The Business Model as a technique for problem identification and scoping: a case study of Brazilian drinking water quality assessment sector

de Souza, F. H., Silva, F. L., McGoran, C., Rondon-Sulbaran, J., Byrne, J. A., Brennan, M., & Sabogal-Paz, L. P. (2023). The Business Model as a technique for problem identification and scoping: a case study of Brazilian drinking water quality assessment sector. *Water Practice & Technology*, *18*(8), 1839-1852. Advance online publication. https://doi.org/10.2166/wpt.2023.107

Published in:
Water Practice & Technology

Publication Status:
Published online: 11/07/2023

DOI:
10.2166/wpt.2023.107

Document Version
Publisher's PDF, also known as Version of record

Uncorrected Proof

Water Practice & Technology

Water Practice & Technology Vol 00 No 0, 1 doi: 10.2166/wpt.2023.107

The Business Model as a technique for problem identification and scoping: a case study of Brazilian drinking water quality assessment sector

Fernando Hymnô de Souza[a], Fernando Lindo Silva[a], Caroline McGoran[b], Janeet Rondon-Sulbaran[c], John Anthony Byrne[d], Michael Brennan[b] and Lyda Patricia Sabogal-Paz[a,*]

[a] Department of Hydraulics and Sanitation, São Carlos School of Engineering, University of São Paulo, Avenida Trabalhador São-Carlense 400, Zip code: 13566-590, São Carlos, São Paulo, Brazil
[b] Department of Management, Leadership and Marketing, Jordanstown campus, Ulster University, Shore Road, Newtownabbey, Co. Antrim, BT37 0QB, Northern Ireland, UK
[c] Faculty of Humanities and Social Sciences, Research and Innovation Office, University of Portsmouth, Park Building. King Henry I Street, Portsmouth PO1 2DZ, Hants, UK
[d] School of Engineering, Jordanstown Campus, Ulster University, Shore Road, Newtownabbey, Co. Antrim, BT37 0QB, Northern Ireland, UK
*Corresponding author. E-mail: lysaboga@sc.usp.br

LPS, 0000-0003-2753-3248

ABSTRACT

In this case study, a Business Model Canvas (BMC) was used as a technique for problem identification and scoping for the introduction of a new technology or methodology for water quality assessment. Therefore, information about the Brazilian water supply sector was used for the application of a BMC based on technological innovations for coliform analysis. The innovations proposed in the study include faster results, internet connection, and portability. To populate the model, data regarding the drinking water quality from Brazil were used from public data banks and reports. Also, a group of accountable representatives from diverse water supply systems and water quality laboratories reported their experience with the new coliform analysis and their perception of its technological improvement. The major gaps identified in this study were simplicity and faster results. These may be associated with technological improvements such as portability and internet connection. It was possible to conclude that the segment is diverse, and the BMC highlighted that value might differ for different niches. The results emphasized that the application of a BMC may be more than a business tool. It can also be used by developers or scientists to understand and improve both, technology concepts and applications.

Key words: Business Model Canvas, coliform analysis, drinking water, technological innovation, water safety

HIGHLIGHTS

- A Business Model was applied to structure coliform analysis in drinking water.
- Characteristics of water supply systems influence value proposition priorities.
- Legal demands have influences in different levels and applications.
- Technological innovation and advantages alone may not fit customer needs.
- Information gathered reveals a technological gap in coliform analysis.

1. INTRODUCTION

Unsafe water sources are more susceptible to microbiological contamination and, when coupled with poor sanitation, serve as the primary cause of a plethora of waterborne diseases (WHO & UNICEF 2017). Microbiological contamination in water is typically detected through the presence of coliform bacteria, as these bacteria can easily survive and grow in water. While total coliforms are considered a disinfection indicator, *Escherichia coli* is a more specific indicator for faecal contamination. To ensure the safety of drinking water, the World Health Organization (WHO) guidelines recommend the absence of coliforms (WHO 2017).

In order to ensure high-quality results in microbiological analysis performance, it is imperative to exercise specific care in certain aspects, such as sample preservation, flask preparation, and residue management. These measures are essential to avoid sample and environmental contamination. Unfortunately, the resources to maintain these standards may be scarce where they are needed (UNICEF 2019). Meanwhile, the WHO

(WHO 2017) recommends using secondary measurements, such as turbidity and disinfectant residue for water quality assessment due to their straightforward nature and ease of implementation. These methodologies provide fast result reports, straightforward interpretation, and portable devices that are already available in the market for evaluation *in loco*. Therefore, the rapid detection of *E. coli* contamination is a pressing concern, as current reference methods for continuous monitoring typically require a minimum of one day to produce results. This presents a significant gap in coliform analysis technologies and ultimately jeopardizes the biological safety of water (APHA 2017a; UNICEF 2019).

Likewise, a preventative approach for hazard prevention and control is highly desirable in the Water Supply System (WSS), as proposed in water safety plans (Brasil 2012; WHO 2017, 2005). In those systems, the critical control points become the monitoring points where hazards may turn water harmful to consumers' health. Monitoring those points efficiently is important since contamination has higher health risks, therefore, frequent and faster results may be advantageous (Brasil 2012; Kanakoudis & Tsitsifli 2017; WHO 2017).

Furthermore, several technological innovations have been taking place in different fields, but their application may not be evident in the water quality assessment sector. A promising example is the so-called 'Internet of Things' (IoT), which may use internet-connected devices for remote monitoring or control. In the water assessment sector, equipment using IoT has been suggested to improve real-time monitoring, data trend analysis, and anomalous events detection at lower costs (Moodley & van der Haar 2019; Ahmed *et al.* 2020; Bria *et al.* 2020).

Introducing innovations or technologies that are considered innovative may pose a challenge in the target market (Sousa-Zomer & Cauchick Miguel 2018; Elmustapha & Hoppe 2020). Business Model (BM) studies have been proposed to drive innovation and facilitate the introduction of technology aimed at breakthrough improvements in the water sector. These studies encompass various aspects, including financial sustainability, sustainable transition, participatory approaches, and inclusive technology access. Consequently, implementing these improvements has the potential to enhance water quality and safety (Gebauer & Saul 2014; Elmustapha & Hoppe 2020; Rossio & Seo 2020). In order to achieve this, inclusive participation has been identified as a valuable approach to innovation, necessitating careful consideration of the water sector's own BM and the incorporation of innovative practices to ensure its long-term sustainability (Gebauer & Saul 2014; Rossio & Seo 2020).

In this study, a BM technique, the Business Model Canvas (BMC), was used as a tool to identify and scope problems in the water sector related to microbiological analysis considering the following key innovation aspects: faster results, portability, and internet connection. With this purpose, a case study on the Brazilian drinking water treatment sector was undertaken to: (i) identify technological gaps in the water biological analysis techniques and how they could satisfy the needs of the water sector companies (total coliforms and *E. coli*); (ii) feature Brazilian market segments for technology upgrades, based on the characteristics of water assessment companies; and (iii) analyze the logistics of current biological analysis implementation in the Drinking Water Supply Sector and how they impact on technology.

