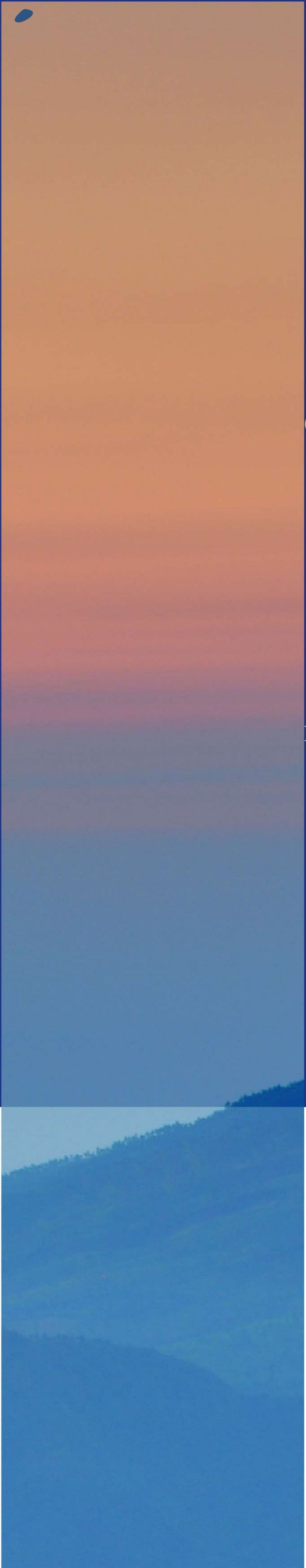

SIWI Stockholm *Junior* Water Prize

"Pontus aqua".

Identification of clandestine drinking water connections through acoustic patterns.

AUTHOR

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Entry to Stockholm Junior Water Prize 2022

PONTUS AQUA

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ABSTRACT:

The present work deals with the development of a "low cost" prototype for the detection of clandestine drinking water connections, comparable with other products in the market such as a geo-radar already used by the EPPAGE or the pipe locator of the Combiphon brand. The prototype consists of a tapping/vibration generator, an omni-directional microphone, a Scarlett 18i20 interface, free REW software and a spectrogram-sound signal analysis method. All combined allows the detection of irregularities in drinking water connection pipes. In practice, the prototype was able to detect 55 clandestine connections between December 2021 and March 2022 in the city of Machachi and its surroundings. Drinking water is recognized as an essential human right for the full enjoyment of life, so the detection of these clandestine connections can demonstrate a significant impact on the unequal access to water in the Canton Mejia.

Keywords: Sanitation Provider Enterprises, drinking water, clandestine connection, acoustic methods.

1. INTRODUCTION

Clandestine water connections, being easy to implement, have the potential to become a major problem on a global scale for municipalities and their entities which provide drinking water, but thanks to the implementation of laws, monitoring of consumption and technology, they can be prevented. But it should be emphasized that there are sectors where innovative methodologies or devices are hardly applied to ensure equal access to drinking water, one of these cases is EPAAGE in the Mejía canton.

Clandestine water connections and their effects disturb the economy of the EPAAGE that provides its services to the Mejía Canton. The effects of clandestine drinking water connections are multiple but can be summarized as follows: effects on the water service, effect on the water resource, economic effects, and direct effects (detailed in Figure 1).

Effects on water service: Less pressure Less quantity	**Effects on water resource:** Risk of water contamination	**Economic effects:** More not billed water	**Direct Effects:** Overconsumption Risk of diseases

Figure 1. Disadvantages of clandestine connections.

Source: Direct.

This leads to the EPAAGE losing around 46% of the water that they capture through clandestine connections, these losses are determined comparing delivered water with the values of water that were invoiced. (EPPAGE, 2021).

The reasons for creating clandestine connections are

- the lack of coverage in certain sectors,
- the difficult access to a water meter,
- not complying with the requirements imposed by the entities

Reasons that are out of the hands of consumers. However, also clandestinely interfere with other people's meters in order to avoid paying for the water service has been observed. Another reason why people opt for clandestine connections is the high cost of installation, which costs approximately $110 for residential connections and $220 for commercial connections (EPPAGE, 2021).

