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Analysis of water leak detection techniques and feasibility to implement in Latin American countries

ABSTRACT

Water scarcity as well as the difficult access to drinking water has become a worldwide problem, even in the countries with the largest reserves of this resource, such as Latin America. Not only because water sources are declining, but also because of the poor management and waste due to poor infrastructure less and less people are having access to drinking water. This paper focuses on the research and analysis of the techniques used in more advanced countries for the water leakage detection and to what extend could these be applied in Latin American countries. First, current technologies and techniques were investigated, then these were divided into two categories according to their technological degree: Low-Tech- and High-Tech-Techniques. Subsequently, two case studies were presented and used to evaluate the possible application of these Techniques in two different scenarios. On the one hand a rural environment and on the other an urban environment. With the help of a decision matrix and seven carefully chosen criteria, the proposed techniques were rated and scored, being Ground Penetrating Radar – GPR the solution which best suited to both situations while fiber optic sensors and pressure monitoring systems being the least suitable for the urban as well as the rural environment respectively. It was concluded that there is no absolute perfect solution for the water leakage detection, hence this matter could be approached from several perspectives and different solutions could be used at a time.

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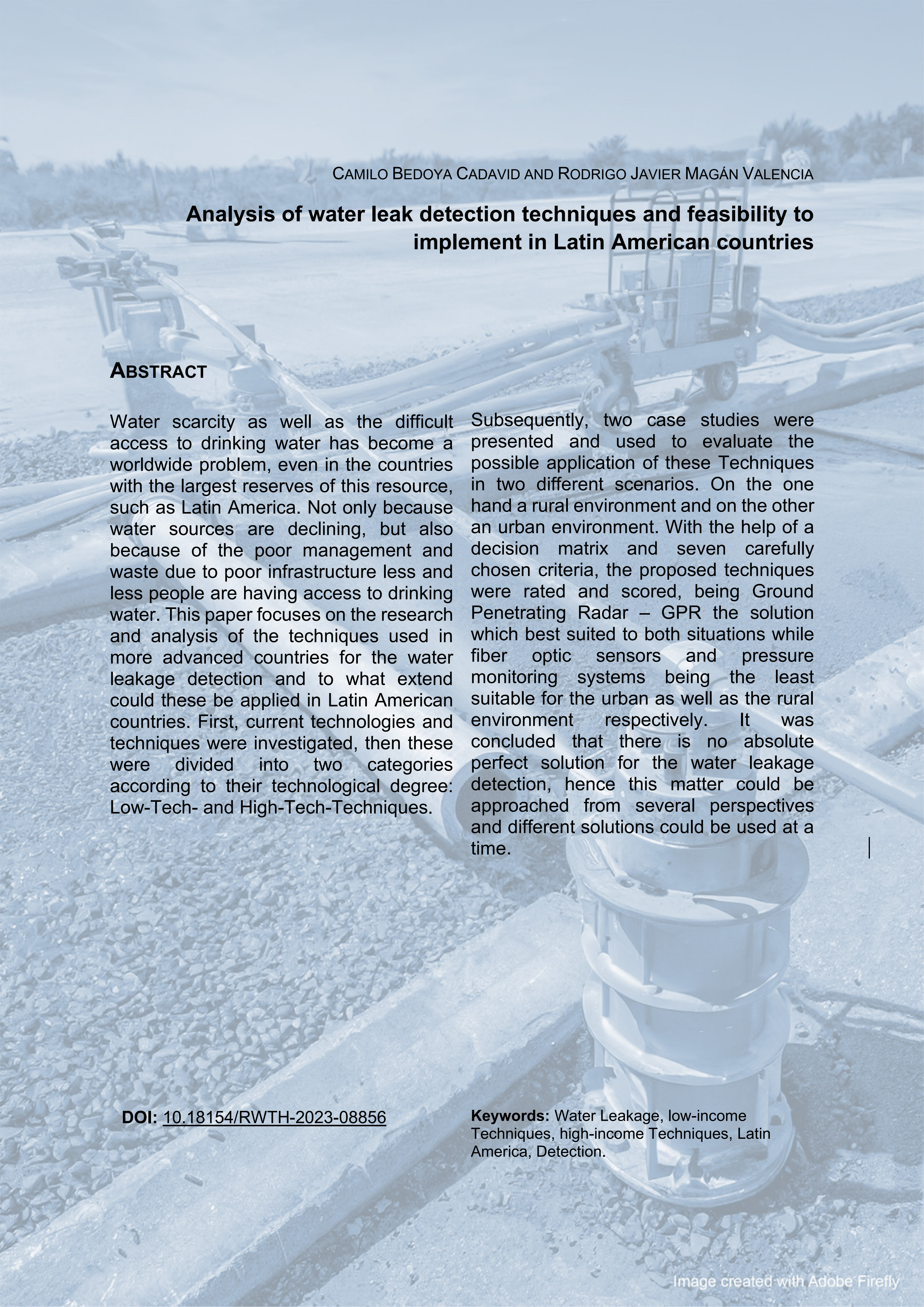
Keywords: Water Leakage, low-income Techniques, high-income Techniques, Latin America, Detection.



