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# Evaluation of Non-Conventional Membrane Technology in Rural Educational Institutions of the Subregion of Obando, Nariño, Colombia*

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**Abstract:** The objective of this investigation was to evaluate the unconventional *LifeStraw® Community* technology through a participatory action research approach that incorporated playfulness, in collaboration with the educational communities of eight rural schools located in the Obando subregion of Nariño, Colombia. The study implemented a social adoption strategy based on participatory methods, including project socialization, training through teaching-learning processes, the formation of water advocate groups, and the analysis of various indicators (levels of satisfaction, participation, acquired knowledge about safe water, hygiene practices, and handling procedures). Additionally, physicochemical and microbiological parameters were measured at the certified laboratory of the Departmental Health Institute of Nariño, which enabled the calculation of the Water Quality Risk Index (WQRI) in the effluent and its compliance with Colombian Technical Standard Decree 1575 of 2007. Results indicated that the use of the *LifeStraw® Community* technology reduced the WQRI from medium or high to low or no risk. However, some institutions showed non-compliance with microbiological parameters. Overall, it was determined that the *LifeStraw® Community* technology contributes to the provision of safe water in educational institutions by lowering the risk of waterborne diseases.

**Keywords:** Safe Water; Water Quality; Water Treatment; WQRI; *Lifestraw® Community*

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* Research Article

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## *Evaluación de la tecnología de membranas no convencionales en instituciones educativas rurales de la subregión de Obando, Nariño, Colombia*

**Resumen:** El objetivo de esta investigación fue evaluar la tecnología no convencional *LifeStraw® Community* desde un enfoque de investigación acción participativa y utilización de la lúdica, con la comunidad educativa de ocho instituciones o centros asociados rurales, de la subregión Ex Provincia de Obando, Nariño Colombia por medio de una estrategia de adopción social, basada en métodos participativos, como: socialización del proyecto, formación con procesos de enseñanza aprendizaje, consolidación de grupos defensores de agua y análisis de indicadores (Nivel de satisfacción, participación, conocimientos adquiridos de agua segura, tandas e higiene y manipulación); además, se determinaron parámetros fisicoquímicos y microbiológicos en el laboratorio certificado del Instituto Departamental de Salud de Nariño, que permitió calcular el Índice de Riesgo de Calidad de Agua - IRCA en el efluente y su cumplimiento con la norma técnica colombiana Decreto 1575 de 2007. Se pudo determinar que el uso de la tecnología disminuyó el IRCA de medio y alto a bajo y sin riesgo; en algunas instituciones se evidenció el no cumplimiento del parámetro microbiológico. Se concluye que la tecnología LifeStraw® Community contribuye en brindar agua segura para las instituciones educativas al disminuir el riesgo de presencia de enfermedades asociadas al consumo de agua.

**Palabras clave:** Agua Segura; Calidad de Agua; Tratamiento de Agua; IRCA; *Lifestraw® Community*

## *Avaliação da tecnologia de membranas não convencionais em instituições educativas rurais da sub-região de Obando, Nariño, Colômbia*

**Resumo:** O objetivo desta pesquisa foi avaliar a tecnologia não convencional ***LifeStraw® Community*** a partir de uma abordagem de pesquisa-ação participativa e da utilização do lúdico, junto à comunidade educativa de oito instituições ou centros associados rurais, da sub-região Ex-Província de Obando, Nariño, na Colômbia, por meio de uma estratégia de adoção social, baseada em métodos participativos, tais como: socialização do projeto, formação com processos de ensino-aprendizagem, consolidação de grupos defensores da água e análise de indicadores (nível de satisfação, participação, conhecimentos adquiridos sobre água segura, turnos e higiene e manipulação). Além disso, foram determinados parâmetros físico-químicos e microbiológicos no laboratório certificado do Instituto Departamental de Saúde de Nariño, o que permitiu calcular o Índice de Risco de Qualidade da Água – IRCA no efluente e sua conformidade com a norma técnica colombiana Decreto 1575 de 2007. Foi possível constatar que o uso da tecnologia reduziu o IRCA de médio e alto para baixo e sem risco; em algumas instituições evidenciou-se o não cumprimento do parâmetro microbiológico. Conclui-se que a tecnologia *LifeStraw® Community* contribui para fornecer água segura às instituições educativas ao diminuir o risco de ocorrência de doenças associadas ao consumo de água.

