rainwater was explored in the fourth section of the questionnaire to define the acceptance of the respondents to this resource for specific items, such as domestic and personal cleaning, watering plants and washing the car, among others. Taking into account the implications and needs concerning a RWHS, the fifth section of the questionnaire starts with a brief description of the RWHS and introduces the concept of RWH to the respondents. While describing the components of the system, the costs and requirements needed to install a RWHS are indicated, and thus determine the willingness to invest in a RWHS and maintain it in good condition. An open question on who should provide financial support for the implementation of a RWHS was also included.

The last section asks about water demand and payment for the supply service, providing information about the savings that may be obtained with rainwater. In this section the persons per household are inquired, as well as the capacity and type of the current storage tank. With the data obtained from the first and last sections, it is possible to estimate, for every locality, the rainwater harvesting potential (RWHP), a concept to be explained below.

TABLE I
COMPONENTS OF SECTIONS 2 TO 5
OF THE APPLIED QUESTIONNAIRE

Water uses
Do you use the water for…?
Personal hygiene
Domestic cleaning
Car washing
Watering gardens and plants
Centralized water quality
Do you drink tap water?
Have you identified some odor or color in piped water?
How many bottle water do you buy per month?
Rainwater use
Would you use rainwater for….?
Personal hygiene
Domestic cleaning
Car washing
Watering gardens and plant
Supplying animals and pets
Drinking water
Drinking water if is treated before
RWHS
Would you install a RWHS in your house?
Would you maintain it in good conditions?
Would you provide economic resources for a RWHS?
Who should provide the economic resources for the installation?
What for do you utilize the roof of your house?
Is the roof of your house in good conditions?

Results

Identifying data

This section of the questionnaire provides information about the gender and dwellings' location of the sample, and was also designed to obtain data on the physical characteristics of the houses in order to estimate the RWHP in the roofs of the study area for future research. The majority of respondents (62%) were women. Only 70.8% of the respondents answered the question concerning ownership or tenancy of dwellings; of those, 85.7% were homeowners, and 14.3% were tenants. Guanajuato had the highest percentage of leased residences (16.9%), but it should be considered that this city has a large student community and is also a tourist location due to being a colonial mining town and the state capital. Regarding the physical characteristics of the roofs, the houses studied in Silao had the largest mean area (131.1m^2) followed by Romita (106.6m^2); Guanajuato had the smallest mean area (89m^2), which can be attributed to the topography of the city that generates an irregular spatial distribution. With respect to rooftop materials, concrete is the most commonly used (88.2%), other materials were used but not in a representative quantity. All of the rooftops in Silao were concrete. Combinations of roof materials were reported in Guanajuato and Romita, mainly concrete with clay or metallic tiles; however, these roof characteristics were presented in a small percentage of dwellings (1.1% Guanajuato and 9.9% Romita).

Water use from centralized supply

The main source for the water supply in the study region is the aquifer, with a complementary volume of surface water. In particular, Guanajuato is supplied using surface water and in the southern part of the city with groundwater, while Silao and Romita take all of their water supply from the aquifer. According to questionnaire respondents, the centralized water supply is used by almost the entire study sample for personal hygiene (99.4%), followed by domestic cleaning (98.8%). The watering of gardens and plants is also an important use of water (66.2%); this usage was found to be reported more often by women (289) than men (195). Conversely, for car washing, which has the lowest rate of water use, men answered positively (44.4%) more often than women.

Centralized water quality

Taking into account the reliability of opinion on the quality of water received from the centralized system, two questions were asked: whether or not the household drinks tap water directly, and whether or not they have perceived some odor or color in the tap water. A high percentage of the respondents (78.9%) does not drink tap water and a higher percentage of female respondents answered negatively as compared to male respondents. Almost the entire Guanajuato respondents (90.9%) answered negatively to the question regarding drinking tap water, which this can be an important incentive when considering new supply alternatives. Regarding the second question of this section 53.4% of the study sample identified some odor or color in the tap water but most men did not find odor or color in the water. The respondents of the city of Guanajuato, regardless of gender, exceed the 50% mark for identifying odor or color in water, while in Romita and Silao less than 40% answered yes to this question.

Mexico is a country with a high consumption of bottled water, and considering the low utilization of tap water as drinking water, the last question of this section is useful to establish the quantity of bottled water acquired per month and the economic spending thus derived. Silao is the place with the highest quantity of bottled water purchased (164.1 liters; USD14.10), followed by Romita (135.7 liters; USD11.70) and Guanajuato (122.9 liters; USD 10.60). Thus, in

Guanajuato the respondents identified odor and colors in water, yet they buy fewer bottles of water than in Romita and Silao, where the sample found fewer negative aspects in tap water.