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1 Introduction

1.1 Motivation

"Latin America is the region with the most water sources in the world, however there are 36 million people - 6 times the total population of Nicaragua – who still lack access to drinking water." [1]

Over time, people have become more aware of the importance of water globally. Water is one of the most abundant natural resources which, at the same time, is one of the most difficult to access [1]. Even Latin American countries, thus being the region with the most water sources, are being compromised by water scarcity. There are many reasons why the access to drinking water is being affected, from global warming to lack of maintenance of piping water networks in the cities.

In this Research Paper we will focus on the second reason. Despite having plenty of drinking water sources in the region, people are unable to access this "benefit". One of the reasons why water does not reach all the people in Latin America are water leaks. For instance, Peru is the 8th country with more water sources worldwide what is more they have 1.89% of the world's drinking water. However, approximately 8 million people do not have access to this resource. This is because 70% of pumped water is lost due to leaks [2].

Yet, this type of problem does not only exist in Latin American or third world countries, but also in more developed countries such as the United States or other countries in Europe. In the United States about 10,000 gallons of water per year are wasted in homes due to water leaks and at a national level it would be equivalent to 1 trillion gallons per year. This amount could be used to supply 11 million homes [3]. On the other hand, on the European continent, countries such as Italy and Croatia are also affected, with losses of 39%, 18% and 80% respectively [4]. While these numbers are not encouraging, there are other countries that have managed to keep their statistics at more optimistic levels, such as Germany with only 5.3% or Denmark with 7.6% [4].

The worrying situation in Latin America together with the encouraging figures from some European countries motivated the authors to investigate what technologies currently exist to prevent, detect, and solve water leaks; as well as which of these technologies can be applied in "low-income countries". These technologies will be analyzed and evaluated in two possible scenarios: on the rural and on the urban area.

1.2 Methodology

The research question that guided the present paper was: How does "low-tech solutions and "high-tech solutions" in the water leak detection industry compare for rural and urban environments in Latin America. To address this question the research began with the collection of the different technologies and techniques to detect water leakage available in the market and the context of the problem across the globe. Subsequently these techniques were classified into the corresponding category: "low tech technique" or "high tech technique". To analyze the impact of these techniques the researchers propose two cases of study: a rural environment and an urban environment. After that each technique was punctuated

Techniques	**Criteria 1**		**Criteria 2**		…		**Result**	
Case of Study	**Rural Env.**	**Urban Env.**	**Rural Env.**	**Urban Env.**	…	…	**Rural Env.**	**Urban Env.**
Solution 1	1-3	1-3	1-3	1-3	…	…	1-21	1-21

Table 1. Proposed Decision Matrix

according to its performance in each of the study cases. Finally for the discussion a decision Matrix with seven criteria was created to provide an easy visualization on how suitable each technique is.

2 State of the Art

Early detection of water leaks is crucial for addressing the issue and being able to repair and maintain the water distribution network on a reliable state. Currently there are numerous water leak detection techniques in the market some make use of latest technology advancements such as artificial intelligence, fiber optic or radars and some rely on existing infrastructure such as water meters and pressure sensors. In the following section these techniques will be described to provide a foundation for the subsequent comparison

2.1 Low-Tech Technologies

Pressure Monitoring Systems

The most common sensors to monitor water systems are pressure sensors, these calculate the water pressure and its variations over time in case of a drop down in the pressure. It is known that high pressures can damage the pipes network what is more cause leaks in them, that’s why it is important to establish suitable pressure management practices [5]. To achieve this the use of sensors or pressure gauges to monitor the pressure as well as to locate probable existing leaks, furthermore the use of pressure reducers to reduce the flow of water is also important [6]. To reduce the probable area, where the leak is located sensors can be installed along the plumbing network. For example, by installing a valve (pressure sensor) in the pipe that connects the city central water supply to the house. We start measuring the water standard delivered water pressure. After this is established, we turn off or cut for a moment the water supply and let it stand for a few minutes. After this time, we can see if the pressure has changed or not, since in a closed system there should be no loss of pressure. A loss in the water pressure would mean that, somewhere inside the house, or in between the different allocated sensors, there could be a water leak or a broken pipe. If the pressure is maintained, we should check if between the main water valve and our pressure sensor there is any loss of water [7].

