Integral diagnosis on the use of sustainable water treatment technologies

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Abstract. The water sector problems are framed by the low rate of adoption of technological innovation, in addition to the great environmental challenges. In Colombia, due to its topography, the provision of the aqueduct and sewerage service is difficult, causing the association of small rural communities to try to supply their need for drinking water for daily activities in a handcrafted way, this added to the increase of the limitations of the different natural resources, it becomes a challenge to guarantee the fundamental right to water and sanitation. This article, based on the UN's Sustainable Development Goals: "Health and well-being", "Clean water and sanitation", "Sustainable cities and communities, and "Responsible consumption and production" presents the results of a research carried out to validate sustainable technologies for safe water treatment systems in communities. Data were collected for a qualitative analysis through interviews applied to representative actors of the sector: water quality laboratories, aqueducts, and utility companies. The study provides information on the different needs identified for each segment, and provides information on the decisions companies make regarding investment in sustainable technologies, highlighting the existing gap in the water sector in innovation management, it presents a diagnosis on the uses of technologies on the water treatment market.

1. Introduction
Since the year 2015, the United Nations General Assembly adopted 17 Sustainable Development Goals -SDGs-. The successful implementation of the SDGs will require achieving a balance in all areas of the social, environmental, and economic pillars of overall sustainable development. These include socioeconomic progress, sustaining the planet's resources and ecosystems, combating climate change, and promoting the use of renewable energies [1]. Sustainable Development Goals assure that achieving sustainable cities must be a priority for local governments, and this responds to the need for joint work so that the SDGs of health, education, water and sanitation, peaceful coexistence, among others, are articulated in favor of human settlements. Lastly, there is a great challenge regarding the rural population, which consists of bringing public goods to them and ensuring that the State has a presence in the countryside to improve the quality of life [2]. In compliance with the national commitments on the 2030 agenda, with the aim of achieving access to drinking water in the world, the Colombian national
government set as a goal that 47 million people in the country have access to solutions that meet the requirements of drinking water, an increase of three million over what was recorded in 2018. This will guarantee the provision of water availability and its sustainable management, as well as sanitation for all people, as stated in the SDG "Clean Water and Sanitation" [3].

Innovation, in general terms, is known as an open, dynamic, multidimensional, and nonlinear activity that can improve the value of products, processes, and services through the creation, adoption, and application of new knowledge to solve needs [4]. Countries characterized by being major powers at the economic level have significant percentages of R&D&I investment, according to data published in 2018 by the Institute of Statistics of the United Nations Educational, Scientific and Cultural Organization (UNESCO) countries such as the United States report an investment percentage of 2.84% of the GDP, Canada 1.57%, China 2.19%, Finland 2.77%, France 2.2%, Germany 3.09%, Sweden 3.34%, Japan 3.27%, Czech Republic 4.81%. These figures indicate the importance of innovation for countries with highly competitive strength, while countries like Colombia report only 0.24% of the GDP in this sort of investment [5].

O'Callaghan et al. define low-end innovation as "an innovation that provides a low-cost service or product to customers who are happy with a good enough product". In their articles, they also discuss the fact that in the water sector, which is driven by regulation, there are very few opportunities for this type of innovation, in terms of complying with drinking water standards [2]. Water as a fundamental human right [6] should be guaranteed from governance policies, the provision of water and sewerage services in Colombia represents a challenge due to its topography. This added to the high rural occupation. Colombia, due to its geographic location, its orography, and a great variety of climatic regimes, is among the countries with the greatest wealth of water resources in the world [7]. Currently, a water supply coverage of 97.4% in urban areas and 72.3% in rural areas is reported [8]. In rural areas, it is common that aqueducts are the product of the association of communities to try to supply their need for drinking water for daily activities in an artisanal way. The scarcity of resources allocated to these organized communities affects their ability to provide good service. In addition to the fact that water pollution factors are diverse, for instance, the increase in the limitation of the different natural resources, the lack of knowledge of the characteristics, the composition, and the use of the water resources, and characteristics of the aqueducts, to which rural communities have access, make water quality and access to it a problem in some regions of the country, an indicator of this problematic is acute diarrheal diseases, which are the second cause of morbidity and mortality in children under 5 years of age [8].