2. METHODOLOGY

2.1. Applying the BMC

The pains and gains approach of customers was used to design the BMC, with certain value propositions pre-established, such as those related to innovation in faster results, IoT, and portability. Therefore, the BMC was developed from right to left (Figure 1).

The right-hand side of the BMC incorporates the value, an evaluation considering the customer's point of view, and a diagnosis of coliform indices in Brazilian drinking water. Pains and desired gains of customers were discussed with accountable representatives from the WSS for an empathetic approach to the problem (Osterwalder & Pigneur 2013). These modules were used to understand the segment market, how a new technology could solve problems of the potential customer, and, eventually, form a suitable value proposition. It was expected that all these data could highlight Brazilian market segments for technology upgrades, based on the characteristics of the water assessment companies.

The analysis presented here is grounded in the introduction of technology. Therefore, the proposed technological improvements were initially used as a value proposition to initiate discussions regarding performance and novelty. Subsequently, insights from customers and public information were incorporated to address the

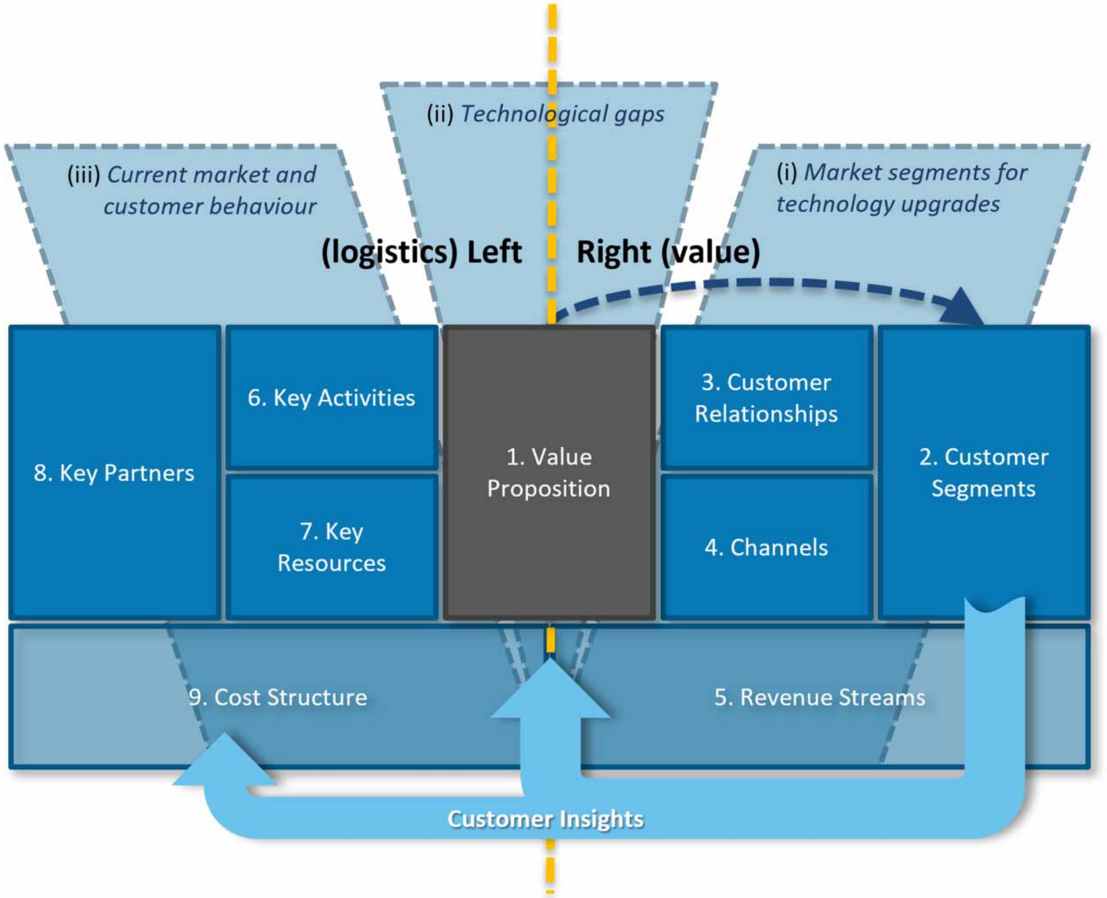

Figure 1 | BMC structure and the study case approach for problem identification and scoping.

identification of technological gaps in water biological analysis techniques and how they can meet the needs of water sector companies.

The left-hand side modules in the BMC pertain to the logistics associated with the value proposition. In this context, logistics information was examined through examples derived from the interviews, offering potential avenues for further research in this specific market. Despite the availability of alternative options for coliform analysis in the market, insights gathered from the Water Supply Companies (WSCs) were used to frame the logistics of the current implementation of biological analysis in the Water Assessment Sector and explore how they can influence technological advancements.

These descriptions were obtained by gathering and discussing information about water assessment in Brazil, including the characteristics of the WSS and coliform monitoring practices. To achieve this, data from two Brazilian databases were used (the Drinking Water Quality Surveillance Information System [Sisagua] and the National Sanitation Information System (SNIS). In addition, representatives from WSCs and laboratories were interviewed for more detailed insights. It was expected that by structuring the BMC in this manner the identification of the problem and the scoping for technological implementation in the water assessment sector could be facilitated.

2.2. The case study framing

Technological improvements or new technologies may not always be applicable in real-world settings. Conversely, certain segments may remain unaware of such new or unconventional technologies that are not commonly used in their specific context. Despite advancements in water quality monitoring, a lack of coliform analysis persists. This deficiency can be attributed to methodological limitations in the analysis, including time-consuming result acquisition, potential sample contamination, and complexity in the use of specialized equipment (UNICEF 2019).

Although new methodologies for coliform analysis have been proposed, incorporating technological advancements like the IoT and *in situ* analysis (remote monitoring) can significantly enhance water analysis by reducing time requirements. However, it is worth noting that the benefits of these combined improvements may not be immediately apparent to users, as they are more evident to developers and researchers.

In this case study, it is believed that a new perspective in the application of new technologies may help to identify and scope a problem from an innovative point of view, and possibly highlight well-known problems with potential innovative solutions. In light of this, a BM focusing on the introduction of new technology for coliform analysis of water at WSSs is proposed in the Brazilian context. This BM serves as a tool for identifying and scoping general problems in this domain.

Total coliforms and *E. coli* were chosen as indicators in this study due to their ability to reflect the biological efficiency of water treatment processes, their indication of potential faecal contamination in water, and their use as biological indicators. The proposed new technology is based on three key principles: rapid results, portability, and internet connectivity (IoT). This proposition draws on the existing literature and current practices in coliform analysis, as well as the application of new and conventional technologies used for monitoring other fundamental water quality parameters. These concepts were implemented in the *SafeWater Project Translate*. To provide structure to the BM derived from target customer insights, a BMC was used to identify opportunities for technological enhancements and the creation of value (Osterwalder & Pigneur 2013). Finally, the BMC proposition was developed, considering the discussion and findings from the study, and analyzing them to pinpoint actual gaps and problems related to coliforms water monitoring in the Brazilian context.