Water Meter Systems

One way that companies in Latin America use to measure the amount of water used in homes, is the use or installation of water meters in the main pipe, these meters control the amount of water consumed in the home to later issue a bill. Each family and/or each person can use these receipts to control their water consumption; if an unexpected difference in the monthly amount is noticed, it could mean the presence of a leak or a pipe in bad condition. While this does not reduce the percentage of water lost in a significant way, it can alert people in time to take the necessary action and avoid wasting large amounts of water and money in the long run. This type of consumption control works in one-family homes where consumption can be controlled and accounted for without any inconvenience. However, in a building with

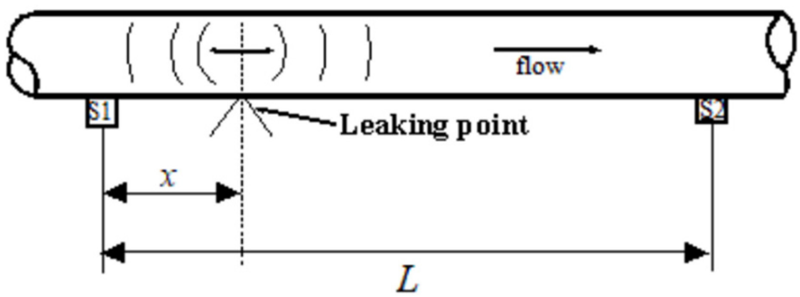

Fig. 1. Illustration Water Leak detection with acoustic sensors [11].

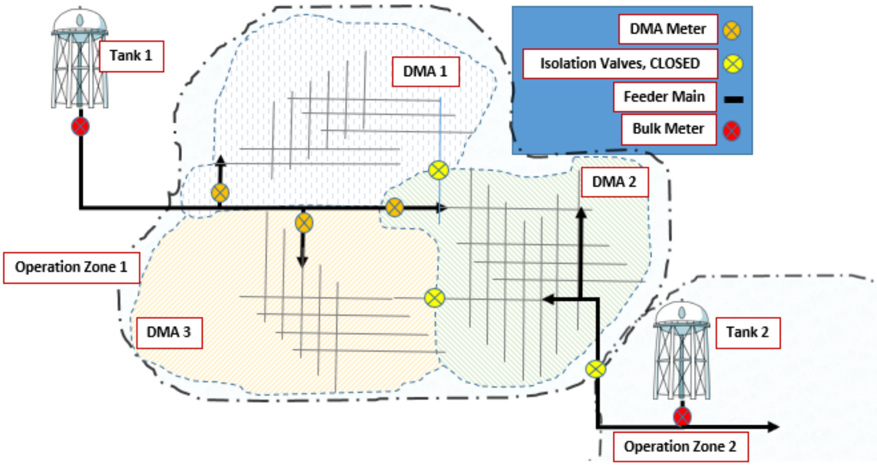

Fig. 1. Example of how a region is divided into DMAs [12].

several apartments it becomes meaningless, since it is not possible, or it would be too expensive, to install a meter for each apartment. For these cases there are other types of meters on the market that are simpler to install and do not require such a large investment, for example the DrizzleX [8].

Acoustic Methods

Acoustic methods are among the most frequently used technologies for detecting water leaks or damage in pipes. There are many operation methods to use acoustic sensors to detect leaks; there are those which are installed at fixed points along the pipe or portable ones that can be carried by an operator [9]. In both cases, the water flowing through the pipe serves as a carrier element for sound waves. Sounds along the pipes are related to different circumstances, such as material, length, or diameter of the pipe but also when a leak is present. For this reason, when the system is in optimal conditions, the waves generated usually don't make noise, which is different from those that may cause any type of damage (e.g., water leaks) [10], making them detectable by the sensors. Subsequently, when these waves spread in both directions, up- and downstream. As a result of this, with the help of mathematical models, the distance between the leak and the preinstalled, or mobile, sensors can be measured, thus helping to pinpoint the location of the leak [11].