The inclusion of sustainable technologies for the microbiological measurement of water stimulates rural and cultural participation, increases the capacity of communities to identify their needs, and promotes the appropriation of their rights and the decisions that affect their lives. The inclusion of technologies forms empowered rural citizens and helps in linking the rural and urban sectors [9]. Governance, public and private investment in water resources management, investment in infrastructure, and provision of water-related services can generate and support employment in all sectors of the economy. Consequently, the lack of investment in water management can lead to an economic slowdown [10]. Despite the fact that the water sector has great potential and opportunities to deploy and innovate in new technologies, it is characterized by having a low adoption rate of innovation and technology compared to other sectors due to its conservative nature [4]. O'Callaghan et al. argue that the water sector is a market area in which creating innovation would help to unlock demand, satisfy an unmet need, and solve an unsolved problem [4], and this in the face of major environmental challenges that frame the issue of innovation.

Investments in safe water and sanitation have high rates of return: for every dollar invested, the World Health Organization (WHO) estimates a return of between $3 and $34 dollars, depending on the region and the technology [10]. Therefore, giving the safe water service provision a market-based approach
changes people's consciousness, as there is dissension when something is obtained "for free" to receive "something valuable", to when people pay for goods and services [11]. Such market-based approaches differ from poverty alleviation initiatives based on government grants, subsidies, donations, and philanthropic contributions because when people pay for goods and services they become aware of their value [12] and are motivated to use it and maintain it more carefully. Structuring the service through innovative business models would resettle a major shift to unlock private investments, allowing the water sector to become more independent from donations, government subsidies, and philanthropic efforts [11]. It is important to emphasize that "regarding the term business is not meant to imply that the business models are only useful for organizations aiming at economic goals. They are also relevant for organizations trying to maximize public welfare (or social value)" [11].

This article presents a comprehensive diagnosis of the current situation of water utility companies in Colombia and laboratories dedicated to the measurement of microbiological water quality, to understand the gap in relation to the inclusion of new technologies in the sector. The objective of the research was to find in the study segments the perceptions they have about the processes related to the microbiological quality of water, in order to capture their knowledge in the introduction of innovative technologies that maximize the efficiency of their processes, allowing in turn to evaluate the state of innovation in the sector.

2. Methodology
The methodology research used is based on qualitative analysis, which focuses on the characteristics of language as communication with attention to the content or contextual meaning of the text [10]. Robert Yin points out that the case study as a qualitative research strategy is suitable: "for dealing with a technically distinctive situation in which there are many more variables of interest than data; the outcome is based on multiple sources of evidence, with data that must converge in triangulation; and also, the outcome benefits from the prior development of theoretical propositions that guide data collection and analysis" [13].

The study was carried out in Colombia, specifically in the region of Antioquia because, according to the census conducted in 2018, it is one of the areas with greater coverage in the provision of water service with a percentage greater than 90% in rural and urban areas. Based on discussions with a panel of experts, it was determined that efforts would focus on two big segments related to the importance of the microbiological quality of water. The first big segment is related to water utility companies, which in turn has an internal classification according to the number of users they serve: The first internal classification is service providers with 5,000 users or less; this classification also defines the sampling frequencies established in resolution 2115 of 2007. On the other hand, small service providers are characterized by their artisanal processes and small budget. The second internal classification corresponds to large providers, with 5,001 users or more, these are more structured companies, which focus their efforts on complying with current governmental standards on microbiological water quality. The second big segment corresponding to laboratories that measure the microbiological quality of water is subdivided into public and private laboratories, and regional autonomous corporations. The latter are public corporate entities, integrated by territorial entities, in charge by-law of managing renewable natural resources, the environment, and promoting the sustainable development of the country. Resolution 2115 of 2007 establishes the Water Quality Risk Index (IRCA) through which the results of water samples for consumption are evaluated and the sampling frequencies are defined according to the type of supplier.

