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Notes

Aquappolis: Mobile application for rainwater harvesting in Mexico City

Aquappolis: aplicación móvil para la captación de agua de lluvia en la CDMX

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Abstract

Rainwater harvesting has become a necessary action around the world to satisfy the big cities needs where the water access is restrained (Shivakumar, 2017), which is the case of Mexico City where the water demand exceeds the supply sources, and many other problems are related to water (Arto-Olaizola et al., 2016). Aquappolis is a mobile application intended to compute the amount of rainwater that can be harvested from specific zones in Mexico City. The app information is provided from extensive rain gauge network data collected from Hydrological Observatory stations across Mexico City. This paper provides an example of how the technological innovation and instant information available for decision-maker authorities and the general population are indispensable to achieve a responsible, careful, and sustainable management of available water resources in Mexico´s Valley.

Keywords: Technology, innovation, application mobile, smartphone, rainwater harvesting, rainfall, water management.

Resumen

La captación de agua pluvial se ha convertido en una acción indispensable alrededor del mundo para satisfacer las necesidades de grandes ciudades donde el acceso a este recurso es limitado (Shivakumar, 2017), tal es el caso de la Ciudad de México, donde la demanda rebasa la capacidad de las fuentes de abastecimiento y donde además se presentan diversos problemas relacionados con el uso del agua (Arto-Olaizola et al., 2016). Aquappolis es una aplicación móvil destinada a calcular la cantidad de agua de lluvia que puede ser captada en una determinada zona. La información que usa esta aplicación es obtenida de los datos recaudados por la amplia red de sensores de las estaciones del Observatorio Hidrológico del Instituto de Ingeniería (II-UNAM) en la Ciudad de México.

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En este trabajo se proporciona una muestra de cómo la innovación tecnológica y la información instantánea puesta al alcance de las autoridades encargadas de la toma de decisiones, así como de la población en general, son indispensables para lograr un manejo responsable, cuidadoso y sustentable de los recursos hídricos disponibles en la Zona Metropolitana del Valle de México.

Palabras clave: tecnología, innovación, aplicación móvil, *smartphone*, captación de agua, lluvia, gestión del agua.

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Introduction

In recent times, Mexico City has manifested a considerable troublesome related to water management. Floods, lack of water, and exceed of drainage system in some seasons of the year have become more common and the impact on the activities and lifestyle of the inhabitants, something that brings risk situations.

Mexico City was established centuries ago over a system of interconnected lakes: Texcoco, Xochimilco, Chalco, and Zumpango, which fill an area of 114000 hectares as shown in Figure 1. These lakes were filled by rivers coming from surrounding mountain ranges. The Neovolcanic Axis, which cross the country from the Gulf of Mexico to the Pacific Ocean, generated this mountainous topography and the volcanic emanations provided the clayey material which went to the lakes.

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Figure 1. Ancient lake system of the Basin of Mexico.

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The ancient Tenochtitlan settled down on an islet from Lago de Texcoco and those citizens developed their agriculture using chinampas, an artificial floor to cultivate over water. They also had a system of dikes that permitted control of the moving level of the lake so that they could avoid floods and additionally separate sweet water from salty. From colonial times, the lakes from the Valley of Mexico underwent a drying process to avoid flooding, however, these continued to occur, so during the Porfiriato, the construction of a drainage system for sewage and rainwater began that had the function of carrying these liquids to Hidalgo. With the passage of time, urbanization, and settlements in the city, the volume of water to evacuate annually grew so the drainage system was exceeded in its capacity and the need arose to create a new drainage system capable of evacuating these large volumes when needed.

In the last 100 years, the population of Mexico City grew abruptly, from 0.7 million people in 1990 to 8.9 million in 2015, according to the latest census of the National Institute of Statistics and Geography (Figure 2 and Figure 3) (INEGI, 2015a). The period with the greatest increase in population was from 1920 to 1970, with a growth of 5.7 million. Currently, if the population of the metropolitan area is counted, the number of inhabitants is 22 million, which places the area as the largest population agglomeration in the American continent. Due to this large number of people, satisfying the water demand of 68 cubic meters per second becomes a great challenge for the Government of Mexico City.