To detect these connections, various devices can be used, such as: Georadar, Combiphon, Sewerin, piezoelectric microphones or sonars. However, EPAAGE’s budget would not be able to cover the necessary expenses to acquire and use all those artifacts mentioned above to be able to identify clandestine connections.

Consequently, I developed a prototype that helps to detect the echo generated by the unusual vibrations recorded in the pipe, which are an indication of the existence of irregularities that can be considered as a clandestine connection. Such a prototype consists of several parts that are quite easy to acquire and of low cost, therefore it allows its rapid establishment and great effectiveness. The materials required for the appliance of the prototype are very accessible, such as a microphone, a vibration generator, a spectrogram viewer, the interface and free software called REW (Room EQ Wizard).

2. Objective

2.1 General objective

- Develop a prototype to identify the existence of clandestine water connections in the Mejía canton, through the analysis of acoustic patterns generated by vibrations or knocking.

2.2 Specific objectives

- Assemble a prototype based on the identification of acoustic patterns for the detection of clandestine connections.
- Evaluate the recordings of authorized and clandestine connections, through an analysis of patterns of the corresponding sound spectra.
- Conduct field tests within the evaluation area to determine the effectiveness of the developed prototype.

3. Theoretical Framework

3.1 Clandestine Water Connections

They are illegal water passages not registered with the official entities, known as theft of drinking water, and this represents one of the main problems faced by these companies both in Ecuador and the developing countries.

Clandestine drinking water connections have several causes and ways of manifesting themselves, so the methods to prevent and combat the problem must also be diverse and related to daily life. Next, some consequences related to the clandestine connections of drinking water are shown (Albacete, 1995).

3.2 Economic effect

It mainly affects the financial stability of the entities, since a correct balance could not be maintained between the value of the water supplied (including machinery, maintenance, purification processes, etc.) and the value charged to each registered consumer (Aguilera, 1992).

In figure 2., you can see data on the water collected and billed in the year 2019, giving an index of unaccounted-for water of approximately 46%, being a considerable loss for the entity that offers its service to the canton (Aguilera, 1992). The cause of these losses would be mostly due to the existence of clandestine connections and leaks.

Captured and billed water		Unaccounted water	
Volume of captured water l/s (Plan Maestro 2013)	130,68 litters/s	Annual volume of unaccounted water m3	1.878.349,75 m3
Volume of captured water m3/year	4.121.123,75 m3	Annual value of unaccounted water m3	$ 1.015.295.23
Volume of billed water m3 year 2019	2.242.774,00 m3	Index of not accounted water LANC	46%
		Number of clandestine connections estimated (consumption of 50 m3)	3.131

Figure 2. Water collected, invoiced and unaccounted-for.

Source: EPAAGE.

Other consequences are:

- The cost of the official connection becomes higher than the cost charged for the illegal connection.
- Fines for overdue payment of bills (frequently 50% or the total cost of the connection).

- Problems with the accreditation or possession of the meter, which is often impossible to obtain.

When making clandestine connections, the legal field also intervenes and here you can see values that enter as fines, which would help pay for the resources used to detect clandestine connections (EPPAGE 2019). Table 1 shows the types of fines and their corresponding value.

Table 1. Types of fines for clandestine connections

Category	Fine	Fine in $ (year 2022)
Domestic	50% of the unified basic salary	212,5
Commercial	3 unified basic salaries	1275
Industrial	5 unified basic salaries	2125

Source: EPAAGE.

3.3 Effect on health

When a connection is made incorrectly, usually clandestinely, the previously purified water can become contaminated again with viruses, pathogens and bacteria (it is mixed with particles of earth, cement, sand, among others) and gets delivered into homes for consummation. Families, not knowing that it is potentially contaminated water, do not take precautionary measures for disinfection and consume it directly, so that later they could present infections that could lead to diseases, such as: acute diarrhoea, hepatitis A, giardiasis, amebiasis or amoebic dysentery, typhoid fever, cholera (Pediatrics, 2021). According to official data from the WHO, the lack of sanitation and poor hygiene in drinking water is what contributes the most to the 1.8 million annual deaths due to diarrheal diseases due to the consumption of contaminated water (Pediatrics, 2021).