For the collection of information, we selected a group of laboratories, utility companies, and aqueducts that have influence and relevant work experience in the microbiological measurement of water in Colombia. We used a survey instrument with open questions. The interviews were carried out with 20 key actors belonging to water utility companies and microbiological water measurement
laboratories. The interview consists of 15 open questions grouped in 2 blocks: first, the technical aspects of the service they provide, their main works, and difficulties regarding microbiological water quality tests. Questions such as the parameters used for the measurement of E. coli, how long it takes certified laboratories to deliver the results of the tests they perform, considerations about the time and frequency of measurements, among others, were asked. The second block considers the administrative aspects related to the purchase of equipment and supplies, as well as the contracting of services for the analysis of the microbiological quality of water, logistics, and communication. We also inquired about other aspects such as sampling times, difficulties in the market for the purchase of equipment and supplies, knowledge of existing methods and technologies for the measurement of E. coli, conditioning criteria in their purchase decisions, and motivations for the purchase of new equipment. Stakeholders were contacted by email, and then the interview was conducted through virtual platforms.

The analysis of the information obtained from the interviews is linked to a process of extracting meaning. The frequency of words used by the interviewees that enunciated similar ideas was evaluated, facilitating categorization and increasing objectivity for the construction of quantitative data. The responses varied in length, so it was necessary to simplify them in order to code them, even though they were in a wide range of variation, the codes were defined as the indicators and variables of the responses of the interviewed segments. These in turn were classified in a general way according to their themes, and 30 codes were obtained for the utility companies. Such codes were divided into 10 themes; as for the laboratories, 37 codes were obtained, and these were divided into 12 themes. In this paper, we will focus on analyzing the costs and delivery times of microbiological water tests.

3. Results and discussions

For the segments interviewed it is not only important that the water consumed by their users has no turbidity or is tasteless, which are two of the main characteristics that humans try to identify in order to consume or not water from a natural source or distribution network, they also state that it is important to know the quality at the microbiological level to provide a safe service to the communities served. When asked whether or not they carry out water quality tests, 100% of the stakeholders answered affirmatively. They recognized that tests for the identification of E. coli are the most important in terms of the responsibility of providing safe water for human consumption, stating that it is a pathogenic microorganism that indicates contamination of fecal origin, in addition to the fact that carrying out these tests is a regulatory requirement in Colombia. One of the interviewees pointed out that "Early diagnosis can avoid public health problems, when E. coli bacteria are present in a sample it means that it is likely that there are other pathogens that are not easy to identify in a laboratory".

3.1. Technical aspects

In Utility companies and aqueducts interviewed, there is a variety of sampling frequencies for E. coli testing, smaller companies may have from one to three sampling points and test the water quality every month or every six months, making it difficult for them to guarantee high-quality services. This may put the communities they serve at risk. The most structured water companies can take samples at six to ten sampling points at each stage of the water treatment process and take samples every hour for physicochemical properties. The highest frequency presented by the interviewees for microbiological tests is three to four times per week, even so, the most common response among the interviewees, which corresponds to 40%, was a sampling below 2 to 3 times per month.

This is the case for rural aqueducts, see Figure 1. Furthermore, with a value corresponding to 10%, we found that in these rural aqueducts, in some cases, sampling frequencies were of six months or more, which is out of compliance with the standard regulations. These low sampling frequencies are due to the remote location of some of the companies interviewed, the limited availability of sampling services, and the scarcity of economic resources.
Figure 1. E. coli test frequency - Aqueducts and Utility Companies

Figure 2 shows that 90% of the laboratories perform E coli testing on a daily basis, with a range between 200 and 1500 samples per month, while the remaining 10% are laboratories that can perform less than 200 samples per month.