In this case study, WSSs were considered the main customers for the technology. WSSs serve a significant portion of the population and are required to monitor regularly the microbiological quality of water. This makes them an ideal target for the scalability of new technology (Brasil 2021a; SNIS 2021). Therefore, representatives from various WSSs were invited to participate in interviews to contribute relevant information about water assessment practices within their respective systems.

2.3. Public water quality data assembling

For the quantitative analysis, data from two sources, SNIS and Sisagua, were used to gain an overview of WSC administration with a specific focus on coliform analysis. To provide a comprehensive understanding, certain data directly extracted from SNIS 2019 were referenced and discussed, as well as the last SNIS official diagnosis report (SNIS 2021a). Additionally, data from the SNIS (2019) publication and a 5-year period (2016–2020) of available from the Sisagua database were processed, organized, and analyzed to enhance the analysis (Sisagua 2021; SNIS 2021). A positive index was calculated by determining the ratio of surveillance samples yielding positive results and the total number of samples, expressed as a percentage.

2.4. WSS' accountable and water quality laboratory interviews

To ensure a comprehensive understanding, meaningful discussion, and model consistency, a diverse group of accountable and independent water quality laboratories (WQLs) from different WSSs were interviewed. WQLs were specifically invited due to their involvement in coliform analysis, as certain WSSs rely on their services for this purpose. This approach aimed to incorporate the perspectives of users, considering their experiences, needs, concerns, and aspirations (Osterwalder & Pigneur 2013).

The diversity in the group was determined by the type of administration and population being assessed. This latter is directly linked to the number of samples of water for total coliforms and *E. coli* analysis per year (Brasil 2021a). The responses to the main questions and the relevant discussions were transcribed. The information gathered from the responses and the public data analyzed, was cross-referenced, forming the basis for the analysis presented in this case study.

3. RESULTS AND DISCUSSION

3.1. Context of coliform analysis of drinking water in Brazil

Overall, there are differences in positive results indexes for different Brazilian states (Figures 2 and 3(a)). Positive indexes for total coliforms (Figure 2) and *E. coli* (Figure 3) ranged from 6 to 68% and 1 to 35%, respectively. It can be observed that over the years the number of results available in the system increased, although positive indexes remained stable (Figures 2 and 3(d)). This highlights how important biological monitoring and technological

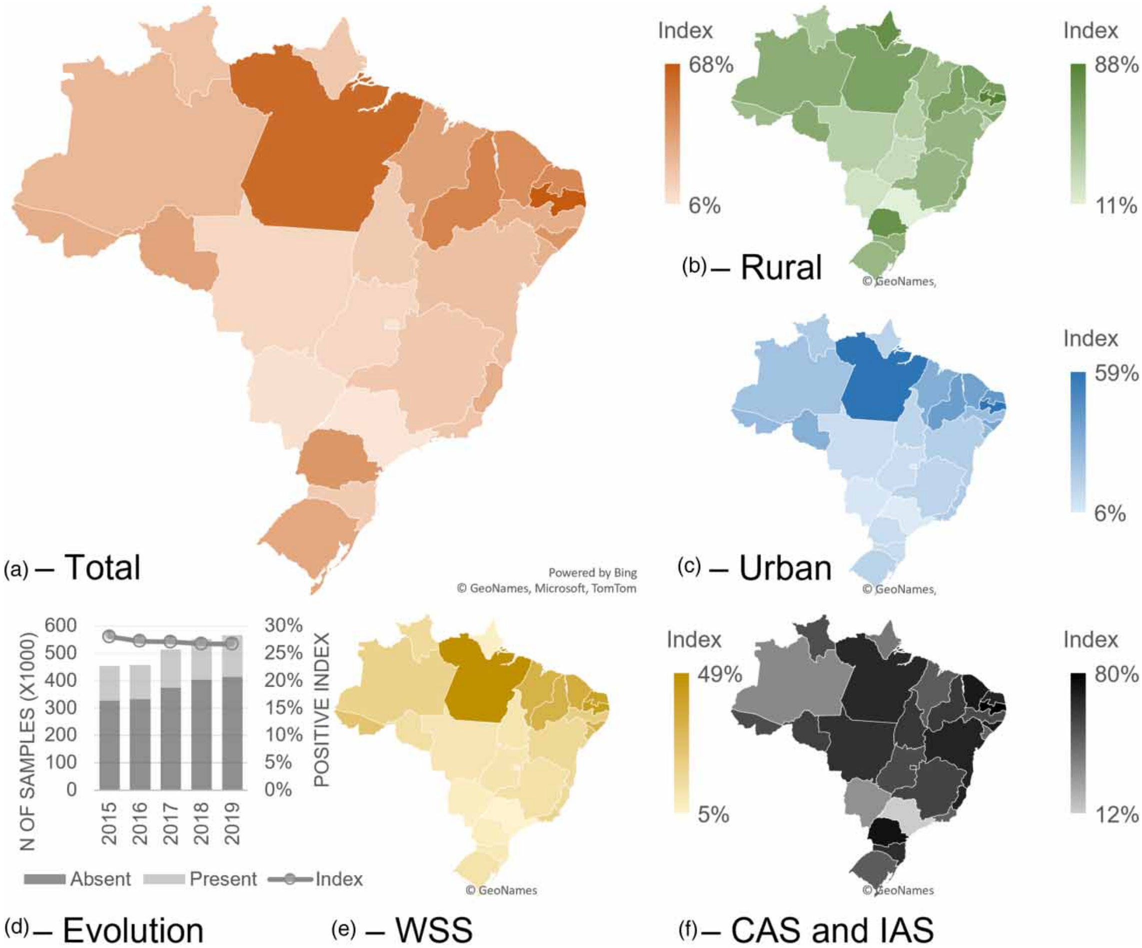

Figure 2 | Total coliform positive indexes over the Brazilian territory base on sample source and data assembling evolution over the years. (a) Total samples, (b) rural areas, (c) urban areas, (e) conventional WSS, (f) alternative supply solutions (CAS and IAS), and (d) overall sampling over the years 2015–2019.

improvement is in this area. It also reveals that different locations may have different needs for water quality monitoring.

Differences were also observed in different occupation zones (rural and urban areas) and type of water supply, which includes public WSS and alternative supply solutions, such as collective alternative solution (CAS) and individual alternative solution (IAS). Notably, rural areas exhibited a higher positive index for coliforms compared with urban areas, especially regarding total coliforms (Figure 2(b) and 2(c)). WSSs had fewer positive results when compared to CAS + IAS for both parameters, total coliforms (Figure 2(e) and 2(f)), and *E. coli* (Figure 3(e) and 3(f)). It is worth highlighting that regardless of the geographical distribution, alternative supply solutions showed a higher number of positive results.

There are four different sampling motivations for coliform analysis monitored by sanitary surveillance, i.e., basic routine water quality monitoring, disease outbreaks, natural disasters, and customer complaints. Routine samples represent the biggest number of samples analyzed (Figure 4(a) and 4(b)). On the other hand, the remaining samples present higher coliform positive indexes compared with those from routine sampling.