3.4 Types of clandestine connections

3.4.1 The trivialization (destruction) of the meter: It consists of the use of brute force so that the meter stops working or can no longer be read. This form is even more difficult to detect due to the brief time for which the meter is removed and the precision with which the customer can manipulate their consumption. Another type of manipulation consists of preventing the meter from working properly, either partially or totally (EPPAGE, 2019).

3.4.2 Derivation: It consists of clandestinely connecting to a neighbour's connection, but in front of the water entrance to its respective meter, in such a way that it does not affect the consumption of the supplier meter and sometimes the manipulation is colluded (EPPAGE, 2019).

3.4.3 Bypass: The meter is prevented from registering the total consumption by installing a section of pipe that diverts the passage of water through a U below or to the side of the meter box, through which the water no longer passes, or partially passes (EPPAGE, 2019). It should be noted that the prototype can be used for detecting this last type of clandestine connection.

3.5 Prototype "Blow Meter" (descomunal medidor)

This prototype has the purpose of detecting clandestine connections/illegal connections of drinking water that are connected near the water meter (before or after), Afterwards, the theoretical appliance for the realization of the prototype is explained:

3.5.1 Reflection due to impedance change

It is the principle on which the project is scientifically based. Impedance (Z) is a measure of the opposition a circuit presents to a current when a voltage is applied. Impedance extends the concept of resistance to alternating current (AC) circuits, and has both magnitude and phase, unlike resistance, which only has magnitude. Impedance can be experimentally measured in various devices through an instrument called a multimeter. This will help to calculate with what force the tapping or vibrations should be practiced (Kirchhoff, 1987).

3.5.2 The echo

The echo is a phenomenon that consists of listening to a sound after the sensation produced by the sound wave has been extinguished. Echo is produced when the sound wave is reflected by a surface, or when the sound encounters an impedance change in its propagation, such as a mother pipe (G.A, 2003).

3.6 Similar market products

COMBIPHON Sewerin appliance. - They are artifacts that measure tapping with piezoelectric microphones, and with a previously modified vibration generator, the cost is 27,000 dollars and it is an imported product, so transportation costs and taxes must be taken into account (COMBIPHON, 2011). It can be seen in figure 3.

Georadar RD1500. - A the Georadar more used in the field of archaeology than in the sanitation sector, which, broadly speaking, consists of the emission of electromagnetic waves to the ground and the successive capture of rebound signals, which allows irregularities, differences in soil density, cavities etc. to be detected. It has an approximate cost of $25,000 and is used by the EPAAGE, it can be seen in Figure 4.

Figure 3. COMBIPHON Sewerin appliance
Source: COMBIPHON.

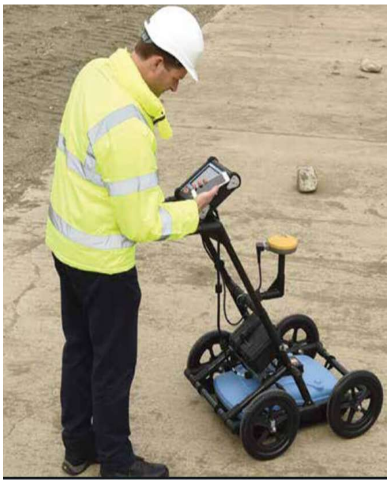


Figure 4. Georadar RD1500.:
Source: EPAAGE.

4. HYPOTHESIS

This project bases its hypothesis on sound pattern analysis that are recorded in tapping recordings in drinking water pipes, making it possible to identify the existence of clandestine water connections. The prototype is based on the idea that the sound traveling through the drinking water pipes is reflected when it reaches a clandestine connection, due to the change in the impedance of the flow, and that this sound reflection presents an acoustic pattern clearly distinguishable from the recordings emitted by legal connections.

The "low cost" prototype presented allows the detection of clandestine drinking water connections at a lower cost than other conventional equipment available on the market.

5. RESEARCH VARIABLES

5.1 Dependent variables:

- The dependent variable of this project is the classification of the existence or non-existence of a clandestine drinking water connection.

5.2 Independent variables

- The force of the machine that generates vibrations: The force of the machine has a capacity of up to 27 kg and reaches 2500 rpm in its most powerful mode.
- Sound behaviour: Pattern that can be identified in a spectrogram and analysis of the acoustic signal recorded in drinking water pipes.