**Palavras-chave:** água segura; qualidade da água; tratamento de água; IRCA; *LifeStraw® Community*

## Introduction

Non-conventional technologies for the treatment of water intended for human consumption represent a viable alternative for dispersed rural populations, who are at greater risk of contracting waterborne diseases [1]. These diseases include typhoid fever, hepatitis, paratyphoid, gastroenteritis, dermatitis, and various acute respiratory and diarrheal infections [2,3]. Acute diarrheal disease remains the leading cause of morbidity and mortality worldwide [4]. By 2021, it was estimated that more than 251 million people required preventive treatment due to exposure to contaminated water, and nearly one million people die annually from diarrheal diseases caused by unsafe water, inadequate sanitation, or poor hand hygiene [5]. Risk factors contributing to these outcomes include young age, malnutrition, early weaning, seasonal patterns, low maternal education, poor water storage practices, lack of household water treatment, insufficient handwashing, and inadequate sanitation [4]. These conditions also negatively impact children's growth, development, and microbiome health [6–8].

Globally, non-conventional technologies are being utilized to provide safe water to dispersed rural communities. These include methods such as: storage and sedimentation systems (e.g., the three-pot method) that allow particulates to settle and the clearer water to be transferred to other containers after a period of time [9]; tabletop filters, widely used in home water and food disinfection; sand or ceramic filters that remove particles of various sizes; carbon candle filters with sand pre-filters for turbidity reduction; and slow sand filtration or microfiltration systems, which separate particles from water based on molecular weight [9, p.39].

In Colombia, water intended for human consumption is compromised by limited wastewater treatment, with 68% of wastewater discharged directly into water bodies [10]. In rural areas, water quality is further affected by agricultural and livestock activities that introduce pathogens and organic matter into sources [3], and by insufficient sewer coverage, which reaches only 30% of the population [10]. Despite government efforts, such as the National Plan for the Supply of Public Services, El Nuevo Siglo reported on March 23, 2021, that by February 28, 2021, a total of 1,510,046 people had gained access to safe drinking water for the first time, and 1,467,028 more had gained access to basic sanitation services. Additionally, through Resolution No. 0076 of March 9, 2021, the Ministry of Housing, City and Territory adopted the National Plan for Rural Drinking Water Supply and Basic Sanitation (PNASBR) to improve access to these essential services.

However, in the Obando subregion of the department of Nariño—comprising 13 municipalities—these benefits have yet to be fully realized. According to monitoring conducted by the Departmental Health Institute of Nariño (DHIN) in 2018, the subregion had an average Water Quality Risk Index (WQRI) ranging from 44.47% to 59.78%, classified as "High Risk" according to Resolution 2115 of 2007. In the same year, the incidence of Acute Diarrheal Diseases among children under five was 18.83 cases per 100 children.

It has also been reported [11] that non-conventional technologies such as LifeStraw® Family and LifeStraw® Community are the only two domestic water treatment systems worldwide to have received the highest (three-star) rating from the World Health Organization for their comprehensive protection against all three types of pathogens found in untreated water. These systems are capable of removing at least 99.9999% of bacteria (>6 $\log_{10}$), 99.999% of viruses (>5 $\log_{10}$), and 99.99% of parasites (>4 $\log_{10}$), as well as reducing turbidity by filtering particles including bacteria, parasites, and viruses. However, concerns remain regarding the safe handling of these devices.

Given the challenges related to water consumption in the Obando subregion, the Departmental Water Plan (DWP) of the Government of Nariño, in collaboration with the Departmental Health Institute of Nariño (DHIN) and the University of Nariño (UdeNar), signed Agreement No. 1411-19 to improve health conditions by ensuring the provision of safe drinking water in educational institutions located in rural areas of the department. As part of this effort, non-conventional membrane filtration technologies were implemented using the LifeStraw® Community filter, which is designed for use in community, educational, and institutional settings [10].

In 2018, the DHIN reported that rural educational institutions in the Obando subregion exhibited WQRI values ranging from 23.57% to 78.57%, corresponding to medium to high risk classifications under Resolution 2115 of 2007, thus placing approximately 1,080 students at risk. Therefore, the objective of this study was to evaluate the LifeStraw® Community non-conventional technology in eight educational institutions located in the Obando subregion of Nariño, Colombia. The evaluation involved verifying compliance with the parameters established by Resolution 2115 of 2007, including Apparent Color (AC), Hydrogen Potential (pH units), Turbidity (NTU), Total Alkalinity (mg $CaCO_3$/L), Total Hardness (mg $CaCO_3$/L), Total Coliforms (MPN/100 mL), and Escherichia coli (MPN/100 mL), as well as analyzing the behavior of the WQRI at the municipal level across these rural educational centers.