Regarding routine sampling, urban areas require a larger number of samples compared to rural areas (Figure 4(c) and 4(d)). Nevertheless, rural areas exhibit higher coliform indexes than urban areas, 60 and 20% for total coliforms, and 30 and 5% for *E. coli*, respectively. Similarly, alternative solutions for water supply show higher positive indexes, particularly IAS (Figure 4(e) and 4(f)). In terms of WSSs, they have the highest number of samples and of positive results indexes with 16 and 4% for total coliforms and *E. coli*, respectively. In contrast, CAS indexes were 52 and 19%, while IAS indexes were 78 and 45%. These findings indicate that alternative supply solutions, particularly individual alternatives, which are probably lacking technical assistance, tend to lack quality in terms of biological water parameters.

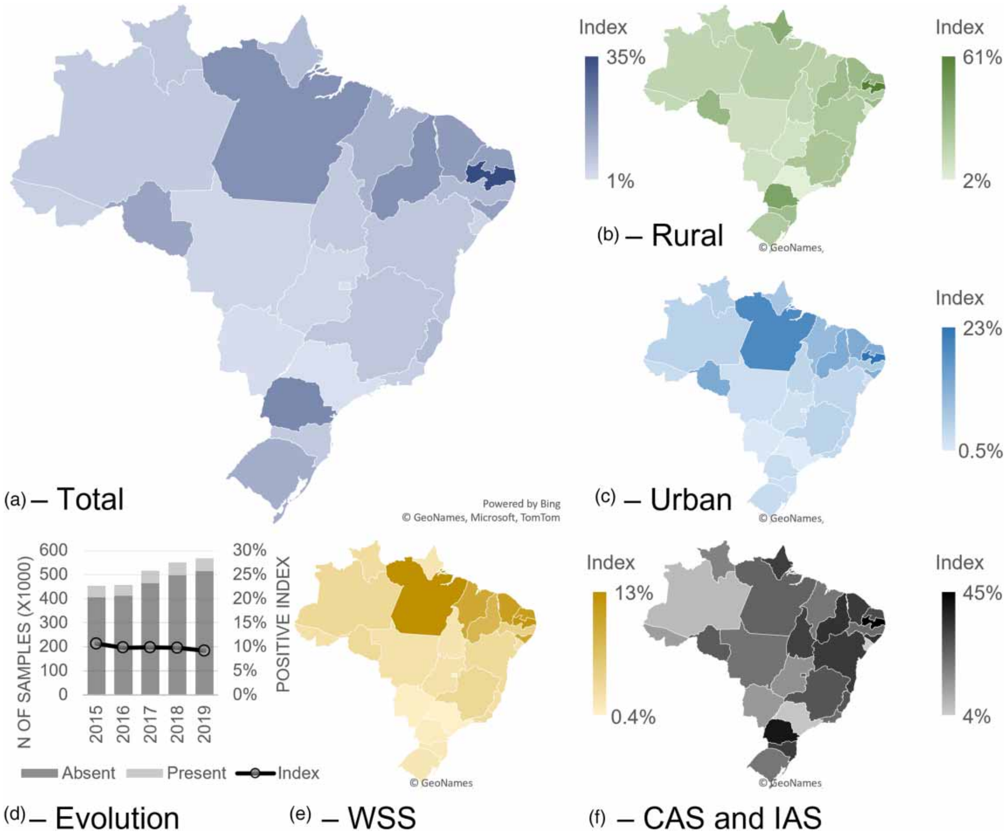

Figure 3 | *E. coli* positive indexes over the Brazilian territory base on sample source and data assembling evolution over the years. (a) Total samples, (b) rural areas, (c) urban areas, (e) conventional WSS, (f) alternative supply solutions (CAS and IAS), and (d) overall sampling over the years 2015–2019.

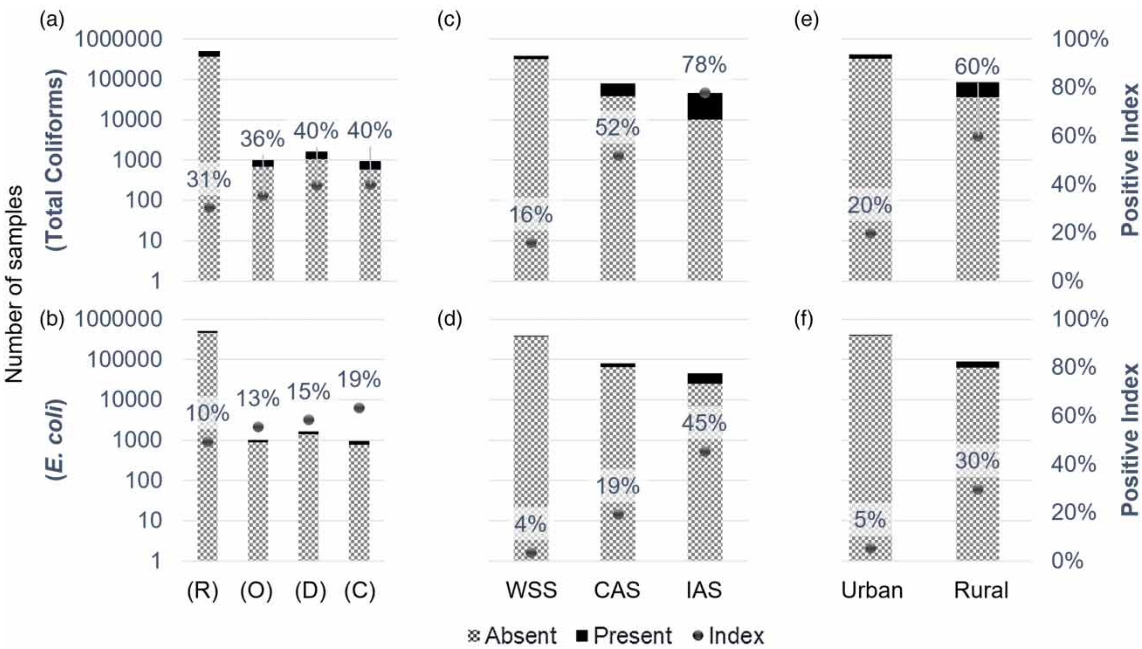

Figure 4 | Overall number of water survey samples and positive index for total coliforms and *E. coli* analysis by sampling motivation and sample source. Routine (R), disease outbreaks (O), natural disasters (D), and customers complaints (C); survey samples for total coliforms (a) and *E. coli* (b) by sample motivation; routine survey analysis for total coliforms (c) and *E. coli* (d) routine analysis distributed by supply type, public Water Supply System (WSS), collective alternative solution (CAS) and individual alternative solution (IAS) for water supply, and respective positive samples indexes; routine survey water samples for total coliforms (e) and *E. coli* (f) routine analysis distributed by urban and rural zones.