Willingness to use rainwater

Hartley (2006) and Marks (2006) indicated that the level of acceptance for reused water is related to the degree of human contact. Ward *et al.* (2008) found that the perceived risk of use rainwater increases as the type of use becomes increasingly personal. For less contact there is a higher acceptance and for the present case study the behavior is the same. Rainwater is the less accepted for drinking and personal hygiene. Figure 1 shows the percentage of the respondents willing to use rainwater for different activities.

The first question of this section was: Would you use rainwater? In response, 91.5% of the sample responded affirmatively. The following questions are directed, however, to a specific use and the acceptance to use rainwater was lower. When asked about the consumption of rainwater as drinking water positive answers were given by only 15.4% of respondents. Nevertheless, in the next question: Would you use treated rainwater as drinking water? (with four possible answers: Yes, Maybe, If I don't have any other option, No) the affirmative answers increased and reached 53.4%.

Rainwater harvesting system (RWHS)

The willingness to take advantage of rainwater through a RWHS is reviewed in this section, where 92.8% of respondents show a high disposition to implement a RWHS; women being more prone to install a system (95.2%) than men (89%). In order to benefit from this resource in an effective way, it is necessary to maintain the surface where the water will run off in good condition, and to administer regular maintenance to the system; thus, the majority of the sample (97%) would accept the need to undertake activities to maintain the RWHS in good condition.

Regarding financial support to take advantage of rainwater, 72.5% of respondents answered positively to provide the financial resources to install a RWHS. Nevertheless, in the open question about who should participate in the investment for RWHS in local dwellings, 41% answered that the government should contribute, without specifying the level of government. It is noteworthy that in the localities of interest, the municipality has the task of water supply, but only 7% of respondents chose it in their answers, which may denote a lack of information about this topic. A mixed participation between the owners and government obtained the second higher percentage with 25.9%. Figure 2 shows the percentage of the actors that, according to the respondents, should participate in the investment in a RWHS for their houses.

In the region, individuals commonly use the roof space for laundry activities. These activities were taken into consideration when calculating the availability of the potential roof catchment surface, and its conditions. Hence, it was asked whether or not they use their roofs, and if so, what they use it for. In a small percentage of dwellings the roof is used, only 3.1% of respondents use their roofs for housing pets, flowerpots, or storage; of the 119 houses where the roofs are used for a specific activity, 95 were for laundry and related activities. According to results, those current rooftop activities would not prevent RWHS installation.

Water storage

The use of plastic barrels for water storage is a common practice in homes in the studied locations. In order to find the storage capacity of dwellings, questions about the kind of reservoirs used and the volume that may be stored were asked. Results show that 410 houses (81.3%) employed plastic tanks, the use of cisterns was lower (only 17.7% of total dwellings had this kind of reservoir), and only 7.7% had another type of deposit with lower volume, such as barrels and buckets. The use of more than one type of reservoir is higher in Guanajuato, as well as is the higher volume of storage; this may prevent the effects of the intermittent supply service in the area. The combination of plastic tanks with cisterns is present in the three localities, and in Guanajuato the use of plastic

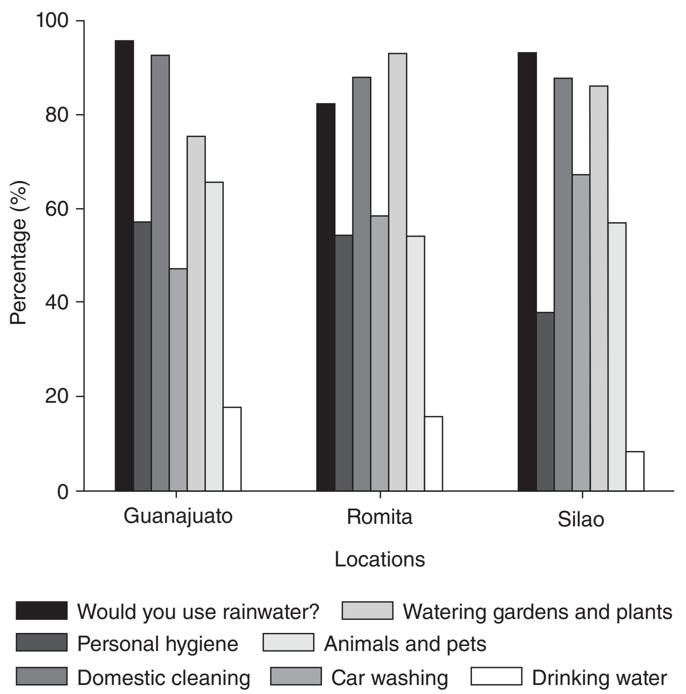

Figure 1. Percentage of respondents willing to utilize rainwater per use.