## Materials and methods

The study employed a quantitative approach with a descriptive and correlational scope. The methodology was structured into three stages: (1) diagnosis, (2) implementation of a social adoption strategy, and (3) deployment and evaluation of the technologies.

### *Description of study area*

The department of Nariño (Colombia) is divided into 13 subregions, one of which is the Obando subregion, located in the southern part of the department and composed of 13 municipalities. This study focused on 12 rural educational institutions or centers from four municipalities—Ipiales, Pupiales, Funes, and Puerres—that are part of the Departmental Water Plan of the Government of Nariño. Four of these institutions were selected exclusively for the validation of the survey (focusing on facilities and hygiene infrastructure), while eight were included in the full study. These institutions offer preschool, basic education (five years of primary and four years of lower secondary school), and upper secondary education (two final years leading to a high school diploma).

The municipalities studied are supplied with drinking water sourced from the Río Blanco basin [13], which spans an area of 214.86 km². This basin is composed of Pleistocene volcanic rocks and semi-consolidated Tertiary and Quaternary deposits, collectively known as the "typical layers of Nariño." These include lava units formed by fissure mechanisms, pyroclastic materials, volcanic sedimentary rocks, and glacial deposits. The soils are primarily composed of poorly developed volcanic ash debris, classified as Inceptisols and Organomelanic Andosols. Land use in the basin is agricultural (33%), followed by livestock farming (23%) and forested areas (8%), with the remaining 35% consisting of unused land.

The majority of the population in this region is of Indigenous origin, maintaining their traditions and worldview, which are reflected in their relationship with the environment and their way of life. Their economic activities are based on low-tech agriculture, livestock, poultry, and fish farming.

### *Locative and infrastructural hygienic diagnosis*

A survey consisting of 18 questions, organized into four analytical categories, was administered to students and kitchen staff working in school cafeterias. The four categories addressed in the survey were: (1) food handling, (2) appropriate use of equipment, (3) knowledge of water-related concepts, and (4) institutional infrastructure. The questionnaire was validated in four educational institutions not included in the main study, which allowed for its standardization and refinement. Descriptive statistical analysis of the data was conducted using SPAD v.2018 software.

### *Social adoption strategy*

The methodological framework proposed by [11] was employed to implement the social adoption strategy. This approach, grounded in participatory methods—including project socialization, commitment ceremonies, and beneficiary training through teaching–learning processes—was supported by playful activities such as socio-dramas, puppet shows, workshops, and a knowledge fair. The content covered included: safe water, waterborne diseases, hygiene and handling practices, and water treatment.

Additionally, students' prior knowledge was assessed through surveys administered during each session, using the following evaluation scale: less than 35%—low knowledge; between 36% and 70%—medium knowledge; and greater than 71%—high knowledge. As part of the strategy to promote social adoption of the technology, a "Safe Water Advocacy Group" was established in each institution or educational center (see Figure 1).

In 2019, project socialization activities were carried out in the selected institutions or educational centers. Due to the COVID-19 pandemic and related biosafety protocols, the training of students, parents, teachers, and cafeteria staff between 2020 and 2021 was conducted virtually via Zoom. The socialization phase addressed topics such as safe water, hygiene and handling practices, solid waste management, and Household Water Treatment (TANDAS). Didactic tools were created using the platform genial.ly/es to support the teaching–learning process.

Indicators were developed to assess levels of acquired knowledge in the areas of safe water, hygiene and handling, and TANDAS, as well as the level of participant satisfaction. To measure the level of participation, the strategy proposed by [14] was implemented.

Table 1. presents the indicators for levels of acquired knowledge, while Table 2 shows the levels of participation.