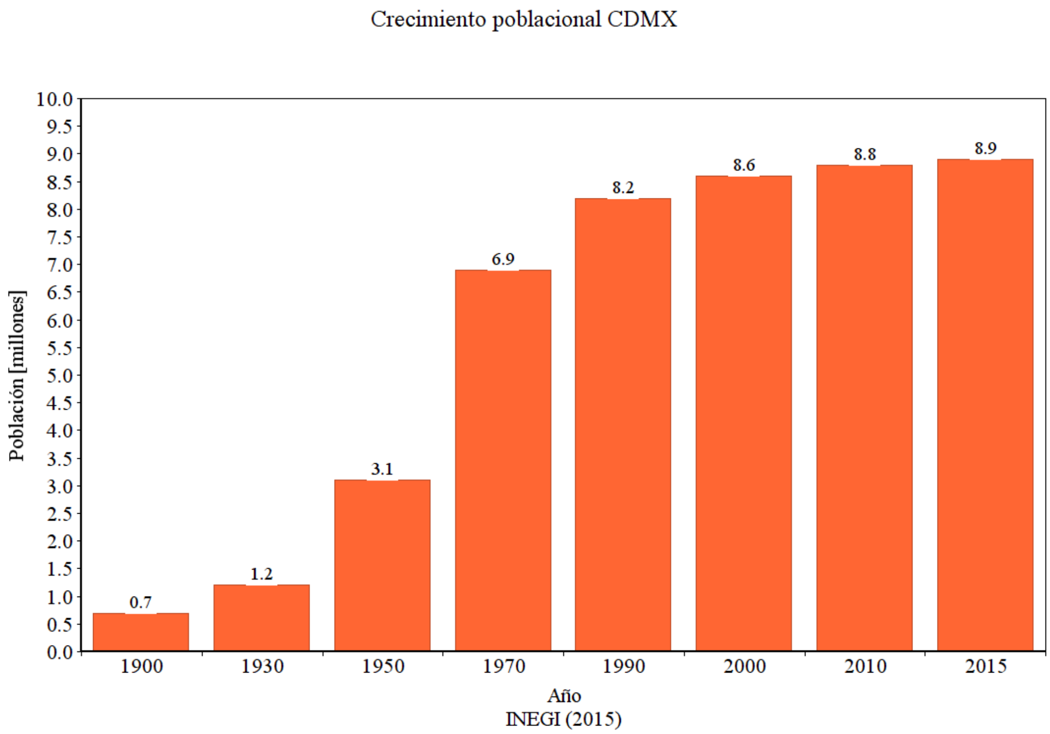

Figure 2. Population growth in Mexico City 1900-2015.

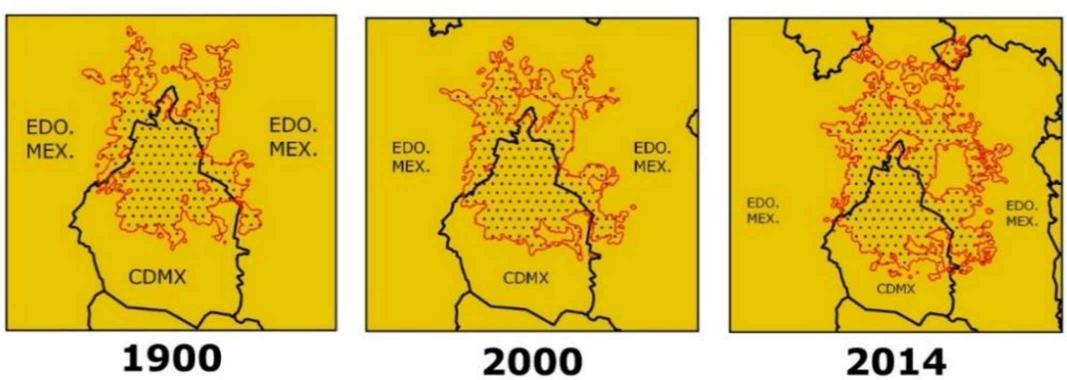

Figure 3. Urban area growth (1900-2014).

Due to the strong demand for water, the city sees the need to import this vital liquid from the neighboring basins of Cutzamala and Lerma, which provide a little more than 30 % of the required quantity (Conagua, 2005), the rest is obtained of wells distributed in the basin area. The fact that the city is mostly covered by concrete, the lack of green areas, and the existence of clay soil that allows infiltration at very low speeds, together with a large amount of water extracted, causes a significant deficit for the aquifers, something that has caused settlements on the part of the city located on the lake bed up to 10 meters in the last 60 years in some points (De Urbanisten, Deltares, 2017).