3.2. Customers insights

Tables 1 and 2 summarize the information gathered from the interviews. Additionally, Tables S1 and S2 (Supplementary Material) present the key characteristics of the accountable representatives from the WSS involved in this study. The interviews covered a range of administrative types and companies of various sizes. Each interviewed company serves a population of more than 7,000 people and processes a minimum of 250 samples of coliform analysis per year. In terms of company size, this represents the reality of half of the Brazilian WSSs (Supplementary Material, Table S1). The main goal of incorporating their perspectives into this analysis was to gather insights about the methodology favoured by their users and include their considerations in the development of new technologies. These perspectives are summarized in Tables 1 and 2. In the discussion, specific aspects mentioned by the interviewees will be taken into consideration.

It is important to emphasize that the diversity of the accountable Brazilian WSSs extends beyond their size and administration structure; it also includes regional particularities. To have a more comprehensive understanding of Brazil, these variations could be further considered. However, in this study, the primary focus was on the BM as a framework for technological innovation. Consequently, all information was considered to the best extent possible, with the aim of using the subsequent discussion as a starting point for the application of the BMC analysis.

3.2.1. Water quality testing practices

Techniques such as multiple-tube fermentation, membrane filter technique, and enzyme substrate tests for total coliforms and *E. coli* detection were cited in the literature among the primary methods for water quality testing. All these techniques are widely accepted for water potabilization purposes as they are not only standardized but also recommended by FUNASA, which provides guidelines for their application (FUNASA 2013; APHA 2017b; Brasil 2021a). Each partner in this study uses specific logistics for conducting coliform analysis, influenced by different factors, including the number of samples, the standard methodology adopted, company resources (human and financial) and whether the analysis is performed locally or outsourced to a laboratory. Supplementary Material, Table S3 provides a summary of the characteristics related to coliform analysis performed by each partner.

Participants who outsource their coliform analysis to other laboratories (Table 1 and Supplementary Material, Table S3) reported challenges related to the lack of a structured approach, insufficient personnel and equipment, and cost-effectiveness issues. One of the WQL mentioned that if their customers are located far away, it is more cost-effective to hire a local laboratory to conduct the analysis. Another motivation for outsourcing is the desire to benefit from a specialized service provided by an accredited laboratory focused only on this activity. However, a challenge in such cases is the lack of autonomy in terms of sampling and performing the analysis.

The main steps involved in coliform analysis, as described in Table 1, were generally consistent across the different methodologies. These steps typically include prior preparation of materials, sampling, sample preparation, incubation, interpretation of results, and cleaning. However, it is important to note that each methodology has its own specific details and characteristics that can impact on the performance and logistic considerations. In particular, the use of multiple-tube fermentation tests and service outsourcing were often associated with obtaining results after a 48-h incubation period.

Opinions regarding the acceptable time for obtaining results varied among the participants, as shown in Table 1. There was an acceptance of a 24-h timeframe for coliform detection when comparing different methods. However, WSS participants emphasized that this minimum timeframe is not suitable from an operational perspective. It may be too late if corrective actions are needed, and resampling would take the same amount of time. Both actions are required, but regardless of the adopted measure, it would take at least 48 h after occurrence to validate the efficiency of that measure in a system with continuous water consumption. The time required for obtaining results emerged as a crucial point of discussion regarding method application, influencing the choice of a particular method as a significant benefit.

In addition to the time factor, participants highlighted other challenges related to coliform analysis. These included purchasing aspects, such as limited suppliers, high costs, and the short expiration date of culture media, which requires frequent purchasing. Uncertainties regarding the interpretation of results were also mentioned as a challenge, particularly in the case of chromogenic methods.

3.2.2. Influences on reaching and purchasing technology

The type of administration, company size, and budget had a significant influence on the procurement of consumables and equipment, as well as service contracts which are regulated by legal requirements (Brasil 2021b).

Table 1 | Overview of the information gathered from the interviews (part 1) regarding the method application for coliform analysis and their buying behaviour

	a. Used methods	***b. Coliform analysis steps:***	***c. Reasons for use***	***d. Benefits***	***e. Challenges***
1. Method application	• Multiple-tubes fermentation. • Membrane culture. • Defined substrate.	• Prior preparation (culture media, sampling flasks and glassware) • Sample collection • Sample preparation • Incubation • Interpretation of results (24–48 h) • Cleaning	• Determination of total coliforms and *E. coli* together • Less glassware • Reduction of contamination routes • Simplicity • Time for the results • Experience of years of use • Meeting different demands • Cost fits budget • Fewer personnel • accreditation for the method • Easy reproducible in other laboratories	• Reduced analysis time • Reduced results time • Few or single step • Easy handling, Simple method • Sterilized material available • Contamination reduction • Easy interpretation of results • Quantitative method • No need for specialized technicians • Cost-benefit • Purchase availability • Reliability.	• Long time (for decision-making) • Few culture media suppliers • High costs • Short culture media expiration date • Uncertainties on results interpretation
	Outsourced analysis:	*Minimum analysis with surplus contract. Hired laboratory performs sample collection. Customer has material for emergency sampling.*	*Costs and accreditation.*	*Specialized accredited laboratory, no cost of equipment and personnel for (few) analyses and no need for sample preparation.*	*Lack of autonomy*
	a. Purchase process	***b. Frequency***	***c. Specific criteria***	***d. Influences***	***e. Approval***
2. Buying behaviour	• Technical description • Quotations • Technical sector approval • Purchasing sector approval (financial viability) • Purchase	• Variable: annual, semi-annual, quarterly, according to demand, or according to the validity of the test kit.	• Technical support • Technical validation • Delivery time • Market trust • Durability • Registered companies • Accredited laboratories	• Technical feasibility • Conscious administration of budget • Good resources management • Costs • Cost–benefits • Budget/Financial evaluation • Market/Technical reliability • Durability • Technical support • Technical validation • Technical evaluation • Price is not impactful	• Laboratories identify needs • Board of directors • Responsible for the sector • Technical sector • Purchasing Sector • Agreement between technical and financial sectors

Table 2 | Overview of the information gathered from the interviews (part 2) regarding the receptivity of new methods for coliform analysis and possible impacts on implementing a technology involving portability, connectivity, and fast results

	a. Known methods	***b. Comparison***	***c. Reasons for choice***	***d. Specific problems solution***	***e. New method expectations***
3. New methods	• Traditional methods have been approached, but there are cases of professionals not knowing any other methods.	• Participants were divided into considering other methods available in the market as better, worse or at the same level as the methods currently used.	• Those who consider other methods better do not change because the current method has lower costs. • Those who consider other methods worse claim that they use the current method because of less manipulation of samples, shorter time results, practicality, long time of use and reliability	• Time reduction • Interpretation uncertainties • Number of samples increasing • Greater control of the analyses	• Technology involving sensors/probes • Less sample handling • Fewer materials • Less equipment • Easy/clear interpretation • More autonomy in operations • As good as those available, at least • Achieve the demand for number of samples • Economically accessible • Recognized by health authorities
	a. Benefits	***b. How could a new method improve water quality?***	***c. Challenges of implementation***	***d. Sustainability of use***	***e. Possibility of replication***
4. Impacts of new methods *(portability, connectivity, and fast results)*	• Reliable results for quality water • Rapid response to problems • Possibility of automation • Analysis on site bases • Safe water for consumers • Better quality of life for consumers	They do not perceive how water quality could improve. Water quality is already good.	***YES,*** *there are challenges:* • Managers' interest in new technologies • Costs involved with new materials • Investment in new equipment • Training of personnel (feasible) • Validation for new accreditations • ***NO,*** *there is no challenge:* • No challenges in implementation • Changes are common	• Upgradable technology • No internet connection limitations • Accepted by legislation • Meet quality criteria • Fewer materials use or reuse • Less waste generation • Economic viability	• Clear and objective interface with users • Technical support available • Training available • Similarity with known technologies • Results clearness • Regulatory bodies recognition