6. PROTOTYPE METHODOLOGY

This project considers an experimental methodology, in which recordings are made both in clandestine connections, as well as in regular connections. The signals generated in the recording go through digital processing, with which the patterns that allow the characterization and differentiation of the two types of connections can be identified.

In figure 5., you can see the phases of the methodology followed to carry out the project.

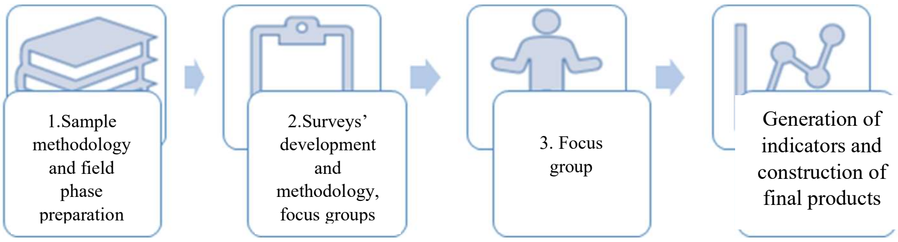


Figure 5. Phases for carrying out the project.

Source: Direct.

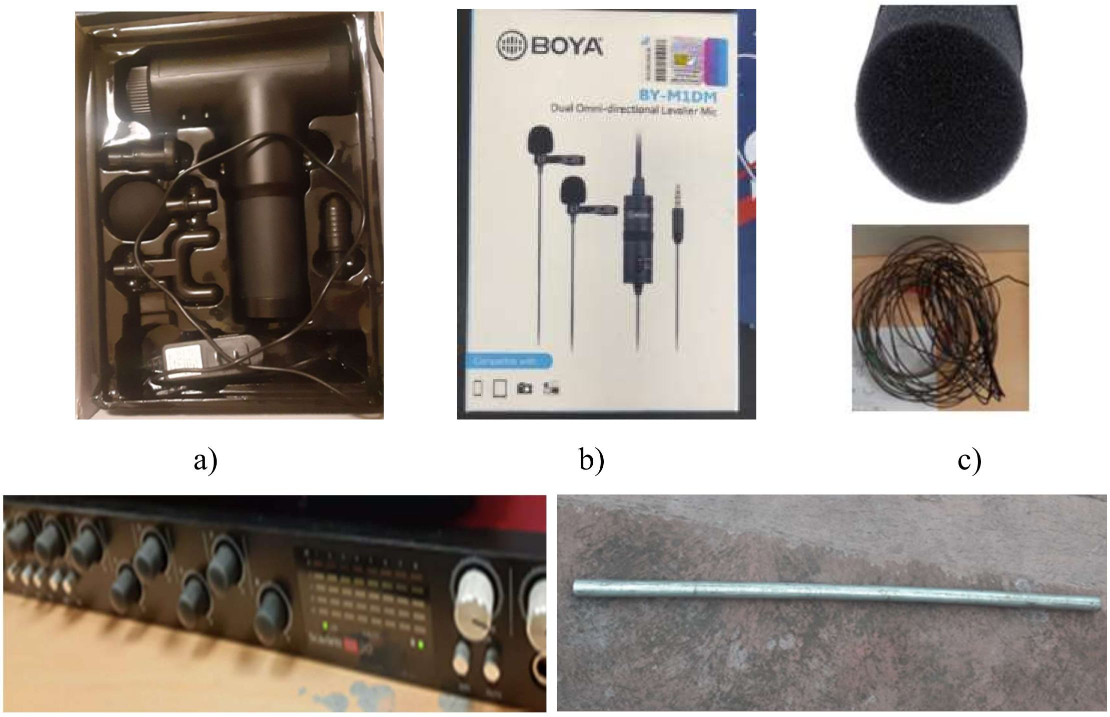
6.1 Materials, implementation and operation of the prototype

The materials of this prototype (See Figure 6.) are easy to acquire for a low cost, it consists of:

- Scarlett 18i20 interface: transforms the sound which is an energy into a binary code which the computer can understand and graph a spectrogram. Costs are approximately $17.
- Computer with REW and REAPER software: this software graphs the spectrograms generated by the beating waves, it graphs any sound picked up by the microphone, with the following calibration T1= -30.0ms - T2= 30.0ms - Frequency= 16.7 Hz (Hertz-Unit of frequency).
- 3.5 mm omnidirectional microphone: captures any sound from wherever it is generated, this is especially important to consider since they are straight water pipes and there are deviations produced by elbows or underground faucets. It has a cost of $28.
- Vibration generator: emits vibrations and generates sound waves that impact with the T or elbow that generates an echo. It has a cost of $17.
- Wire and sponge: help to dry the tube and measure its length, this length is important because it will show up if it is need to send vibrations with an special machine (more than 8 meters) or knocks (less than 8 meters) in order to receive

the ecos that will be recorder to determine if there are clandestine connections. The total cost is $3.

- 1060 Steel Tube: sends the beating so that the waves are generated. It costs $3-$8.



a) b) c)

d) e)

Figure 6. Prototype Materials:
a) Vibration generator, b) Omnidirectional microphone, c) Wire and sponge,
d) Scarlett 18i20 Interface, e) 1060 Steel Tube.
Source: Direct.

The establishment and operation of the prototype costs $600 compare with the other products available in the market, this being one of the main justifications and advantages presented by the development of the experiment that was created in an unprecedented way by the author of the project.

6.2 Assembly of the prototype

- Connect the Scarlett 18i20 power cord to a power source.
- Connect the Scarlett 18i20 USB cable to the computer.
- Turn on the computer and open REAPER and REW.
- Connect the microphone to the 1/8 input that is on the Scarlett 18i20
- Carefully remove the meter from the home without damaging it.
- Close the water stopcock.
- Insert the wire plus the sponge into the water pipe to dry and measure its length.
- Introduce the microphone to the middle of the tube or to 1/3 a third of the tube to detect the waves.
- The final assembly can be seen in figure 7.

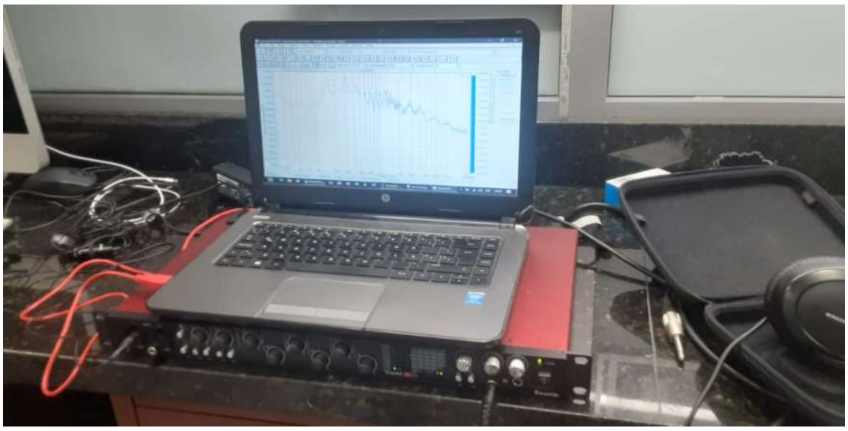


Figure 7. Assembled prototype.

Source: Direct.

6.3 Additional information required to detect a clandestine bypass connection

- Prototype “blow meter”.
- Tracing the drinking water invoices (6 months) in the drinking water invoices registered by the company.
- Permission from the authorities to visit the home.

6.4 Steps to detect a clandestine bypass connection

- Locate the meter

- Cut off the water supply to the house that is going to be registered to carry out the detection.
- Remove the entire meter without damaging the infrastructure.
- On the side where the water is supplied, which is always on the right side looking from the meter, insert the wire plus the sponge to dry up the residual water and measure the length of the tube until you feel a small obstruction.
- Enter the microphone through the already dry duct and reach with it to where the obstruction was felt.
- Open in the REW and REAPER program and proceed to record.
- Send the vibrations through the main 5 cm of the tube so that they generate sound waves.
- Record its behaviour for 3 seconds
- Perform audio to spectrogram conversion in REW.
- Perform the reading of it and determine if there are peaks or not. If the spectrogram graphic behaviour shows irregular peaks of the sound waves, it is determined that it is a clandestine connection.