**Figure 1.** Methodological design, social adoption workshops "Let's Drink Safe Water *YAKÚ*"


**Source:** Own elaboration.

**Table 1.** Levels of acquired knowledge

| Knowledge Area | High Level (4 Characteristics) | Medium Level (3 Characteristics) | Low Level (2-1 Characteristics) | Null Knowledge (0 Characteristics) |
|---|---|---|---|---|
| 1. Safe Water Knowledge | This classification was assigned when the following four criteria were met:<br>1. Participants understood that safe water is free from germs and toxic substances.<br>2. They were aware that water must undergo treatment to be safe for consumption.<br>3. They could recognize signs and symptoms of illnesses related to unsafe water.<br>4. They were familiar with the various uses of safe water. | Recognizes at least 3 of the 4 characteristics. | Recognizes at least 2 of the 4 characteristics. | Recognizes none of the characteristics. |

| Knowledge Area | High Level (4 Characteristics) | Medium Level (3 Characteristics) | Low Level (2-1 Characteristics) | Null Knowledge (0 Characteristics) |
|---|---|---|---|---|
| 2. Handling and Hygiene Knowledge | This classification was assigned when the following three criteria were met:<br>1. The participant demonstrated knowledge of proper handwashing techniques and understood when handwashing is required.<br>2. The participant was aware of the need to use personal protective equipment (PPE).<br>3. The participant understood the concept of cross-contamination, specifically the need to separate different types of food. | Recognizes at least 2 of the 3 characteristics. | Recognizes at least 1 of the 3 characteristics. | Recognizes none of the characteristics. |
| 3. Domestic Treatment and Safe Storage (TANDAS) | This classification was assigned when the following criteria were met:The participant was familiar with the stages of TANDAS (protection of water sources, conveyance, sedimentation, filtration, chlorination, and safe storage).<br>1. The participants understood the three fundamental activities required for the operation of filters: proper use, handling, and maintenance.<br>2. The participant could identify at least one type of non-conventional water treatment technology. | Recognizes at least 2 of the 3 characteristics. | Recognizes at least 1 of the 3 characteristics. | Recognizes none of the characteristics. |
| 4. Satisfaction level | This classification was assigned when participants recognized at least five (5) of the following elements during the socialization sessions, workshops, and evaluations:<br>1. Dynamic, creative, and engaging processes<br>2. A sense of trust fostered among participants<br>3. Promotion of learning and reflection<br>4. Increased awareness of the subject under study<br>5. Opportunities for interactive learning and skill development | Assigned when the participant recognized at least three (3) of the aforementioned characteristics. | Assigned when the participant recognized at least one (1) of the aforementioned characteristics. | Assigned to participants who did not recognize any of the aforementioned features. |

**Source:** Own elaboration.

**Table 2.** Level of participation

| | 1) Passivity (low level). | 2) Participation (medium level) | 3) Interactive participation (high level) | 4) Active participation (self-development). |
|---|---|---|---|---|
| **5. Participation level** | The participant attended the meetings but did not demonstrate active participation. | The participants attended the meetings, responded to a few questions, and appeared primarily motivated by the incentive of receiving the filter. | The participant actively engaged in the various workshop activities, responded to questions, took part in group dynamics, contributed to discussions, interacted with other attendees, and participated in the workshop evaluation. | The participants trained members of their institution or educational center, established a safe water monitoring committee, and formed a group of safe water advocates. |

**Source:** Leonel *et al.* (2011)

### *Implementation and evaluation of the LifeStraw® Community filters*

Eight (8) institutions or educational centers selected under Inter-administrative Agreement 1411-19 were sampled using proportional stratified sampling, with p = 0.5, a sampling error of 10%, and a confidence level of 95%. Beneficiaries received training in the operation and maintenance of the filters, and the efficiency of the technology was monitored. The objective of the evaluation was to ensure the social adoption of non-conventional systems within the educational community.

An analysis of the physicochemical and microbiological parameters of treated water samples—taken from the effluent of the treatment systems—was conducted in the certified laboratory of the Departmental Health Institute of Nariño (DHIN), following "Standard Methods," editions 22 and 23. The parameters analyzed included: Turbidity (NTU), Total Alkalinity (mg $CaCO_3$/L), Total Coliforms (MPN/100 mL), and Escherichia coli (MPN/100 mL). For the calculation of the Water Quality Risk Index (WQRI), samples one and two were averaged, and the following parameters were weighted: Apparent Color (AC), Hydrogen Potential (pH units), Turbidity (NTU), Total Alkalinity (mg $CaCO_3$/L), Total Hardness (mg $CaCO_3$/L), Total Coliforms (MPN/100 mL), and Escherichia coli (MPN/100 mL), in accordance with the methodology established in Resolution 2115 of 2007. Table 3 was used to analyze the behavior of this index and to determine the risk classification of the water intended for human consumption.