District Metered Areas – DMAs

Leaving aside the systems for controlling water consumption in each home and concentrating on a more comprehensive way of controlling the water consumption of a country, a region or, on a smaller scale, within a city, the alternative proposed in the European Frameworks for Water Management can be used, which consists of dividing the water system network "into District Metered Areas (DMAs) by shutting valves permanently and installing meters equipped with telemetry data loggers" [4]. An extension to this is the "so-called virtual DMAs", which with the help of artificial intelligence software and monitoring and measuring the flow, consumption and pressure within a reduced space can identify the areas where excessive consumption is being generated, which can be the result of water losses [4].

2.2 High-Tech Techniques

Fiber Optic Sensors

Fiber optic is typically known as a way to transmit data (internet for example), but lately other use cases have arisen. One of this use cases is Fiber Optic sensors which are a type of sensor that use fiber optic cables to detect changes in the light transmission. A fiber optic-based sensing system operates on reflection and transmission principle, in which

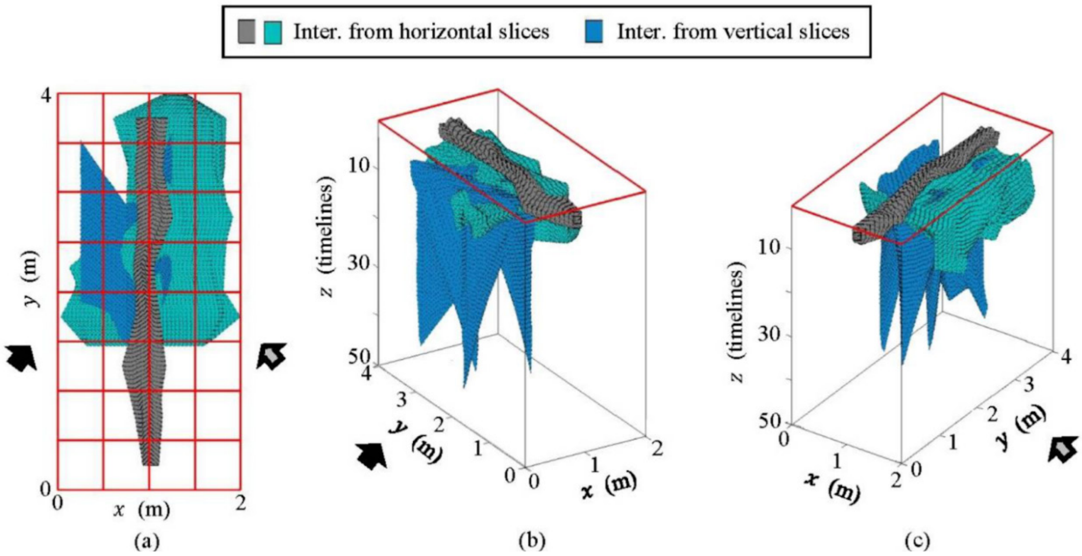

Fig. 2. 3D pipeline model generated from GPR raw images to detect leakages [14].

the fiber optic acts as a sensing component to changes in the external environment [13]. This changes in the environment can be associated to a leak in water networks. There are diverse types of Fiber Optic Sensor. For water leakage the sensor used is intensity-based sensors: These sensors measure changes in the intensity of light that is transmitted through the fiber. They are typically used to detect leaks in pipelines and other water infrastructure.

Ground Penetrating Radar – GPR

Ground-penetrating radar (GPR) is a non-destructive water leakage detection system that uses GPR images (radagrams) contrasts between the leaked water and the surrounding soil that are caused by differences in dielectric characteristics [14]. GPR works by transmitting radar waves into the ground, detecting them once they bounce back by an antenna. The time it takes for the waves to travel through the ground and back to the surface can be used to determine the depth and characteristics of subsurface features such as underground utilities, soil layers, and buried objects. In water leakage detection, GPR is used to locate, and map buried water pipes, sewers, and other underground infrastructure. The technique can be used to non-destructively locate pipes, identify their depth and size, and to detect leaks in buried water pipes. GPR has several advantages over other types of water leakage detection methods. It is non-destructive, meaning it does not damage the pipes or surrounding area during the detection process.