Before sending the vibrations or tapping, it is necessary to ascertain the value of the tube length, for this you can use a wire with a sponge tied at the end. Insert into the tube until you feel an obstruction caused by a T of a clandestine connection. Once this point is reached, the wire is removed and measured to obtain the desired dimension.

In general, the tubes of these connections have lengths of 1.10 m, 1.20 m, 1.60 m, and the largest recorded is 2.90 m. Depending on the length of the tube, knocks (up to 1.70 m) or vibrations (greater than 1.70 m) will be sent.

Then the microphone is placed in the part of the obstruction, subsequently the recording begins, 3 seconds where 3 taps will be done each with 1 second of difference, or 6 seconds where 3 periods of vibrations will be done each with a distance of 2 seconds.

How to determine if it is a clandestine connection?

In the spectrographic reading irregular peaks are going to be seen after the blow, these are gradually decreasing because they bounce back? from the T and generate the ECHO.

How to determine that it is not a clandestine connection?

In the spectrographic reading no irregular peaks after the shock are visible because there is no T where they bounce back? and no ECHO is generated.

7. Results

7.1 Tests

After the experimental prototype assembly, it is possible to demonstrate its functionality. In the pre-experimental phase, tests were carried out on tubes of the following sizes: 80 cm, 1.00 m, 1.10 m, 1.20 m, 2.90 m, both clandestine and non-clandestine connections and a total of 160 recordings were taken into account, in order to determine differences or similarities in the acoustic patterns that allow recognizing and differentiating a clandestine and non-clandestine connection.

In figures 8, 9 and 10 the temporal variation of the sound signals can be seen which helped to differentiate a clandestine connection from a non-clandestine one, where other types of signals were also found that were produced by leaks that occur when a water pipeline has a fissure or a small rupture which causes the water to leak through that hole.

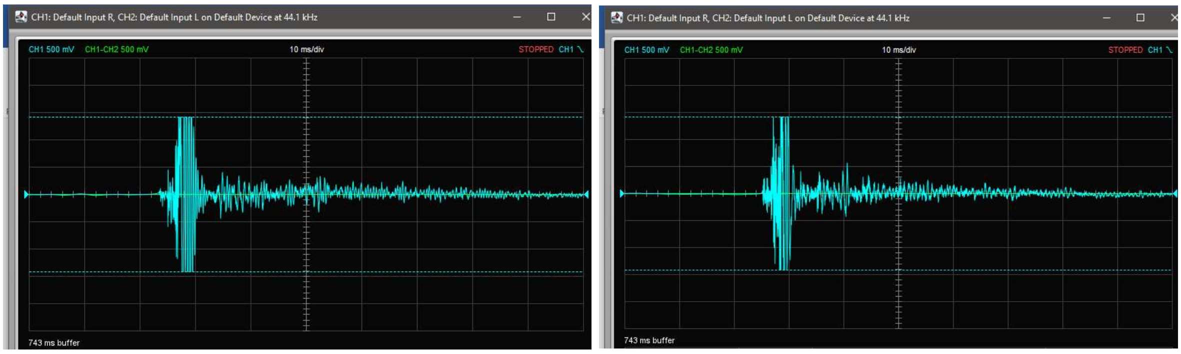


Figure 8. Sound signals of clandestine connections**. Source: Direct**

Figure 9. Sound signals of non-clandestine connections**. Source: Direct**

Figure 10. Sound signals of leaks.

Source: Direct.

Here we can see the knocking which is generated with the 1060 steel tube followed by a continuous line, this is where the water runs. A continuous line indicates a leak.

The results obtained with the prototype appliance can be corroborated through a monitoring analysis of the drinking water consumption behaviour registered in the forms of the previous months with the aim of verifying irregularities in billing.

In addition, more precise data can be verified with the echoes since it cannot be appreciated with the human ear, all combined with the previous monitoring that is carried out when paying the water bills show precise results when detecting a clandestine connection

It should be mentioned that the water in the house must be turned off to guarantee the correct function of the microphone. By using the wire and the sponge, the wastewater pipe is dried. This way, the "T" type connection can also be verified.