The city suffers from two contradictory situations, the shortage of drinking water and excess water in the rainy season. The average citizen in Mexico City consumes approximately 366 liters of water per day, an amount that far exceeds the consumption recommended by the World Health Organization of 80 liters (OMS, 2003). This great demand causes that each year the extraction volumes of the wells are increased, accelerating the decrease in the water level in the aquifers and increasing the settlements that, day by day, cause damage to the infrastructure of the city, especially to that that supplies water to network users, causing around 35 % of the water transported by the pipeline to be lost in leaks (Sacmex, 2017). The 16 mayoralties of Mexico City are affected by water shortages when there are cuts in the supply but especially Iztapalapa and Tláhuac where the average consumption drops to 230 liters per day per inhabitant (Sedema, 2016), see Table 1, and the supply is given through batches as shown in Figure 4.

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Table 1. Population and endowment by a town in Mexico City.

Town	Population	Endowment (l/hab/day)
Iztapalapa	1 783 535	235
Gustavo A. Madero	1 242 676	237
Álvaro Obregón	690 568	321
Coyoacán	643 838	355
Tlalpan	584 992	560
Cuauhtémoc	519 224	332
Venustiano Carranza	465 571	203
Azcapotzalco	443 071	404
Iztacalco	413 649	219
Xochimilco	372 111	374
Benito Juárez	362 591	406
Miguel Hidalgo	354 803	502
Tláhuac	304 611	210
Magdalena Contreras	223 266	554
Cuajimalpa	152 306	293
Milpa Alta	96 922	410

Figure 4. Mexico City's government supplies water to the population that has been affected by the shortage of water.

The frequency of urban floods has increased since in the mountain areas of the south and southwest of the city, the advance of the urban area has deforested and paved a large part of what was previously forest and infiltration areas, causing that in the events of rain, runoff flows at high speeds, a situation that prevents water from infiltrating during its journey and that, upon reaching low areas, accumulates and causes puddles and floods (Figure 5). When this happens, the drainage system becomes overwhelmed not only by the amount of precipitated water but also by the carry-over of garbage that obstructs the entry of water into the system.

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Figure 5. During the rainy season, flooding vulnerable areas are affected and cause mobility problems.

Speaking of political action regarding this problem, the main governmental actors have recently entered into friction between themselves and the mediating instances have not put an end to the disagreements so that the governments work together. Mexico City, formerly the Federal District, was a dependency of the Federal Government, which is why it was favored in terms of the construction of infrastructure for the supply of drinking water and the evacuation of sewage, after its political reform the need to relate to the neighboring states, mainly the Estado de México to be able to negotiate the water necessary to satisfy the demand of the population. Although Mexico City pays on time for the volumes of water that are supplied to it, it should not continue with the importation of water on a large scale, although it remains essential to satisfy demand.

As for the Estado de México, it demands a Federal Government budget for the recovery of aquifers and that the Government of Mexico City take responsibility to compensate the ecological and hydrological damages that have been caused during the time that water has been exported to the metropolitan area. Likewise, it should be noted that EDOMEX has been favored by the infrastructure that was given to CDMX that also supplies its neighboring towns.

Both entities must collaborate and with the states that are recently included in this situation, which are Hidalgo and Michoacán, together with the intervention of the Federal Government, through CONAGUA, to provide a solution to the problems that afflict the Metropolitan Valley of Mexico.

It is insufficient to adopt as the only solution the construction of large infrastructure works, as well as the expansion of current systems, the importation of water from other areas, or greater exploration of the existing aquifers, since carrying out these actions entails a great political, social, economic and ecological challenge, therefore, the limitation of solutions leads to consider alternatives that are contrary to the traditional form of hydraulic policies (Perló-Cohen & González-Reynoso, 2005).

The Metropolitan Area of the Valley of Mexico sees the need to adopt comprehensive water management to meet the needs of the current and future population, eradicating the water stress to which the basin is subjected is of utmost importance, as well as reducing the per capita consumption of water, the creation of better public policies on its management, reduce leakage from supply systems, encourage the use of treated water for agricultural use, increase the number of green areas, have greater regulation on urbanization and public awareness of responsible water consumption to conserve, care for and use this liquid. Taking these actions can significantly reduce the current problem.

It is then that the collection of rainwater in homes appears as a very viable option both for users and for the agencies responsible for supplying water for human consumption. Rain in Mexico City is not scarce, in the rainy season, it contributes large volumes that are not used and are sent directly to the drainage systems. Rainwater collection systems work simply: the water that falls on the roofs is collected and is conducted through a system of tubes to a filter that purifies it to finally be stored in a tank for disposal and thus reduce consumption direct from the network.