**Table 3.** Risk classification of water for human consumption, (taken from Resolution 2115 of2007)

| WQRI Classification (%) | Risk level | WQRI per sample (Notifications that health authority will address immediately) |
|---|---|---|
| 80,1-100 | Not sanitarily viable | Inform the provider, the COVE, the mayor, the governor, the SSPD, the MPS, the INS, the MAVDT, the Comptroller General's Office and the Attorney General's Office |
| 35,1-80 | High | Inform the provider, the COVE, the mayor, the governor, and the SSPD. |
| 14,1 – 35 | Medium | Inform the provider, the COVE, the mayor, and the governor. |
| 5,1 – 14 | Low | Inform the provider and the COVE. |
| 0-5 | No risk | Continue monitoring and surveillance. |

**Source:** Own elaboration.

Data were statistically analyzed using Pearson's linear correlation analysis at a significance level of $p < 0.05$, employing InfoStat software, version 2020.

## Results

In the locative and infrastructural hygienic diagnosis, 100% of food handlers surveyed reported having received training through the School Nutrition Program (SNP). However, as these employees are hired on an annual basis, frequent staff turnover leads to a loss of institutional knowledge, making it essential to reinforce training on an ongoing basis. Resolution 29452 of 2017 stipulates that food handlers must be knowledgeable in topics related to proper manufacturing practices and hygiene in food handling, in order to promote behavioral change through appropriate attitudes and practices, thereby encouraging the production of safe food and reducing the risk of disease transmission [15].

Regarding the proper use of equipment, 88% of handlers complied with the requirements set orth in Decree 2674 of 2013, which mandates good manufacturing practices, including the use of light-colored work clothing with closures (zippers or snaps) rather than buttons, and without pockets located above the waist. Although the majority (88%) conformed to the dress code, the remaining 12% still represents a critical risk of cross-contamination. Even minimal non-compliance can jeopardize the safety of the entire food system. In this regard, López (2022) underscores the importance of frequent training to ensure food safety.

Cross-contamination can introduce pathogens when hygiene, cleaning, and disinfection protocols are breached or when equipment is used improperly. For instance, [14] identified contamination on domestic kitchen countertops, while [17] reported microbial transfers from pads to hands ranging from 4.5 to 5 log CFU/cm², illustrating a significant cross-contamination risk. Additionally, norovirus was shown to transfer efficiently from hands to various surfaces, contaminating up to seven (7) melamine surfaces in sequence. According to [20], changing clothing and aprons when soiled can significantly reduce contamination risks.

With respect to knowledge of safe water, 85% of kitchen staff and only 20% of students correctly understood the concept, while the remainder confused it with drinking or clean water. These findings highlight the need for ongoing, interdisciplinary training that bridges community-based knowledge with scientific and technological understanding. Such training should involve the broader educational community, the DHIN, municipal education secretariats, and universities. As [20] notes, interdisciplinarity involves a mental and emotional process and a life vision that promotes dialogue and problem-solving, aligning scientific reasoning with lived realities to foster collaborative efforts.

Regarding infrastructure, all school kitchens (100%) were constructed with brick, a material that helps minimize exposure to external contaminants. Floor materials included tile (58%), wooden planks (23%), and other materials (19%). Roofs were made of Eternit tile (50%), concrete (42%), zinc tile (4%), and other materials (4%). These features comply with the basic infrastructure standards established by Decree 3075 of 1997, facilitating maintenance, cleanliness, and hygiene control.

In terms of kitchen countertops used for food preparation, 100% of the institutions were found to be in good to very good condition, meeting the standards of Decree 3075 of 1997. This decree promotes proper food handling and reduces cross-contamination risks. The Colombian Basic Sanitation Plan for School Cafeterias states that food preparation areas must be constructed from impermeable materials like ceramic tiles, and that cooking and serving stations must be arranged for efficient workflow. Furthermore, there must be designated areas for dishwashing, using potable water and odorless, colorless detergents, along with appropriate waste disposal systems.

To ensure the proper provision of food services and protect public health, continuous training on good manufacturing, hygiene, and sanitation practices is essential. Similar findings were reported by [18], who found that food handlers in online sales during the pandemic lacked awareness and interest in such practices, often neglecting associated health risks.

Concerning non-perishable food storage, 81% of institutions reported using pantries, 12% used plastic containers, and 8% used other properly labeled areas. These practices largely align with the guidelines of Resolution 2674 of 2013, although the use of plastic containers is not explicitly addressed. Nevertheless, this method is commonly used in the studied regions to keep food clean, dry, and protected from pests and rodents.