Machine Learning and AI

Machine learning is a branch of artificial intelligence (AI) and computer science which focuses on the use of data and algorithms to imitate the way that humans learn, gradually improving its accuracy [15]. They can be used to analyze data from various sources, such as smart water meters, drones, and ground-penetrating radar, to detect leaks in water pipes and other infrastructure more accurately.

In water leakage detection, machine learning and AI works as a compliment to process data and obtain better outputs from existing high-tech or low-tech sensors and other water leak detection systems, nowadays is commonly used for:

1. Analyze sensor data: Machine learning algorithms can be used to analyze sensor data from smart water meters, drones, and other sources to detect leaks in real-time.
2. Identify patterns: Machine learning algorithms can be used to identify patterns in sensor data that indicate the presence of a leak.

3. Predict leaks: Machine learning algorithms can be used to predict when and where leaks are likely to occur, based on historical data and other factors.
4. Optimize maintenance: Machine learning algorithms can be used to optimize the scheduling and routing of maintenance personnel, based on the likelihood of leaks in different areas.
5. Smart Water Network: Machine learning and AI can also be used to create a smart water network, where the system learns from the data and continuously optimizes the performance of the network by detecting and isolating the leaks, balancing the pressure, and predicting the future demand.

Fig. 3. A smart meter manufactured by the Swiss company Landis+Gyr [19]

Machine learning and AI are still in the early stages of being adopted for water leakage detection, but they have the potential to improve the efficiency and effectiveness of the process. In some projects already implemented it's observed reduction of around 20% in leakages [16].

Smart Sensors

Smart water meters are advanced water meters that use sensors and wireless communication to measure water usage and detect leaks in real-time. Smart water meters typically operate through reading inbuilt and calibrated magnetic pulses produced by the water meter as it turns [17]. They can also be used in water distribution systems to monitor water usage and detect leaks in large pipelines.

Smart water meters typically have the following features:

1. Advanced sensing: Takes. The sensors can detect slight changes in pressure, flow rate, and temperature that can indicate a leak.
2. Wireless communication: Smart water meters use wireless communication to transmit data to a central hub or cloud-based system. This allows the water company to monitor water usage and detect leaks in real-time.
3. Alerts: Smart water meters can send alerts to maintenance personnel when a leak is detected, which allows the water company to respond more quickly and efficiently to repair the leak.

This type of Smart Sensors is already deployed in projects worldwide. For example, the Denver's water company is already using an IOT device that connects to the current water meter sensors, to analyze and transmit data both the utilities company and the customer [18].

2.3 Cases of Study

Even though the paper is focused on the application on the before mentioned technologies in Latin American country, one more differentiation is made due to the drastic different scenarios present in the Latin American context. Therefore, this paper will analyze the water leakage detection methods previously researched and its application on two different types of scenarios, rural and urban environment which will be defined next.

Rural Environment

Rural area refers to the geographical region located outside of urban areas. It has a far lower population density than urban environments, and the Office of Budget and Management (OMB) of the United States classifies as rural any region with less than 50.000 inhabitants. In Latin America around 123 million people live in this kind of environment [20]. These areas usually are less developed than urban areas and face diverse challenges such as low investment funds which directly affects infrastructure and therefore water leakage detection programs. For rural environments the main challenges concerning water leak detection can be summed up in the following:

1. Accessibility: Many rural areas have limited infrastructure and rugged terrain, making it difficult for technicians to reach and inspect pipelines and other water systems.

2. Limited resources: Rural communities often have fewer resources available for maintenance and repair, making it harder to detect and fix leaks in a timely manner.
3. Aging infrastructure: Many rural water systems are old and have not been updated in decades, increasing the risk of leaks and making them harder to detect.
4. Limited monitoring: Some rural areas may not have advanced water monitoring systems in place, making it harder to detect leaks in real-time.
5. Lack of expertise: Limited workforce and technical knowledge can make it harder to detect and fix leaks in rural areas.
6. Low water pressure: in rural areas water pressure is often low, it can make it harder to detect leaks through pressure changes.
7. Remote location: Some rural areas may be located far from repair crews and replacement parts, making it harder to quickly fix leaks once they are detected.