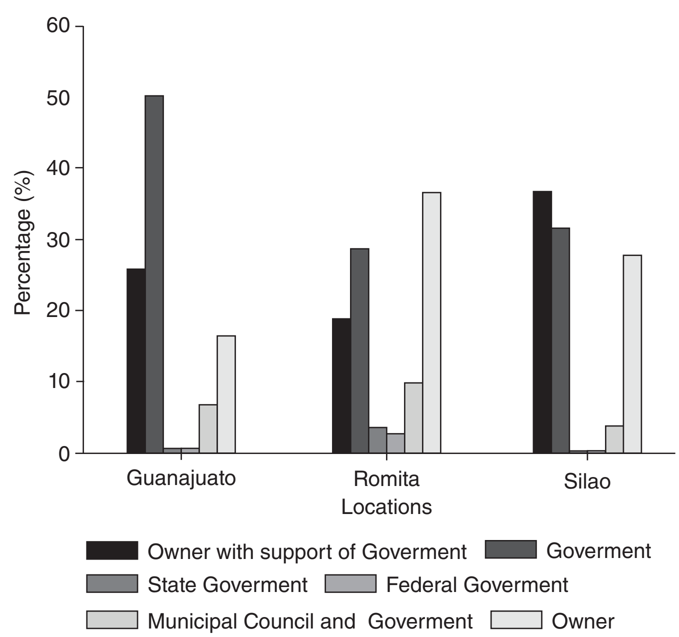

Figure 2. Actors that according to the respondents should participate in the investment of RWHS.

tanks together with barrels and buckets was also reported.

The diversity of storage volumes is high, but in accordance with the construction practices in the region, the plastic tanks mostly used have capacities of 450, 750, and 1100 liters. The most common ones in Silao and Romita were the 750 liter tanks, whereas in Guanajuato city were of 1100 liters. Regarding the volume of cisterns the most common capacity was 10,000 liters. These results make clear the importance of storing water for the community because out of 504 visited dwellings 479 had at least one type of reservoir.

The number of persons per household and payment for the supply service were asked in the final two questions. The average household size per locality are: 4.1 in Guanajuato, 4.9 in Romita and 4.6 in Silao. The last question asks about the water demand and the payment for the supply service, but only 5.6% of respondents knew the quantity of water that they used. However, 91.5% of them knew their monthly payment to the centralized supply organization. More men knew this quantity than women and the same occurred with the small percentage of the sample that knew the cubic meters consumed. A relationship between payment and consumption could be established taking into account the service establishments of each locality. Regarding the amount paid for the supply services, the higher costs are presented in Silao, followed by Guanajuato. The smaller community, Romita, pays less, where the base fee included 10m^3, a situation that does not occur in the other communities, where the base fee does not include a given volume. Table II shows the consumption and payment for the supply service and the calculated water consumption per person per day, according the results of the questionnaires. All this data can provide information about the savings that can be obtained using rainwater and about the water demands of the communities.

Rainwater harvesting potential (RWHP)

The RWHP is the quantity of rainwater that can be collected on a surface and, according to Farreny *et al.* (2011), it can be estimated based on the local precipitations, the roof area and the runoff coefficient. For the locations of study the RWHP was estimated taking into account the material and average roof area present in the results of the applied questionnaires and the normal monthly precipitation from the locality stations obtained from the CONAGUA (2015) database.

The roof material influences collection efficiency and the losses for a given material are considered in a non-dimensional runoff coefficient (RC). For roofs, RC is within the range of 0.7-0.9 (Farreny *et al*., 2011). The RC is used to estimate the RWHP at 0.8, based on a concrete roof, in accordance with the results of the questionnaires applied that shows that more than 80% of the roofs employed concrete in the three areas. In addition, according to the information in the population census (INEGI, 2000), more than 70% of the total rooftops in the localities of interest are made of concrete. The area (A) is a relevant factor that influences the volume of rainwater that can be collected and the abovementioned roof average surfaces for the three locations were considered. The volume of rainwater that is possible to harvest in each city is estimated using $V= (P \times RC \times A)/1000$ (Ghisi, 2006; Abdulla and Al-Shareef, 2009), where V: annual volume of harvestable rainwater (m^3), P: accumulated average monthly precipitation (mm), A: harvesting area (m^2). RC is non-dimensional and 1000 is the factor used to convert P from mm to m.