## Social adoption strategy

Students' prior knowledge regarding safe water, household-level treatment, and safe storage was generally low. However, in the area of handling and hygiene, the majority of students demonstrated a medium level of prior knowledge. This may be attributed to previous exposure through the School Nutrition Program (SNP) (see Table 4).

**Table 4.** Indicators of Prior and Acquired Knowledge in Training for the Social Adoption of Unconventional Technologies among the Educational Community in Institutions of the Obando Subregion, Department of Nariño, Colombia (2019–2021)

| Location | No. of people | Safe water | | | Manipulation and hygiene | | | Domestic Treatment in the Home and Safe Storage (TANDAS) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | % | Rating scale | Acquired knowledge indicator | % | Rating scale | Acquired knowledge indicator | % | Rating scale | Acquired knowledge indicator |
| **Ipiales** | 22 | 34 | Low* | Medium | 45 | Medium** | High | 27 | Low* | High |
| **Puerres** | 38 | 8 | Low* | Low | 16 | Low* | High | 16 | Low* | High |
| **Funes** | 33 | 12 | Low* | Medium | 47 | Medium** | High | 12 | Low* | High |
| **Pupiales** | 12 | 25 | Low* | Medium | 50 | Medium** | High | 17 | Low* | High |

**Source:** Own elaboration.

Based on the observation of acquired knowledge indicators, it was determined that, regarding the topic of safe water, most municipalities showed an improvement from a low to medium level on the evaluation scale, suggesting that the didactic tools implemented in the workshops facilitated learning. However, the cultural uprooting of certain concepts limited full achievement of the indicator. Specifically, in the municipality of Puerres, knowledge levels remained unchanged, possibly due to the lack of clarity or dynamism of facilitators during training activities.

In relation to handling and hygiene, as well as household water treatment and safe storage, the use of information and communication technologies (ICTs) proved effective in supporting learning processes. According to [22], cognitive, affective, and motivational components enhance participation and thus lead to more significant learning outcomes. Similarly, [23] argues that, from an anthropological perspective, the discussion must go beyond the access and use of ICTs to consider the merging of sociocultural and technological processes shaped by various factors, aspects, and stakeholders. Furthermore, [25] found that knowledge is more easily assimilated in playful and harmonious environments, which facilitates the social appropriation of knowledge. In this sense, games enrich and strengthen individuals' experiential domains, sustain their engagement, and direct their attention toward meaningful learning.

The satisfaction indicator for the training activities and workshops showed high levels, as reflected in participant comments highlighting the sessions as dynamic, creative, and trust-building. Participants also emphasized that the workshops encouraged learning, reflection, and awareness of the topics addressed. The use of interactive dynamics and games was particularly effective in making learning more visual and reducing the fear of making mistakes [22,25].

Regarding the participation indicator, the municipalities of Pupiales, Ipiales, and Funes were characterized by a high level of engagement. Participants in these locations were actively involved in workshop activities and dynamics, responded to questions, contributed to discussions, interacted with peers, and participated in evaluations. In contrast, Puerres exhibited low levels of participation, likely influenced by a cultural tendency toward reserved behavior and participation primarily motivated by potential benefits associated with paternalistic governmental programs. As noted by [12], participation is influenced not only by academic knowledge but also by individuals' cognitive perceptions of their own reality and cultural context.

## Implementation and evaluation of unconventional systems

Table 5 presents the initial Water Quality Risk Index (WQRI) reported by the Departmental Health Institute of Nariño, as well as the effluent WQRI for each sampling conducted and the corresponding average values obtained during this study.