Urban Environment

Urban Area is referred as the geographical region with a high-density human settlement. To be considered an urban area it is necessary to have a population of at least 50.000 people according to the OMB. in Latin America around 81.2 % of the population live in this type of area [21]. With this type of settlements many challenges arise such as the intense demand for natural resources such as clean water therefore big networks of pipe to supply this high demand make a pressing challenge for cities to detect leaks and maintain the infrastructure to guarantee its population with the much-needed resources. The main challenges of urban areas in terms of water leak detection are the following:

1. High population density: Urban areas have a high concentration of people and buildings, making it difficult to access and inspect pipelines and other water systems.
2. Aging infrastructure: Many urban water systems are old and have not been updated in decades, increasing the risk of leaks, and making them harder to detect.
3. Lack of expertise: Limited workforce and technical knowledge can make it harder to detect and fix leaks in urban areas.
4. High water pressure: Urban areas often have high water pressure, which can mask leaks and make them harder to detect through pressure changes.
5. Limited space: Urban areas are often built on limited space, which can make it difficult to access and repair leaks.
6. Noise pollution: Urban areas are often noisy places, which can make it difficult to hear water leaks.
7. Traffic and congestion: Urban areas often have heavy traffic, making it harder for repair crews to access and fix leaks in a timely manner.

3 Analysis

For the current paper, the studied technologies and techniques have been analyzed in each criterion and for each context provided. After a score from 1 to 3 (1 for poor performance, 2 for average performance and 3 for high performance) is assigned in the decision matrix in table two.

3.1 Effectiveness

Effectiveness corresponds to how well the technique helps in detecting water leaks. In the pool of techniques this paper is analyzing the effectiveness varies largely. For Urban Areas where there’s a dense network of pipes of different types, and several layers of material above the networks the most effective technology is the Fiber Optic Sensor since it’s laid across the whole network it can detect leaks of less than 1% the flow of the pipe [22], and while the congested and highly pressurized water in Urban Areas does not affect this type of systems, other lower cost systems like DMAs and conventional meters are more prone to error while trying to detect water leakages under this circumstances. For

Table 2: Decision Matrix

Techniques	Effectiveness		Cost		Human Resources		Accuracy		Ease of Installation & Compatibility		Scalability		Remote Monitoring		Results	
Case of Study	Rural Env.	Urban Env.	Rural Env.	Urban Env.	Rural Env.	Urban Env.	Rural Env.	Urban Env.	Rural Env.	Urban Env.	Rural Env.	Urban Env.	Rural Env.	Urban Env.	Rural Env.	Urban Env.
Fiber Optic Sensors	3	3	1	1	1	1	3	3	1	1	1	1	3	3	12	12
Smart Meters	3	3	1	2	1	2	2	2	2	2	1	2	3	3	12	14
Ground Penetrating Radar	3	2	2	2	1	1	3	3	3	3	3	3	3	3	17	16
Machine Learning and AI	2	3	1	2	1	2	2	2	2	2	1	2	3	3	11	14
Pressure Monitoring Systems	1	3	3	3	3	3	1	1	2	2	1	2	1	2	9	13
Water Meter Systems	3	3	3	3	3	3	1	1	3	3	2	2	2	2	14	14
Acoustic Methods	2	3	1	2	2	3	2	2	3	3	3	3	1	1	12	14
District Metered Areas	1	3	3	3	3	3	1	1	3	3	2	3	1	2	11	15

Rural Areas, while high tech solutions are still considered to be more effective, DMA and conventional Water Pressure Sensors increase their effectiveness due to the regularly lower pressure network. For both Rural and Urban environments Pressure based systems perform in an appropriate way making it the low cost best ranked alternative in for this criterion.

3.2 Cost

Cost refers to the money required for this technique to be implemented in the appropriate manner. Contrary to the previous criteria, DMA and conventional water meter sensors present as a more attractive opportunity due to the financially low cost of implementing this kind of solutions for both cases of study. For Urban Areas techniques such as Fiber Optic Sensors become very expensive due to the amount of trenching required for sensor installation and the costs associated road disturbances as a poor performer, GPR technology is also included as a low performer in this category due to the cost of the sensors and the human resource required. For Rural Areas both Fiber Optic Sensors and GPR repeat as the worst performers.

3.3 Accuracy

Accuracy is defined by how close the technique is able to the detect the actual leakage point. This is especially important in environments like Urban Cities where the space is severely limited and is necessary to pinpoint exact locations on the network to address the issue with the lowest disturbance possible accordingly GPR Systems and Fiber Optic represent the best solutions for this as they are the most accurate solutions. Smart Meters pair with AI Monitoring present an intermediate solution since the AI and Machine learning models are able to more accurately locate where the leak is, and it can be used to even predict the location of future leaks. Low-cost solutions perform poor as usually these techniques provide an approximate of the location and a visual or other type of inspection is required to accurately find the leak. Which is especially critical in cities where layers of soil and concrete cover the water network and hide leaks.