In Mexico, some projects aim to distribute water equitably without exploiting the aquifers present in the area. This is done with the use of rain, a resource that is wasted in the drainage and that, in Mexico City during 2018, presented an average of 714 mm of rain (Semarnat, 2018).

Isla Urbana is an organization that is dedicated to the implementation of projects focus on rainwater harvesting. Since its inception in 2009, it has installed a total of 15 000 collection systems with 90 000 users who have collected 600 million liters annually. In Mexico City, 7134 systems have been installed for 49938 beneficiaries (Isla Urbana, 2018).

Due to the interest in knowing the behavior of the urban hydrological cycle, in particular, the intensity and spatial variability of rainfall in Mexico City, the Hydrological Observatory (OH) of the Engineering Institute of UNAM was created in 2016. This is a project that aims to provide real-time information on precipitation in Mexico City. This is through a system of measurement equipment that, in a matter of minutes, makes available to the general population and to those in charge of making decisions, the data of where and with what intensity the rain occurs. The Observatory has 55 measurement stations, distributed in the Valley of Mexico. Most of them are made up of a disdrometer that has a laser that counts the number of drops that cross the sensor. It also measures the diameter of the drops and their speed.

Each of the stations works with the help of a low-cost microcomputer that receives the measured information and stores it in the cloud where it is processed to finally be shown on the OH precipitation map and published on Twitter. The system has a solar cell and a battery that aim to provide energy autonomy. Some of the stations that do not have the disdrometer have another measurement sensor: a weighing rain gauge. This instrument cannot perform all the measurements that a disdrometer does; however, it does determine the intensity of the rain. The observatory contemplates the placement of more measurement stations intending to increase their density in the city (OH-II UNAM, 2016) (Figure 6).

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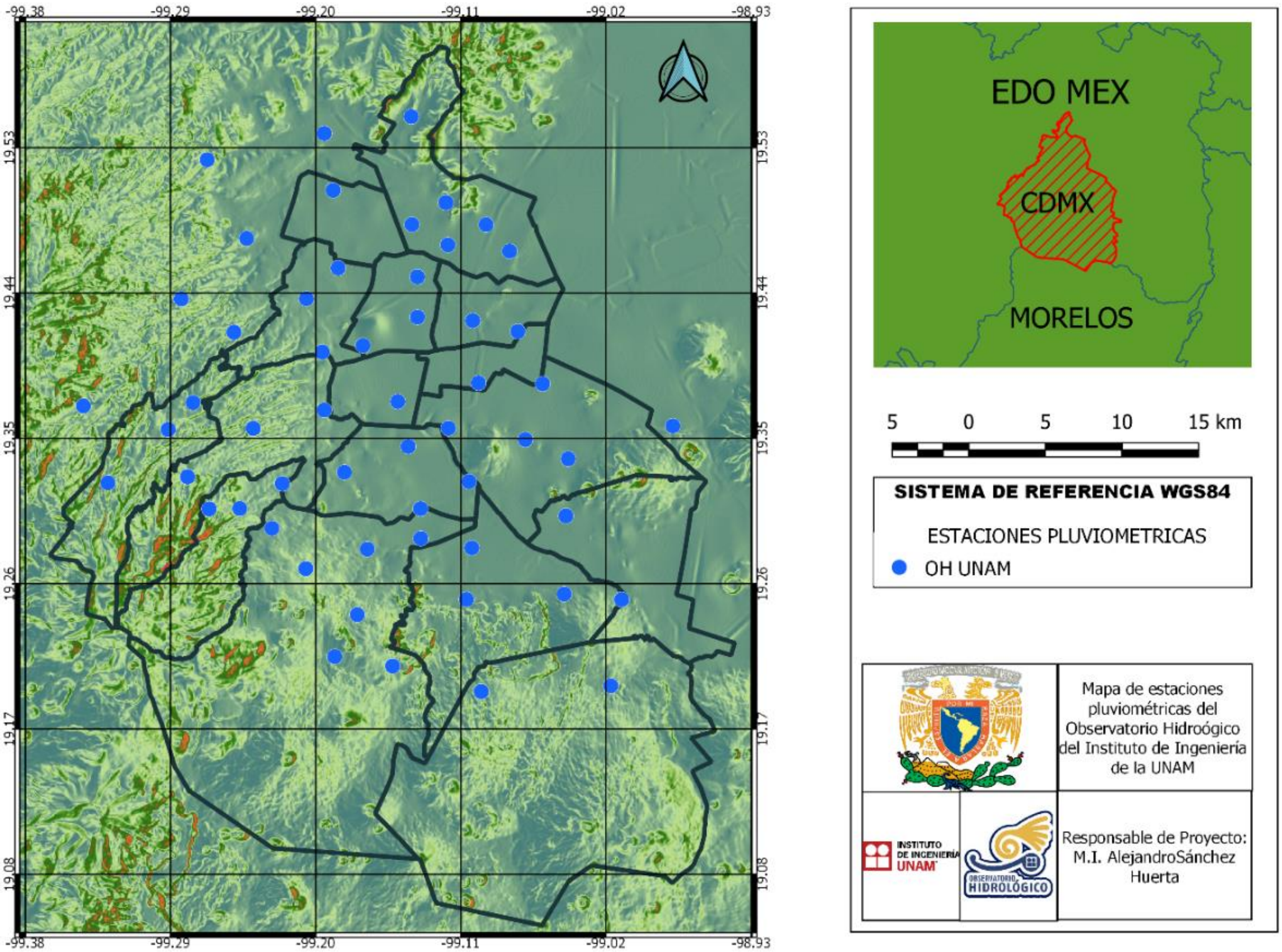