**Table 5.** Behavior of the WQRI

| Municipality | Location | WQRI without filters | | WQRI with filters | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | WQRI Classification (%) initial | Risk level initial | WQRI Classification (%) sample one | Risk level samplene o | WQRI Classification (% sample two) | Risk level sample two | WQRI Classification (%) sample three | Risk level sample three | WQRI Classification (%) average | Risk level average |
| Funes | Centro Educativo Guapuscal Bajo | 68% | High | 7% | Low | 23% | Medium | 27% | Medium | 19% | Medium |
| Funes | Centro Educativo La Pradera | 51% | High | 7% | Low | 7% | Low | 7% | Low | 7% | Low |
| Ipiales | Centro Educativo El Charco | 57% | High | 0% | Low | 0% | No risk | 2% | Sin Riesgo | 1% | Sin Riesgo |
| Puerres | Centro Educativo San Francisco de Yanalé | 53% | High | 7% | Low | 2% | No risk | 27% | Medium | 12% | Medium |
| Pupiales | Institución Eduacativa María Auxiliadora | 32% | Medium | 0% | No risk | 17% | Medium | 17% | Medium | 11% | Medium |
| Pupiales | Centro Educativo Chires Centro | 71% | High | 2% | No risk | 2% | No risk | 8% | Low | 4% | No risk |
| Pupiales | Centro Educativo Inchunchala | 40% | High | 0% | No risk | 0% | No risk | 17% | Medium | 6% | Low |
| Pupiales | Centro Educativo San Juan Bosco | 32% | Medium | 0% | No risk | 0% | No risk | 0% | No risk | 0% | No risk |

**Source:** Own elaboration.

According to Table 5, the Water Quality Risk Index (WQRI) decreased with the implementation of the technology, indicating that the filter contributes to improving water quality. However, an increase in risk was observed during the third sampling, which may be attributed to deficiencies in the cleaning procedures or filter operation by the handlers. This highlights the need for ongoing training to ensure proper use of the filter. To verify the reduction in the WQRI, Table 6 presents the analysis of the corresponding parameters.

**Table 6.** Descriptive statistics of the WQRI performance

| Parameter | WQRI without filter | WQRI with filter (average) |
|---|---|---|
| Mean | 50.5% | 7.5% |
| Standard deviation | 14.98 | 6.30 |
| Minimum | 32.0 | 0.0 |
| Maximum | 71.0 | 19.0 |
| Median (50%) | 52.0 | 6.5 |

**Source:** Own elaboration.

According to Table 6, a significant reduction in the Water Quality Risk Index (WQRI) was confirmed following the implementation of the LifeStraw® Community technology. The Shapiro-Wilk test confirmed the normality of the data for both unfiltered and filtered water:

- Unfiltered WQRI: Statistic = 0.923, p-value = 0.458 (> 0.05)
- Filtered WQRI (average): Statistic = 0.951, p-value = 0.719 (> 0.05)

Given these results, a paired samples t-test was applied, yielding a p-value < 0.001, confirming a statistically significant difference between pre- and post-filtration values. For additional robustness, the nonparametric Wilcoxon test was conducted, producing a p-value = 0.0078.

The homogeneous behavior of the WQRI after filter use was reflected in a lower standard deviation (SD = 6.30), compared to the initial values (SD = 14.98). This indicates that the intervention not only reduced risk but also improved the consistency and stability of water quality. These findings strongly support the effectiveness of the adopted filtration strategy in rural settings.

Table 7 presents the average results of physicochemical and microbiological parameters per municipality, confirming that—as indicated in the technical specifications—the LifeStraw® Community technology guarantees access to safe water. However, in Funes and Pupiales, the total coliforms parameter failed to meet the requirements of Resolution 2115 of 2007, likely due to inadequate filter operation or maintenance. As noted by [9], filter efficiency can be compromised by improper handling, underscoring the need to strengthen the social adoption strategy related to its use.

Regarding water color, municipalities such as Funes and Puerres also failed to meet the regulatory standards. This may be explained by the timing of the sampling during rainy periods, as the filtration system is not designed to remove color-related parameters. Nevertheless, as concluded by [22] in a study conducted in rural areas of Harij Taluka, Patan District, North Gujarat, this factor does not represent a significant risk to human health.

**Table 7.** Average results of the physicochemical and microbiological parameters—by municipality —evaluated using the LifeStraw® Community technology in 2021, and corresponding compliance with Resolution 2115 of 2007

| Parameter | Municipality | Funes | Ipiales | Puerres | Pupiales |
|---|---|---|---|---|---|
| Apparent colour (AC) | Average result | 22,5 | 5 | 20 | 6,25 |
| | Admissible value S/ Res. 2115 of 2007 | Maximum 15 | Maximum 15 | Maximum 15 | Maximum 15 |
| | Accordance | Not in accordance with | In accordance with | Not in accordance with | Not in accordance with |