Taking into account the quantity of water used by the population, it is possible to appraise the percentage of demand that rainwater could meet. Table III shows the accumulated average monthly precipitation (P) for each locality; the volume (V) of rainwater estimated according to the results of the questionnaires applied; and the coverage (C) is the percentage of the demands that could be met by rainwater. The average annual V per person in the study area is 12.8m^3.

TABLE II
CALCULATION OF DAILY WATER *per capita* CONSUMPTION BASED ON PAYMENT TO CENTRALIZED WATER DISTRIBUTOR

Locality	Payment (USD/month)	Volume (m^3/month)	Consumption (liter/person/day)
Guanajuato	15.1	12	97.56
Romita	10.1	10	68.03
Silao	24.6	16	115.94

Discussion

According to the results of the first section of the questionnaire, the majority of respondents were homeowners; this allows for the possible management of a RWHS. The uses of the centralized water supply at the domestic level are mainly for personal hygiene and domestic cleaning, followed by watering gardens and plants. Considering rainwater instead of piped water, the respondents would use rainwater less for personal hygiene, and almost the same percentage would use rainwater or piped water for domestic cleaning, car washing, and watering gardens and plants. The number of respondents that are willing to use rainwater is higher, which may be because these uses involve less human contact and because, currently, these uses represent unnecessary spending and if they use rainwater for them the cost will not be reflected in the payment for the supply service.

TABLE III
POTENTIAL OF RAINWATER USE IN THREE CITIES OF GUANAJUATO STATE

Locality	P (mm)	V (m^3)	C %
Guanajuato	732.8	52.18	36.2
Romita	669	57.05	47.5
Silao	618.2	64.84	33.8

The willingness to use rainwater for domestic cleaning, car washing, and watering gardens and plants makes these activities ideal for the direct use of rainwater for the dwellings in the areas of study, given the more negative attitude of the respondents towards the use of rainwater for personal hygiene and as a drinking water resource. These facts can orient the strategies to foster rainwater use and the design of systems that can cover the needs of the population according their characteristics.

Considering the results of the third section, it may be stated that the respondents identify a risk in the use of piped water as drinking water, as 93.7% of them buy bottled drinking water. Regarding these respondents that buy bottled water, Guanajuato has the higher percentage (97.4%) followed by Silao and Romita, but by volume Silao and Romita buy a greater quantity of water.

It was found that the people in Guanajuato, Romita and Silao, present a high willingness to use rainwater by installing systems in their households, and they also indicated a willingness to undertake maintenance activities. Nevertheless, financial support for a RWHS installation is a point of discussion. The roles of the water management institutions and councils are not clear, which was evident in the fourth section, where it was asked who should provide the support to adapt a RWHS. Hence, information is a relevant factor to establish for the community the actors in water management at different levels and the activities and responsibilities that correspond to each one. Another important factor is the need for financial support from the government to encourage the installation of a RWHS.

RWH could propitiate savings of almost 50% of the annual water consumption, at least 33% considering the characteristics of the locations. This information can be useful to promote the use of the RWH and encourage the population and the water authorities to take advantage of this resource to complement the water endowment and lower the pressure over the groundwater in the area and propitiate the recovery of this source.

Conclusions

A strong determinant factor for RWH use is its cost, and specifically the investment needed to install and operate the systems. Thus, financial support from governmental institutions turns out to be one of the main factors to encourage respondents to implement a RWHS but, at the same time, where this support should come from was not identified. The information relating to local water management is an important point to foster sustainable practices of use and management of this resource. Making available information about the management of water to different levels of community is an important factor to advance in this topic.

According to the results obtained from the questionnaires applied, rainwater is a source that the population in Guanajuato, Romita, and Silao are willing to use (91.5%) and the respondents show a high willingness to install and maintain a RWHS. Dwellings have the necessary characteristics for RWH and common activities conducted on rooftops, and rooftop materials are not an impediment. Water uses with less human contact such as domestic cleaning, watering gardens, and car washing, are the most likely uses of rainwater in the locations of interest according to the level of acceptance of respondents.

The overview of the current water perception in the study locations is useful to encourage the use of rainwater as an alternative water supply and obtain the basis to generate water management strategies according the particular characteristics of each place.

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