Figure 6. Location map of Hydrological Observatory II UNAM pluviometric stations.

The Hydrological Observatory of the UNAM Engineering Institute, in collaboration with Isla Urbana and the developer ABEHA, developed the Aquappolis application, which aims to be the first mobile application for the generation and use of information related to rainwater in Mexico City.

This application provides data on the potentially accumulative rainwater in a given area and a proposed period using the precipitation data measured by the Hydrological Observatory teams located throughout the city. This document aims to show the positive impact that rain collection can have on the water situation in Mexico City.

Materials and methods

The disdrometers present in the OH-II UNAM stations record the characteristics of each rain event through a laser that comes from an emitter and reaches a receiver, which measures the voltage differences when the particles cross through it, obtaining thus indirectly the diameters of the drops that pass through the sensor. To record the speed, the time it takes for each particle from hitting the laser to fully crossing the sensor is determined. For each rain event, the diameter and size data are recorded for each particle. These are classified into 32 groups, where the drops range from small to large or slow to fast.

Subsequently, with the help of the data already collected, the calculations are performed to obtain intensity, kinetic energy, reflectivity, visibility, and spectrum at one-minute intervals for each event. These data obtained can be affected by different causes such as instrumental

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uncertainties (optical alignment, intensity of the light beam, and distortion by wind), sampling (due to the small occupied sampling volumes and that the drop size distribution depends on these volumes), and observation (caused by the different speeds of the drops, related to their size, the particles that begin their fall at the same point reach the ground at different times and horizontal distances that can be up to kilometers). These uncertainties are being reduced by increasing the density of the measurement equipment within the Valley of Mexico area and by calibrating the sensors appropriately.

Once the collection of precipitation data for the entire city has begun, the problem arises on how to offer this information to domestic users of the water network so that they can quantify the volume of usable liquid depending on their catchment area. If these data are shown simply, users can express the desire to reduce the expenses associated with the provision of drinking water by the government of Mexico City and, also, show a certain degree of independence to the service provided by the government. It is through the creation of an application for mobile devices that reliable data on collection volumes are made available to the public (Silva et al., 2018).

The Aquappolis application works with two APIs (Application Programming Interface), ABEHA and OH. The OH API contains the information on precipitation, intensity, velocity, and size distribution of the precipitated droplets for CDMX within a gridded mesh of 750 meters spacing. The ABEHA API receives the information from the OH and processes it for the user.

The application uses the GPS navigation system of the mobile device to locate the area where the user is located and in this site, or any other that the person proposes, to place a rainwater harvesting system that depends on the available area, that is, of the free area that the user has.

Using the area, rainfall, and an adjusting factor, the volume of water that can be captured can be estimated. The application also has a date selector, a tool that allows you to select a specific day or a range of dates to show the volume that can be used based on statistical estimates.

The application also allows the user, using the camera of their mobile device, to capture images of stagnant water so that a calculation of its volume can be made and have statistical data of the flooding in the city and of susceptible areas (Figure 7).