Usually, the process begins with a technical description of a product or service. Quotations are then obtained for further approval from the technical and purchasing/finance department. Once approved, the purchase or service contract is finalized. Consumables are usually purchased at different frequencies, while equipment is acquired during key moments such as the need for replacement or investment. Costs and budget considerations play a key role in the purchasing process, and purchases must meet specific technical criteria within the allocated budget, as determined by the purchasing department and approved by a senior employee (see Table 1).

3.2.3. Knowledge of new methods and comparisons

The comparisons made by the participants regarding the methods they currently use were diverse, with the preference for alternative methods often driven by lower costs (as indicated in Table 2). Conversely, those who considered their current methods to be the best or equivalent to others highlighted advantages such as minimal sample handling, short turnaround time for results, familiarity with the method, and reliability.

Several specific problems were identified that could potentially be solved by adopting a different or new method. These included reducing the time required for analysis, addressing interpretation uncertainties, increasing the number of samples that can be processed, and improving overall control in the analysis process (such as acquiring necessary resources).

Expectations for new technologies included features that would enhance operational autonomy (e.g., automation), provide at least equivalent performance to existing market options, achieve the demand for the number of samples handling, and be economically accessible. Desired functionalities included the integration of sensors/probes for detection, reduced sample handling, fewer materials and equipment, and easy and clear result interpretation. Finally, participants expressed concern about gaining recognition from health authorities for the adoption of new methods.

Participants also reported how they kept abreast of new methods or equipment. Larger WSS, in particular, reported receiving various offers from different suppliers for alternative options. Other valuable sources of information cited were the exchange of experiences at water sector events such as technology fairs.

3.2.4. Impacts of new methods and technology

To explore the potential benefits of new methods and technology, participants were specifically asked about their views on the possibility of faster results, portability, and the integration of IoT. They were also invited to express their needs and how they could benefit from and sustain a new method or technology. The responses from participants highlighted a diverse range of benefits, including water quality improvements, operational efficiency aspects, and better customer relationships as shown in Table 2.

Regarding the sustainability and replication of the innovation, participants expressed concerns regarding IoT implementation and internet availability, as well as software upgrades and compatibility. It was emphasized that technology should not have a limited lifespan or have its life cycle shortened due to constant upgrades and improvements. Given that cost was also a significant concern, participants expressed apprehension about technologies that would require frequent upgrades, as it could impact their sustainability efforts.

3.3. Framing the BMC

The development of the BMC was dynamic, whereby multiple drafts were produced. These initial drafts focused only on the technological innovation aspect (fast results, portability, and connection to the internet). These drafts served as a guide to the methodology and were constantly updated as more information was gathered and analyzed. The final version of the BMC, reflecting the culmination of its iterative process is presented in Figure 5.

The presented BMC integrates new technology with existing coliform analysis practices, as informed by the insights gathered from the partner interviews. This integration is primarily depicted on the left side of the BMC, which outlines the logistical aspects of the business (see Figures 1 and 5). In contrast, the right side of the BMC represents the more innovative and creative aspect, as it connects the value propositions with the customers. Although established relationships and channels are described, this section of the BMC explores new possibilities and potential enhancements (see Figures 1 and 5).

3.3.1. Value proposition and the technological gap

The value propositions in the BMC (Figure 5) stemmed from the three key innovations and were further refined through the incorporation of customer insights, including their needs, pains, and potential gains. As indicated in Table 1, the benefits derived from the methods were the main reason for use. This implies that participants' choices were driven by the benefits they could obtain. In the case at hand, which simplified and streamlined the analysis steps were frequently mentioned. In addition to these practical attributes, cost considerations were also highlighted as a determining factor, with cost-effectiveness being recognized as a significant advantage.

Considering technological innovation as a starting point for the value proposition was instrumental in initiating the discussion. However, as the conversation progressed, it became evident that different aspects of the value proposition held varying levels of importance for different potential users. The interviews revealed that some