3.4 Human Resources

Human resource refers to the required technical skills of the workers to successfully implement the detection system. This is a crucial factor especially for the high-tech techniques which by being more advance require more specialized skills. Also another factor to take into account is that usually high skilled workers tend to concentrate on urban areas making the access for rural areas harder. Based on this, as seen in the table the high-tech solutions rank lower, and for the low-tech solutions which are already usually implemented they rank as high performers.

3.5 Ease of Installation and Compatibility

Ease of Installation and Compatibility refers to how easy is to install and compatibility refers to how compatible is the system with the existing infrastructure. On Ease of Installation and Compatibility low cost technologies rank best since in most cases the infrastructure is already in place, for example in the DMA technique the sensors used to track water consumption are the ones in place for billing making it a matter of adopting the appropriate procedure, for water meters in most countries it is required by law that each establishment has its own water meter to monitor consumption therefore making it easier to monitor leakages using this devices. For Rural Areas, generally can be easier to install sensors due lower density and more space availability. But can be challenging depending on the site access. GPR even being a high technology technique, presents a big advantage as there's no need for installation which makes it the easiest to implement.

3.6 Scalability

Scalability refers to the ability of the technology to expand or change depending on the requirements of the system. In the higher end of this criteria, we can find once again the GPR as it is highly scalable to run this technique due to the lack of installation of new infrastructure to monitor. Taking the example of the technology provided by the Israeli Start UP Asterra, it will be highly scalable to deploy this monitoring system as it's only required to point the satellites to the required location and analyze the data both in rural and urban areas. In the lower end for both types of environments we have fiber optic sensors, as any modification or expansion of this type of systems requires trenching, which is a very complicated process, specially in urban environments.

3.7 Remote Monitoring

High Technology solutions in both Urban and Rural environments come as the best ranked, due to the versatile characteristics it presents, mainly in terms of ease of use and scalability.

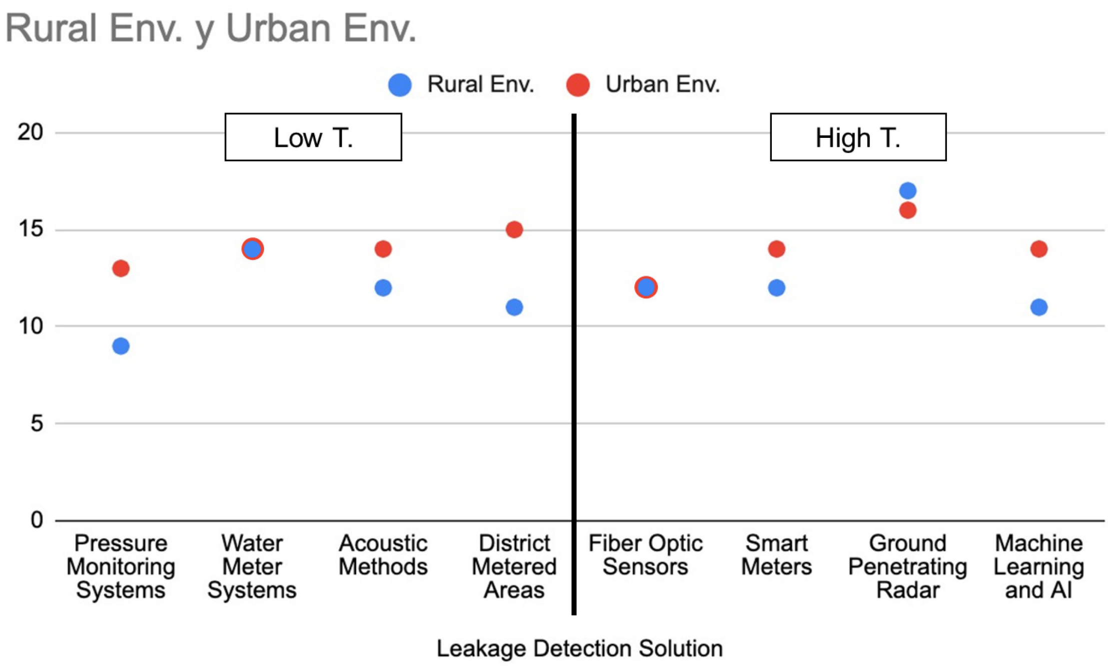

Fig. 5. Point-Distribution according to the effectiveness of each Technique in the different case of study