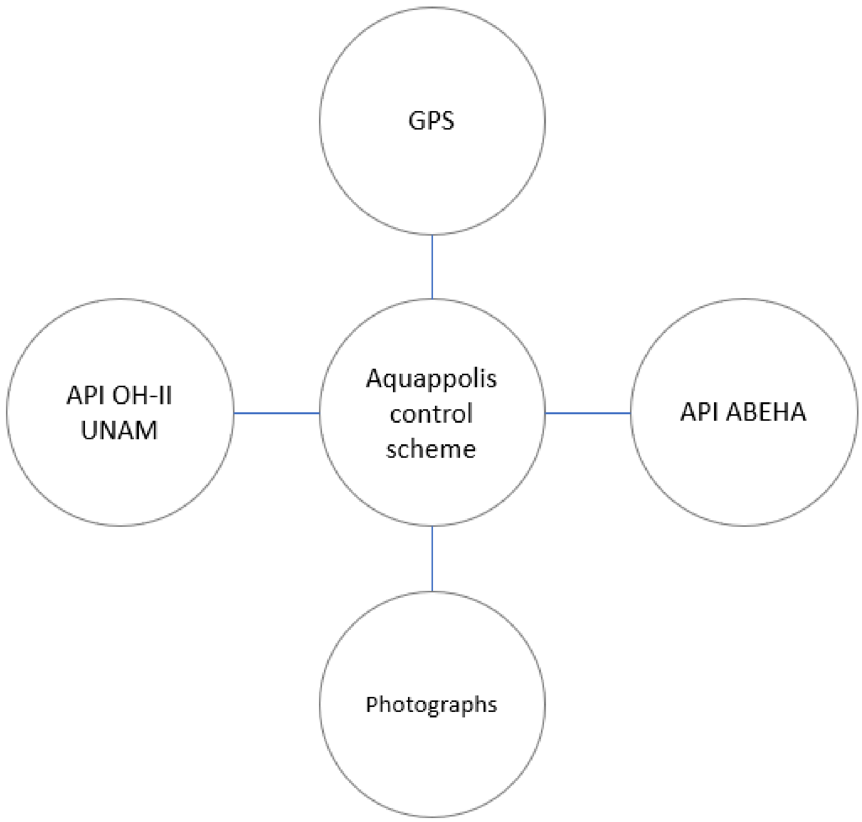

Figure 7. Aquappolis high-level architecture scheme.

In this way, if a user wants to measure the volume of precipitated water over an available area, he first has to provide the location of the place (longitude and latitude coordinates given by the device) and the dimensions of the catchment area. Thus, the ABEHA API locates the coordinate provided in the OH API mesh and takes the information associated with the table where the user is located. Later, with the characteristics of the system, it obtains the volume for the selected dates, and finally, the information is presented to the user by the application.

To carry out the study, two important points in the CDMX located in the towns of Iztapalapa and Cuajimalpa were analyzed due to their water condition. In the first mayor's office, the shortage of water is constant, while in the second there are important points of flooding. In both cases, the impact that water catchment could have on these areas can be seen. In the first case, you want to know if the volume that can be captured works as a supplement to drinking water. According to data from Isla Urbana, the collection of rainwater in Mexico City could save its users from 5 to 8 months of consumption of the public network for a family home. For the Cuajimalpa area, the water shortage is not analyzed; placing a catchment system in this area could mean a buffer, together with public infrastructure, for runoff and accumulation of water on public roads.

Results

The Aquappolis application fulfills the objective of extracting and showing the user, for each point selected within the measurement area of the equipment, the volume of the water precipitated in the selected time interval (the data is only shown for dates after the start of operation of the API ABEHA) taking as data the available area that will receive all the rainwater.

The Aquappolis application requires certain data for its operation. To access it, you first need to have a user or start as a free user, then you have to specify the dimensions, length, and width of the area where the analysis is to be performed. For this case, an area of 12 meters long by 5 meters wide will be assumed (Figure 8).