Figure 2. E. coli test frequency – Laboratories

Time is a determining factor for utility companies in providing a quality service, since water is in constant movement through the distribution networks, having prompt results on the microbiological quality of the water reaching the communities facilitates timely decision making. Figure 3 shows that 30% of the utility companies obtain results within the first 3 days, emphasizing that one day is the minimum time in which they receive an alarm indicating the presence of bacteria. Another 60% obtain results in a range between 3 and 5 days. The remaining 10% obtain results in 30 days or more, as they depend on the service provided by the regulatory entity to ensure that they are complying with the regulations since they are the companies with the most difficult access and the fewest resources.
Figure 3. Time to utility companies can obtain E. coli test results

The laboratories interviewed stated that, given the methods approved by Colombian regulations, they are not able to deliver results to their clients in less than 18 hours, as shown in Figure 4.

Figure 4. Time to laboratories delivers E. coli test results

The techniques approved for microbiological analysis in Article 11 of Resolution 2115 of 2007 are Membrane filtration, Enzyme substrate, Defined substrate, and Presence-absence. With the first three of these techniques performed by certified laboratories, it is not possible for them to determine the real count of E. coli until after 18 hours, making it difficult for their clients to make decisions. The longer the delivery time for results, the longer the companies lose the ability to guarantee a reliable and safe service for their users. In Figure 5 are the results of the qualitative analysis of the companies interviewed in relation to the results delivery time. It is observed that 60% of the companies interviewed consider these times as "normal", a perception associated with the inexistence of faster-approved methods and not having comparative indicators. There is conformity and adaptation to these times without leaving aside the concern about the health of the communities served. When there are cases where they exceed 15 days, the interviewees perceive it as "extremely long", since they cannot respond or take timely corrective actions to questionable water quality events.
Figure 5. Utility companies and aqueducts time perception of E. Coli test results

Figure 6, corresponding to the laboratories, shows that 50% of those interviewed stakeholders qualify the time to deliver E. coli test results as long, while 30% qualify it as normal. According to them, the time depends on how long the microorganisms take to be cultured, therefore, the time with the methods approved in the Colombian regulations cannot be shortened. To issue an official report, laboratories can take up to 5 days, although they state that the first step after 18 hours of incubation is to alert their clients when there is a sample with E. coli present via e-mail.

Figure 6. Laboratories time perception of E. Coli test results

3.2. Administrative aspects
In Figure 7, on utility companies, different factors associated with their capabilities were highlighted. For this segment, the cost was the most frequently mentioned factor, followed by the detour of government funds that serve as support for these institutions. The interviewees state that their income is mostly the payments made for the provision of the distribution service. The investment of these funds is mainly focused on maintenance, payroll, and other factors required to comply with the necessary measures to continue operating. Their resources are limited, which hinders the possibility of acquiring new technologies. In addition to this, new capabilities must be acquired within the institution for the management of these technologies, such as personnel, training, infrastructure, among others, which would be added to the acquisition costs. Thus, cost becomes the most relevant factor for this segment. Although they are aware of their limitations, they express a high interest in acquiring new technologies
if there were financing plans and government aid, because for them, having these resources would increase their production capacity and improve the services they currently provide.

**Figure 7. Limitation factor for utility companies in purchasing new technologies**

The limitations of the laboratory segment, as shown in Figure 8, is that they do not identify cost as a limitation; they state that the technology acquired must maintain a cost/benefit ratio for their institution. The most frequent limitation for the group of interviewees is the importance of the methods being accredited and standardized according to current regulations, otherwise, they would not be able to use them.