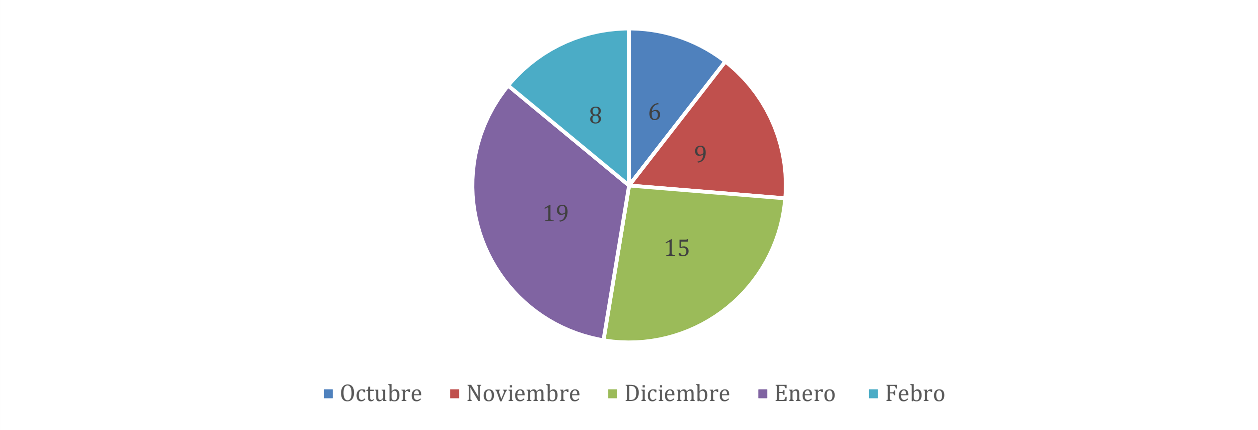


Figure 11. Number of clandestine connections detected

Example:

In the month of October 2021, the sanitation provider invoiced the amount of $35, for the month of November 2021 the amount of $20 was invoiced, for December 2021the amount of $12.50 was invoiced, for January 2022, the amount of $7.5 was invoiced and for February 2022 only the amount of $2.25 was invoiced. During this period, the same household with the same consumption was living in the house, however, an alteration with a water consumption reduction during the indicated months is observed, reflected by irregularities in billing. In this case we determine that was a clandestine connection.

7.2 Information on surveys that were carried out

To date, 57 clandestine connections have been surveyed, here is an example of where it was done (see Figure 11.):

- Route-Sector-Address: Aloasí Calle Simón Bolívar.
- Location: -0.516645, -78.584949.
- Months of Debt: 103.
- Debt: 838.16.

Figure 11. Clandestine connection notification.

Source: Direct.

7.3 Cost

The total price of the prototype reaches $600, which, compared to the cost of the products of the competitors mentioned, is viable for entities that provide drinking water services, compared to other devices such as combiphon or Georadar RD1500 with costs around $25,000.

7.4 Prototype functionality

Its functionality is 94% since there was a small leak that wettened the microphone which caused damages on 3 occasions, but its results are very effective and reliable since quality materials were used despite its low construction price.

$$\textbf{(Correct Trials)/ (Total Trials)} \times 100\% = 54/57 \times 100\% = 94.7\%$$

This Blow Meter is quite easy to assemble, its materials are easy to acquire, and it generates optimal and reliable results compared to the RD1500 georadar and the COMBIPHON Sewerin.

8. Conclusions

In the present project, it was possible to develop a prototype for the identification of the existence of clandestine water connections in the Mejía canton, through an analysis of acoustic patterns (temporary variation) generated by vibrations or knocks that allow to clearly differentiate the acoustic waves that networks of authorized and unauthorized connections emit.

It was possible to assemble the "low cost" prototype in the water meter without damage to the materials and constructions previously established for the detection of clandestine connections, which represents a significant impact on equal access to water, in this way guaranteeing the right to drinking water and sanitation, this being recognized as an essential human right for the full enjoyment of life and all human rights.

The prototype, in addition to detecting clandestine connections, can also help determine water losses such as leaks where aggravations of the prototype can be identified by its acoustic pattern that is continuous and does not bounce. This leaves a door open for future research that complements or benefits from this project.

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