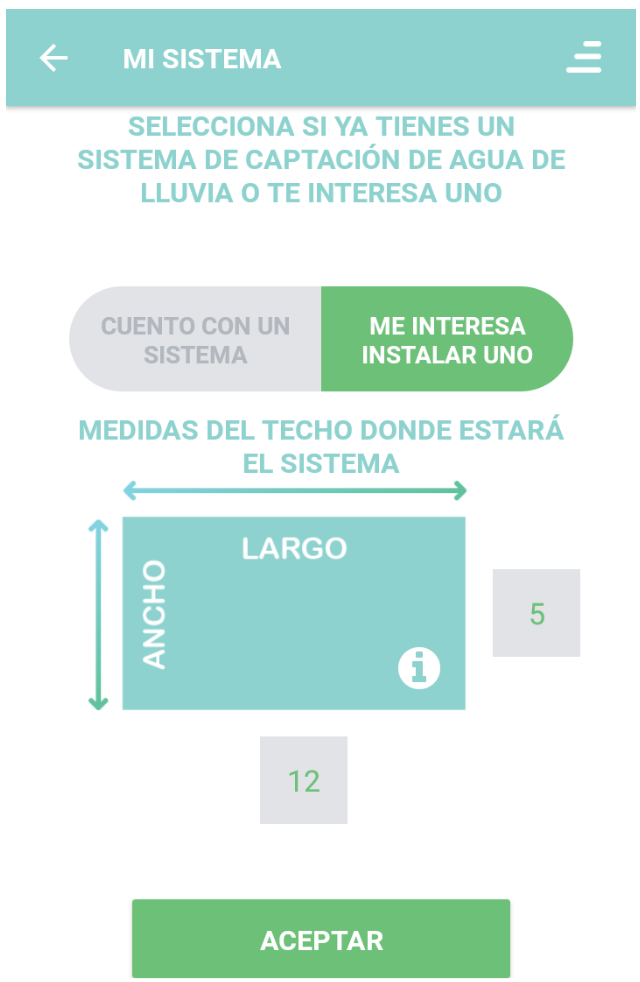

Figure 8. Harvesting available area.

The next piece of information to be provided is the geographic location of the study area. A point was chosen in the Las Américas neighborhood, Iztapalapa town (Figure 9), and one in Lomas de Santa Fe, Cuajimalpa town (Figure 10).

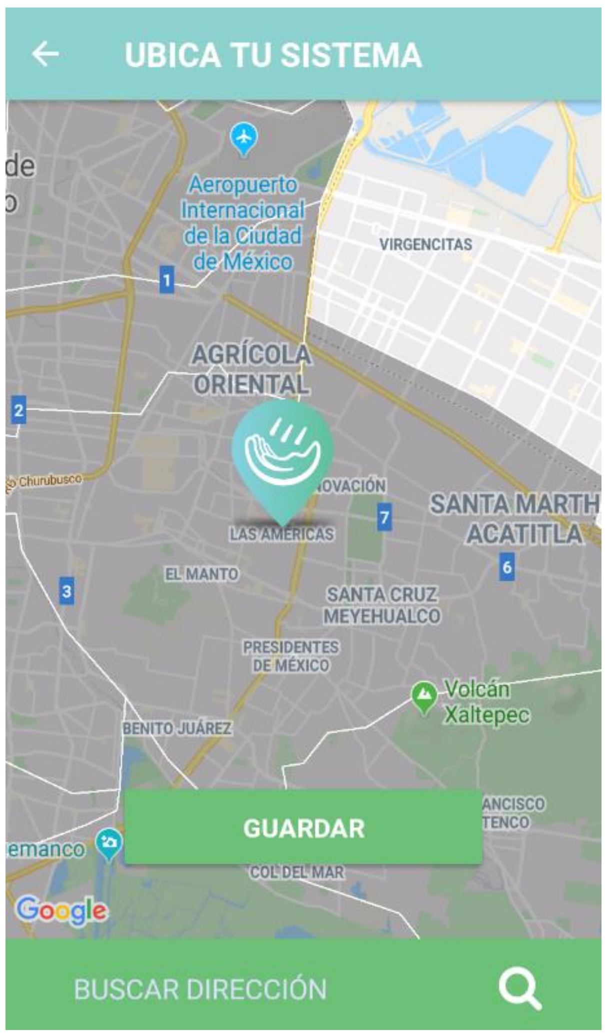

Figure 9. Harvesting system location, Iztapalapa town.