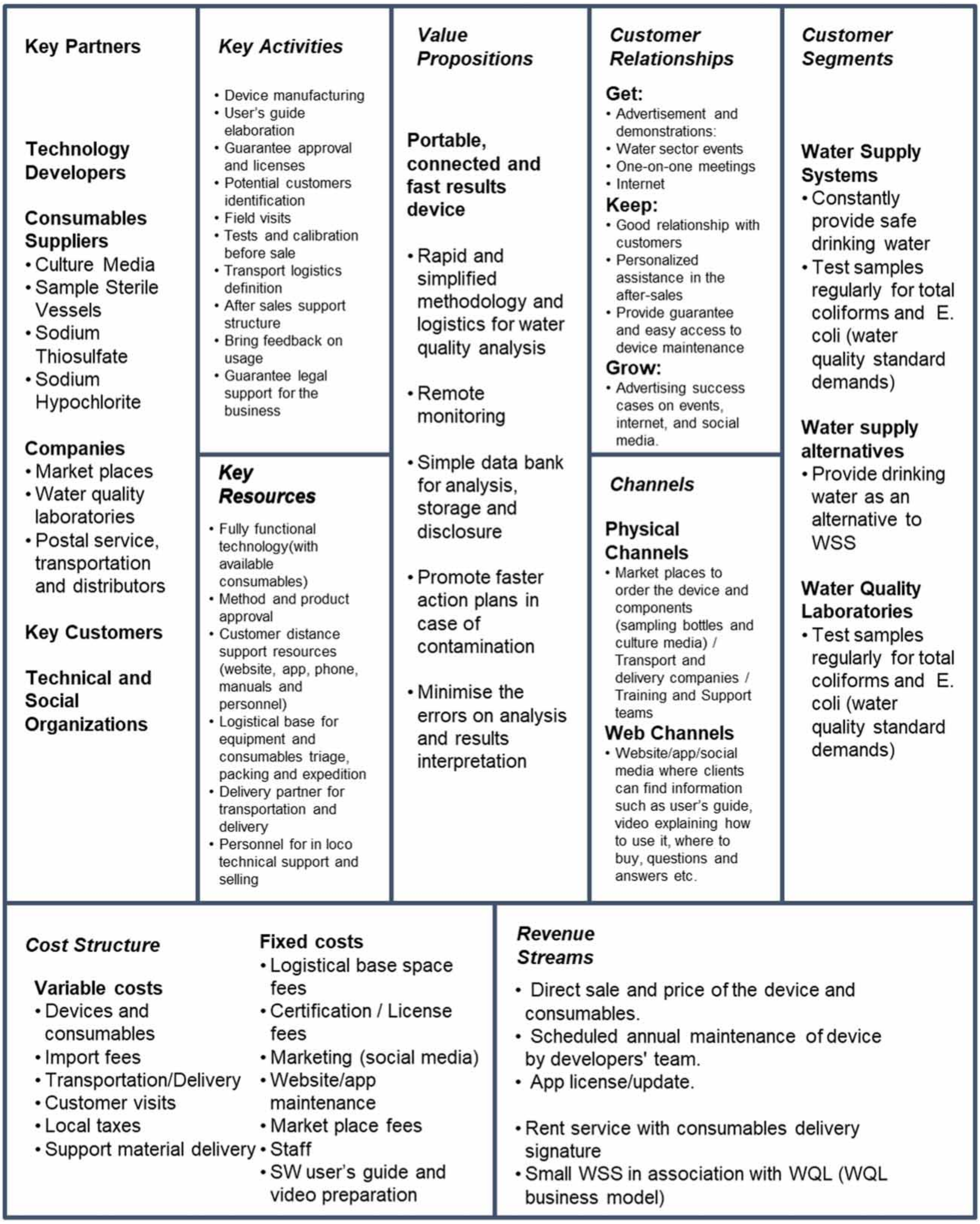

Figure 5 | Overall BMC proposition for the technological innovation for coliform analysis in Brazil.

participants expressed a particular desire for faster results in specific cases, such as network problems. Figure 4(a) and 4(b) illustrates that, in general, these types of samples constitute a smaller fraction of the overall sampling process in Brazil. This implies that there is a technological gap that does not necessarily need to address the demand for all samples. Therefore, while WSSs represent the largest market segment in terms of coliform analysis, the value proposition of new technology should cater to the gaps in only a fraction of their requirements. Consequently, WSSs may not necessarily be the primary customer or target of the value proposition, and the BM will need to adapt accordingly. Conversely, a minority of the water sector, comprising CAS, IAS, and smaller WSSs, may stand to benefit more from the value proposition than larger WSSs that process a significant number of samples (Figure 4(c) and 4(d)).

By developing the BMC using data analysis and interviews with WSSs, it was possible to identify and frame the initial technological gap, as well as propose potential solutions. While these gaps may be general in nature, the application of the BMC in terms of meeting real customers' needs vary. This was particularly evident in the identification of the value proposition stemming from technological innovation. The main gap identified was the need for faster results through a simple method, which could potentially be addressed by utilizing tools such as remote monitoring, a user-friendly database, and internet connectivity. However, it is important to note that the solution may not be solely dependent on these tools, and other approaches could also provide benefits in addressing the identified gap.

3.3.2. Featuring the Brazilian market segments for technology upgrades

When considering the value proposition and its relationship with customers, it became apparent that the Brazilian market segments for technology upgrades could be delineated based on the characteristics of WSSs. The diversity observed among WSSs in terms of size, administration type, location, and number of samples processed for coliform analysis highlighted the need to tailor value propositions to specific customer segments. Each segment has unique requirements and preferences, and any technological upgrade should take these factors into consideration. By understanding the different customer segments and their specific needs, it becomes possible to develop targeted solutions that align with their expectations and deliver value in a meaningful way.

Further segmentation is required to account for the specific characteristics of the target customer segments, as indicated by the framing of the BMC and the information gathered from the water supply sector. It is important to consider the variations in the number of samples processed by the WSSs laboratories and WQL, as different technologies must be able to accommodate these varying needs (see Supplementary Material, Table S3). Additionally, different sampling motivations may require more urgency in obtaining results, such as addressing customer complaints or problems in the network. Expanding the scope beyond WSSs and WQL, it is essential to consider a broader water sector, including CAS and IAS. These alternative water supply solutions also play a significant role and should be taken into account when developing value propositions and technological upgrades. By considering these diverse customer segments and their specific requirements, it becomes possible to tailor solutions that address their unique needs and challenges, ultimately maximizing the value delivered to the entire water supply sector.

CAS and IAS were not specifically targeted in the interviews conducted in this case study. However, the information gathered from the interviews with WSSs and VIGIAGUA reveals that there is scope for the application of technology based on the contamination index in these water sources. Issues such as price and consumables availability could be solved through the development of partnerships with different stakeholders (e.g., NGOs, community associations, consortiums, WSC, health surveillance or system, sector-associated companies, etc.) to increment the number of samples and purchases. Similarly, strategies for Customer Relationships and Channels will be crucial for the sustainability of the technology. In the module of Revenue Streams, the economic goals and social goals must also be considered for both, the BM proposition and the successful introduction of the technology (Gebauer & Saul 2014; Elmustapha & Hoppe 2020). The BM proposition should encompass both aspects, ensuring that the technology not only generates economic value but also contributes to social goals such as improving water quality and public health.

3.3.3. The current logistics for technology introduction

Framing the logistics for implementing new technology in the Brazilian market has provided valuable insights into the impact of the existing system on the adoption and implementation of innovative solutions. The logistics associated with the current biological analysis implementation in the Drinking Water Supply Sector play a significant role in how customers relate with technology in a practical way.

Buyer behaviour is largely influenced by the type of administration of WSSs. For instance, private companies often have more flexibility in purchasing consumables and equipment compared to public entities. However, regardless of the administration type, the buying process typically follows a standardized bidding process that involves several key steps.

Some of the largest companies that participated in this study reported that they commonly engage in testing different methods for analysis whenever the opportunity arises. As recognized entities in the water sector, they are usually required by manufacturers to run tests with different products. Participants also reported that they usually test equipment prior to purchase, particularly when it involves technologies that they have limited knowledge about or when significant investments are involved.

The qualitative or quantitative nature of analysis significantly influences the prices. The price for qualitative methods varies from 2.17 to 8.58 GBP per sample. Meanwhile, quantitative methods have a wider price range, with costs varying from 1.13 to 12.43 GBP per sample (replicates not included). It is important to note that these prices reflect the values in 2021, specifically for June 2021. The Brazilian Real (BRL) currency was converted to British Pound Sterling (GBP) at a rate of 1.00 BRL = 0.15 GBP = 0.20 USD (30/06/2021). Prices may vary, especially for equipment with a high range of specific characteristics. Considering external WQL services, values may vary for different methods and transport distance from the laboratory, but the analysis single price may start from 10 GBP, considering defined substrate methods as reference.

Therefore, the activities outlined on the left-hand side of the BMC involve logistics that indirectly impact technology access. As highlighted in the interviews undertaken, the costs associated with these logistics have a significant impact on customers' decision-making. It is crucial to consider the customers as potential partners in technological improvements, ensuring their participation throughout the process Additionally, specific customer segments may face logistics cost-related challenges that could make certain technologies (e.g., imported enzyme substrates,) economically prohibitive prompting the need to inspire new BM innovations.