This criterion is specially relevant for Rural environments because this type of settlements usually lack local offices of the water companies and it's expensive to monitor the. GPR technology even though can become more expensive than the alternatives are widely adopted in high income countries and with the advancements in radar technologies costs are rapidly decreasing in the equipment area which makes it a suitable solution in the mid-term for low-income countries. While other forms of GPR like Asterra's satellites based GPR are erasing ease of implementation and scalability constraints, which could potentially be incurred in a fully automated remote monitoring system. Smart Meters are also a solution that due to its IOT capabilities provide a solid remote monitoring framework as they can directly connect to the water company systems and provide information. On the low tech solutions side water meter systems rank the highest with an average performance due to the fact that usually this are used to bill customers which means there are already systems in place to collect the data even if it's not in a real time automated way.

On the low-tech solutions, DMAs are the best solution in Urban Environments due to the high population density, which means a higher density of meters and a higher pressure in the system which are key factors for the DMAs to work properly. This solution provides developing countries with a useful and cost-effective tool to start investing in water leak detection programs, and the possibility to combine with Machine Learning and AI algorithms to detect more accurately leaks as well as to predict network behavior and preemptive maintenance. In Rural areas due to the low density of people meters and lower water pressures, Water Meter Solution becomes more relevant as it doesn't rely that much in these factors.

4 Discussion

As a fulfillment of the research question this research paper provide an overview on low tech technologies most used in low-income countries as well as the latest technology implemented in high income ones and compares their performance using a decision matrix. Furthermore, it is important to highlight that this these techniques vary greatly in the approaches to detecting leakages and as any other solution for leak detection they depend on different factors and conditions of use which means that it is always best to evaluate on a case by case basis to really be able to determine which is the most appropriate solution which usually involves a combination of systems [23].

Based on the research presented a decision matrix is presented in Table 2 and the following diagram (Fig. 5) it's possible to assess the performance across solutions and context. As seen in Figure 5 the best ranked technology for both study cases are GPR. GPR is a technology commonly used nowadays in high income countries and a series of different approaches are being developed [24]. Latest technology on GPR uses satellite images that can penetrate around 5 m underground [25] and leverages this to detect leaks in both urban and rural environments without human intervention on site, which could provide a big leap forward in terms of scalability and eliminate constraints of human resources and ease of installation especially for low-income countries in Latin America.

Also in the high technology side, Smart Meter and Machine Learning technologies are highly accurate in an urban environment inside the sensor monitored areas [26], better access to financial resources, talent, and current infrastructure, make them an attractive opportunity to start complementing current in place monitoring systems to expand their capabilities with more accurate detection and better remote monitoring capabilities. This is also suitable for a systematic phased approach where different parts of the water network are enhanced through time and therefore lowering the total initial investment cost which is usually critical in this type of projects.

For low technology approaches performances vary but are highly aided due to their low cost of implementation and generally fewer human resources are needed which makes them the default leak detection solutions used in Latin American Countries even if they are inaccurate. For example, in DMA's where machine learning methods are required to produce accurate results [27]. These approaches have been used until now, with the current expansion in Latin American urban areas and consequently the stress induced in the aging water distribution infrastructure and the scarcity of the easy access potable water resources. It is necessary to begin the transition towards a more modern leak detection infrastructure.

5 Conclusion and Outlook

This paper presented water leaks as a growing problem with some of its consequences, especially financial, in different countries around the world with the focus on Latin American countries. In addition, the techniques that are used today to detect water leaks, from the most common and simple (low-tech Techniques) to the most high-tech ones, were presented. After presenting and analyzing each one of them furthermore, later, evaluating them in 7 categories for 2 different scenarios, it was concluded that on the one hand low income countries rely on low-tech solutions for the water leakage detection due to the lack of experienced workers and the lower costs they have; while on the other hand, in more developed countries there are new technologies that could be applied even in the most rustic scenarios as in the rural areas of Latin America, for example the GPR. Furthermore, as mentioned by T. Amram, there is no unique perfect solution to mitigate water losses due to leakages, but it depends on several factors and conditions for which different solutions can be applied at the same time [23]. With the water pipeline leakage detection market in South America expected to grow from 47.31 million USD in 2021 to 72.48 million USD in 2028 [28], it would be important to further evaluate and analyze the cost-benefit of the investment in new technologies to better serve this market.

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