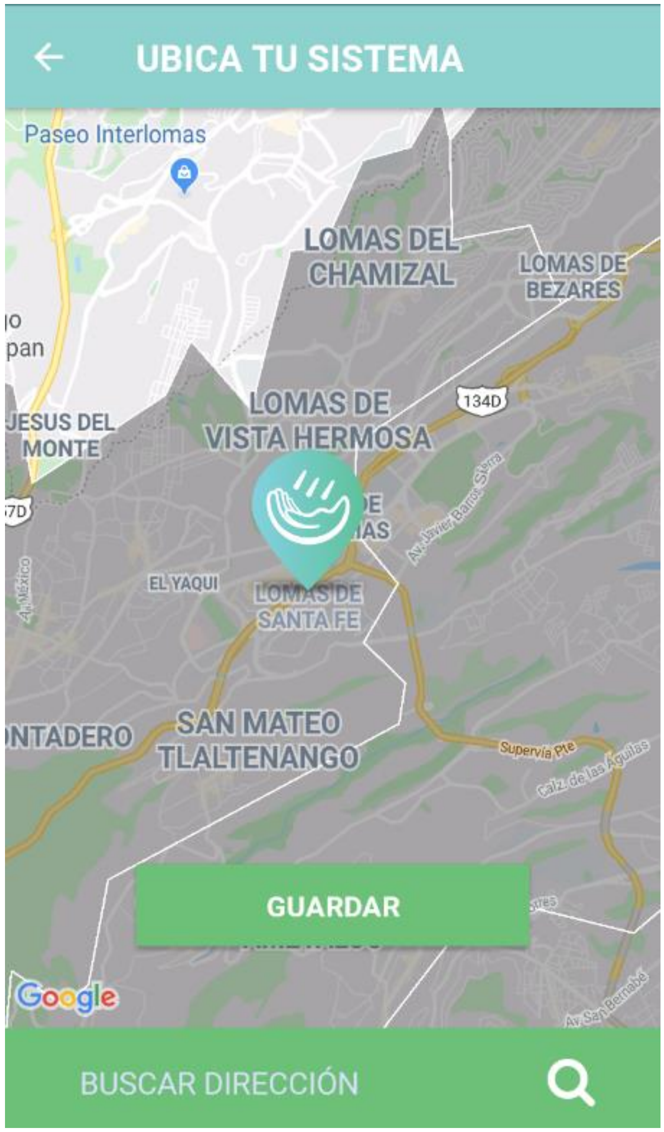

Figure 10. Harvesting system location, Cuajimalpa town.

The date range is selected from January 1, 2019, to September 30, 2019, with a total of 272 days between the mentioned dates.

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For the selected date range, a volume of 33 418.24 liters was obtained (Figure 11), and 46 641.42 liters (Figure 12), for the point in Iztapalapa and Cuajimalpa respectively.

Figure 11. Potential volume harvested in Iztapalapa.

Figure 12. Potential volume harvested in Cuajimalpa.

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Discussion

From the results obtained, we can see that the volume was higher for the Cuajimalpa mayor's office, this is because in the southern and southeastern areas the average annual rainfall is higher than for the northeast area (Semarnat-Conagua, 2018). In the first case, the volume shown can be used in people's homes and thus reduce the impact of urban floods. The second point of analysis is important because urbanized mountainous areas cause runoff to be of greater speed and volume, causing accumulations in low areas where water can no longer runoff.

For the study point in Iztapalapa, the volume means 122.9 liters per day for a home located in this area and considering an average of 3.4 people per dwelling (INEGI, 2015b). Therefore, this would be equivalent to 29.25 liters per day per inhabitant. This volume captured, although not complementary to the average consumption of the CDMX, does represent a great decrease during the rainy seasons, where there would be less dependence on the public supply network. However, in the dry season consumption would be higher direct from the network.

Conclusions

The water situation in the Valley of Mexico needs a solution. At this moment the condition is not chaotic and there is time to make decisions and apply them correctly. The actions that are decided appropriately must be applied permanently and well managed. Collaboration between the states involved in decision-making and public awareness of water use is necessary to provide a quick solution to water problems.

The integral management of water must be essential, the actions that entail a sustainable and responsible use of water resources must be adopted by the population (Andales et al., 2014), it is here where the use of technology through mobile applications must be developed and used to have better tools with which it is possible to seek a better optimization of the use of the available resources.

The idea is to seek less dependence on imported water to the CDMX, the recovery of aquifers that have been overexploited in recent years, achieve a greater and better distribution of water throughout the Metropolitan Area, reduce the floods that affect the points lower than the city, avoid exceeding the capacity of the drainage systems, give more use to treated water instead of first-use water, and prevent neighboring states from including them in this situation (De Vriend et al., 2015). This may seem like a lot of work to be done, but there is a horizon of possibilities to solve it and thus avoid reaching catastrophic scenarios and the struggle for such a basic resource for humanity.

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