4. CONCLUSIONS

The BMC was used to identify and address challenges related to the introduction of a new water analysis technique in the water supply sector using a case study about coliform analysis innovation. With this study it was possible to identify both, the gaps in the Brazilian market, as well as innovative technologies tailored to users' needs by value propositions. With the case study, it was also possible to conclude the following:

- The BMC technique helped to highlight key factors for problem identification and scoping about the specific case of coliform analysis in the Water Treatment Sector in Brazil. This method may be used to highlight further solutions based on technological innovation.
- Insights gathered from representatives from the WSS segment were used to gain a deeper understanding of the problems involving water coliform analysis (this goes beyond the identification of problems and scoping). This knowledge can enhance potential solutions based on their experience, needs, concerns, and aspirations.
- Water quality varies according to different factors, such as water supply type, occupation zone, and sampling motivation. These factors may directly influence the technology and market segment, thus, having a direct impact on the BM, and vice versa.
- Key characteristics of WSSs, such as the number of samples and sampling motivation also affect the technological aspects of the process and its value. Meanwhile, administration type plays a key role in customer relationships and channel strategies, and further along the line, in the logistics of the BM.
- Main gaps are related to sector needs and the related tools for improvement. They altogether may be represented as a value proposition in the BMC. In this case, fast results, IoT, and portability may help to fill the gap of faster results from a simple method.
- Finally, the data provided insights into the motivations for drinking water sampling, type of water supply, and different zones (urban and rural) reflecting different indexes of contamination. This highlights the current gap in simple methods for frequent water assessment for water safety.

ACKNOWLEDGEMENTS

This research was supported by the Global Challenges Research Fund (GCRF) Global Research Translation Awards, UK Research and Innovation (SAFEWATER Translate, EPSRC Grant Reference EP/T015470/1), and by National Council for Scientific and Technological Development (CNPq-Brazil, process no. 308070/2021-6).

ETHICS COMMITTEE APPROVAL

The study, interview subjects, and participants' approach were approved by an ethical committee and registered at the Brazilian National Research Ethics Council under registration number: CAAE 39927820.6.0000.5422.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Ahmed, U., Mumtaz, R., Anwar, H., Mumtaz, S. & Qamar, A. M. 2020 *Water quality monitoring: from conventional to emerging technologies*. *Water Sci. Technol. Water Supply* **20**, 28–45. https://doi.org/10.2166/ws.2019.144.

APHA 2017a 9211 rapid detection methods. In: *Standard Methods For the Examination of Water and Wastewater*. American Public Health Association. https://doi.org/doi:10.2105/SMWW.2882.185

APHA 2017b *Standard Methods for the Examination of Water and Wastewater*. American Public Health Association.

Brasil 2012 *Ministério da Saúde. Secretaria de Vigilância em Saúde. Departamento de Vigilância em Saúde Ambiental e Saúde do Trabalhador. Plano de Segurança da Água: Garantindo a qualidade e promovendo a saúde: um olhar do SUS (Ministry of Health. Secretary of Health Surveillance. Department of Surveillance in Environmental Health and Occupational Health. Water Safety Plan: Ensuring quality and promoting health: a view from SUS)*. Minist. Saúde Secr. Vigiência em Saúde Dep. Vigilância em Saúde Ambient. e Saúde do Trab. Available from: http://www.who.int/water_sanitation_health/dwq/GDWQ2004web.pdf

Brasil 2021a *Ministério da Saúde. Anexo XX da Portaria de Consolidação GM/MS no5/2017 alterado pela Portaria GM/MS no 888/2021 (Ministry of Health. Annex XX of Consolidation Ordinance GM/MS No. 5/2017 amended by Ordinance GM/MS No. 888/2021)*. Ministério da Saúde, Brasil.

Brasil. 2021b *Congresso Nacional. Lei no 14.133/21. Lei de Licitações e Contratos Administrativos (National Congress. Law No. 14.133/21. Law of Tenders and Administrative Contracts)*. Diário Oficial da União, Brasília, DF.

Bria, A., Cerro, G., Ferdinandi, M., Marrocco, C. & Molinara, M. 2020 An IoT-ready solution for automated recognition of water contaminants. *Pattern Recognit. Lett.* **135**, 188–195. https://doi.org/10.1016/j.patrec.2020.04.019.

Elmustapha, H. & Hoppe, T. 2020 Challenges and opportunities of business models in sustainable transitions: evidence from solar energy niche development in Lebanon. *Energies* **13**, 1–18. https://doi.org/10.3390/en13030670.

FUNASA 2013 *Manual prático de análise de água (Practical Water Analysis Manual)*, 4th edn. Fundação Nacional de Saúde, Brasília, Brasil.

Gebauer, H. & Saul, C. J. 2014 *Business model innovation in the water sector in developing countries*. *Sci. Total Environ.* **488–489**, 512–520. https://doi.org/10.1016/j.scitotenv.2014.02.046.

Kanakoudis, V. & Tsitsifli, S. 2017 *Potable water security assessment – a review on monitoring, modelling and optimization techniques, applied to water distribution networks*. *Desalin. Water Treat.* **99**, 18–26. https://doi.org/10.5004/dwt.2017.21784.

Moodley, T. & van der Haar, D. 2019 *Comparisons in drinking water systems using K-means and A-Priori to find pathogenic bacteria genera*. *Lect. Notes Electr. Eng.* **514**, 351–359. https://doi.org/10.1007/978-981-13-1056-0_36.

Osterwalder, A. & Pigneur, Y. 2013 *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers, The Strategyzer Series*. Wiley.

Rossio, C. P. Y. & Seo, Y. 2020 Participatory approaches in the planning of drinking water supply and basic sanitation projects in the rural areas of Colombia. *KSCE J. Civ. Eng.* **24**, 1374–1382. https://doi.org/10.1007/s12205-020-1091-1.

SNIS 2021 *Diagnóstico Temático Serviços de Água e Esgoto – Visão Geral Ano de Referência 2020 (Thematic Diagnosis Water and Sewage Services – Overview Reference Year 2020)*. Sistema Nacional de Informações sobre Saneamento – SNIS.

Sousa-Zomer, T. T. & Cauchick Miguel, P. A. 2018 *Sustainable business models as an innovation strategy in the water sector: an empirical investigation of a sustainable product-service system*. *J. Cleaner Prod.* **171**, S119–S129. https://doi.org/10.1016/j.jclepro.2016.07.063.

UNICEF 2019 *Target Product Profile: Rapid E. Coli Detection Tests [WWW Document]*. Available from: https://www.unicef.org/supply/media/2511/file/Rapid-coli-detection-TPP-2019.pdf (accessed 7.1.21).

WHO 2005 *Water Safety Plans – Managing Drinking-Water Quality From Catchment to Consumer*. Water, Sanitation and Health; Protection and the Human Environment; World Health Organization, Geneva.

WHO 2017 *Guidelines for Drinking-Water Quality: Fourth Edition Incorporating the First Addendum, 4th edn, WHO Library Cataloguing-in-Publication Data*. World Health Organization, Geneva.

WHO, UNICEF 2017 *Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines*. Who. Licence: CC BY-NC-SA 3.0 IGO, Geneva. https://doi.org/10.1371/journal.pone.0164800

First received 24 February 2023; accepted in revised form 27 June 2023. Available online 11 July 2023