**Figure 8. Limitation factor for laboratories in purchasing new technologies**

### 4. Conclusions

The research carried out allowed us to know the current situation of utility companies and laboratories regarding the microbiological quality of water, through interviews conducted in the department of Antioquia. Despite the wealth of water resources, water quality is a problem in Colombia. The communities organized for the provision of safe water distribution services do not have sufficient
economic support from governmental entities, nor a sufficient budget, which results in the provision of limited service and the lack of innovation processes. Our study shows that there is a gap in the inclusion of new technologies in the water market, which does not allow improving the existing processes in the value chain of microbiological water testing. The methods currently approved by the regulations in Colombia are not efficient, and this is reflected in the dissatisfaction of utility companies with the delivery times of E. coli test results. It is imperative to make a change to unlock more efficient processes that allow the institutions involved to manage their knowledge and improve their competitive capacity. New technologies that are directly associated with E. coli testing in a shorter time and at an affordable cost would allow the interviewed segments to provide a better service in terms of monitoring and controlling the water consumed by people. Laboratories could deliver faster, more efficient, and reliable results, allowing service providers to make quick and timely decisions in the distribution network of their customers, generating confidence and improving the satisfaction of the users served. Likewise, the insertion of new technologies for water monitoring that is portable, sustainable, and efficient in areas of difficult access would allow radical changes in the quality of life of these communities. Changes such as the reduction of gastrointestinal diseases that cause deaths in children under 5 years of age. At the same time, the inclusion of such technologies in rural areas would increase their capacity to identify needs and make decisions and would enable them to ensure their right to water.

Access to safe water has a challenge that involves the conformation of more solid cost structures for stakeholders, unlocking private sector investments through the creation of inclusive business models that ensure profitability and, at the same time, access to people to this fundamental right to safe water and sanitation. The confirmation of such structures implies the development of competencies within the organizational structures that allow the creation of value propositions, and build capacity for the inclusion of innovation, helping to improve their competitive capacity at a national level.

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References
[1] S. Lamichane, G. Egilmez, R. Gedik, M.K. Bhutta, and B. Erenay. Benchmarking OECD Countries’ Sustainable Development Performance: A Goal-Specific Principal Component Analysis Approach. J Clean Prod; (xxxx):125040, 2020.
[2] F. Herrera Araújo. ODS en Colombia: Los retos para el 2030 [Online] Programa de las Naciones Unidas para el Desarrollo -PNUD-. 2018. p. 74. Available at: https://www.undp.org/content/dam/colombia/docs/ODS/undp_co_PUBL_julio_ODS_en_Colombia_los_retos_para_2030_ONU.pdf (in Spanish).
[3] DNP. No Title [Online] 2020. Available at: https://www.ods.gov.co/es/objetivos/agua-limpia-y-saneamiento.
[4] P. O’Callaghan, L.M. Adapa, and C. Buisman. How can innovation theories be applied to water technology innovation? J Clean Prod 276:122910, 2020. https://doi.org/10.1016/j.jclepro.2020.122910.
[5] UNESCO. R&D Spending By Country; Available At: R&D Spending By Country, 2018.
[6] ONU. Resolución 64/292. El derecho humano al agua y al saneamiento Vol. 1, Asamblea General de las Naciones Unidas. p. 3. [Online] 2010. Available at: http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/64/292&Lang=S.
[7] MAVDT. Política Nacional para la Gestion Integral del Recurso Hídrico. Vol. 1, Colombia, Ministerio de Ambiente, Vivienda y Desarrollo Territorial. 124 p., 2010 (in Romanian)
[8] de Salud IN. Situación de la enfermedad diarreica aguda en Colombia. Instituto Nacional de Salud. 2020 (in Spanish).
[9] Ashifa KM. Modelling of community service projects for rural technology implementation. Mater Today Proc; (1) 2020. https://doi.org/10.1016/j.matpr.2020.08.535.
[10] WWDR. Informe de las Naciones Unidas sobre el Desarrollo de los Recursos Hidricos en el Mundo 2016 - Agua y empleo. p. 164, 2016 (in Spanish).
[11] H. Gebauer, and C.J. Saul. Business model innovation in the water sector in developing countries. Sci Total Environ; 488–489(1):512–20, 2014. http://dx.doi.org/10.1016/j.scitotenv.2014.02.046.
[12] T. London, and S.L. Hart. Reinventing strategies for emerging markets: Beyond the transnational model. J Int Bus Stud; 35(5):350–70, 2004.
[13] R. Yin. Case study research: design and methods. Vol. 5, Sage Publications. 183 p., 2003.