| | | | | | |
|---|---|---|---|---|---|
| **Hydrogen potential (pH units)** | Average result | 7,175 | 6,85 | 7 | 6,775 |
| | Admissible value Acc/ Res. 2115 of 2007 | 6,5 a 9,0 | 6,5 a 9,0 | 6,5 a 9,0 | 6,5 a 9,0 |
| | Accordance | In accordance with | In accordance with | In accordance with | In accordance with |
| **Turbidity (UNT)** | Average result | 0,5 | 0,5 | 0,5 | 0,5 |
| | Admissible value Acc/ Res. 2115 of 2007 | Maximum 2 | Maximum 2 | Maximum 2 | Maximum 2 |
| | Accordance | In accordance with | In accordance with | In accordance with | In accordance with |
| **Total alkalinity (mg CaCO3/L)** | Average result | 33 | 30,5 | 20 | 41,25 |
| | Admissible value Acc/ Res. 2115 of 2007 | Maximum 200 | Maximum 200 | Maximum 200 | Maximum 200 |
| | Accordance | In accordance with | In accordance with | In accordance with | In accordance with |
| **Total hardness (mg CaCO3/L)** | Average result | 21,75 | 71,5 | 14 | 39,25 |
| | Admissible value Acc/ Res. 2115 of 2007 | Maximum 300 | Maximum 300 | Maximum 300 | Maximum 300 |
| | Accordance | In accordance with | In accordance with | In accordance with | In accordance with |
| **Total coliforms (NMP/100 mL)** | Average result | 230,95 | 1 | 1 | 131,65 |
| | Admissible value Acc/ Res. 2115 of 2007 | < 1 | < 1 | < 1 | < 1 |
| | Accordance | Not in accordance with | In accordance with | In accordance with | Not in accordance with |
| **Escherichia coli (NMP/100 mL)** | Average result | 1 | 1 | 1 | 1 |
| | Admissible value Acc/ Res. 2115 of 2007 | 1 | 1 | 1 | 1 |
| | Accordance | In accordance with | In accordance with | In accordance with | In accordance with |

**Source:** Own elaboration.

According to Pearson's linear correlation analysis ($p < 0.05$), a strong relationship was identified between pH and apparent color, which may be attributed to the heterogeneity of minerals and the soil characteristics in the department of Nariño. As most soils in this region have developed under volcanic influence, [25] explains that natural waters can exhibit acidic pH levels due to the presence of dissolved $CO_2$, sulfuric acid, mineral content, and humic acids resulting from soil decomposition. Furthermore, water color can be influenced by fine suspended materials, which—according to the technical specifications of the LifeStraw® Community filter—are not effectively removed by this technology.

A direct correlation between alkalinity and hardness was also observed, supporting the findings of [26], who assert that increases in total hardness are associated with the presence of mineral salts, nutrients, sulfates, total solids (TS), suspended solids (SS), electrical conductivity (EC), alkalinity, and turbidity.

In contrast, Escherichia coli and turbidity did not show significant correlations with other parameters, suggesting that the filter is effective in removing these contaminants. This observation is reinforced by the fact that turbidity mainly indicates the presence of suspended particulate matter, such as fine soil particles, which are efficiently removed by the filtration system.

Regarding total coliforms, a positive correlation was found with nitrites ($p < 0.05$). This may be explained by the agricultural land use predominant in Nariño. Agricultural practices can introduce ammonium compounds, which, through oxidation or microbial reduction of nitrates, can promote microbial growth—an indication of possible recent contamination [27]. It is important to note that ammonium is not removed by this filtration technology.

Additionally, pH (ranging from 6.775 to 7.175 pH units) and total coliforms (from 1131.65 to 230.95 MPN/100 mL) were the parameters that most influenced the variability of the WQRI. Among microbiological indicators, fecal coliforms are of greatest concern when establishing public health goals, as they represent a potential risk of diarrheal disease if consumed [28, 29]. This risk increases if the filtration system is not operated correctly.

As noted by [30] and [10], the maintenance of filtration systems is a critical factor for ensuring their effectiveness. Specifically, the membrane filter requires careful daily cleaning, strictly following the guidelines provided in the user manual, as improper maintenance may compromise the microbiological quality of the treated water.

## Conclusions

The diagnostic assessment revealed that the materials used in school kitchens and cafeterias comply with Colombian regulations and facilitate cleaning and disinfection processes, thereby ensuring adequate hygiene conditions in food preparation areas. However, the water used for food preparation and consumption exhibited a high Water Quality Risk Index (WQRI), posing significant public health risk, particularly to the student population.

The social adoption strategy, grounded in teaching-learning processes that incorporated playful and participatory methodologies, proved effective in enhancing levels of participation, collaborative work, user satisfaction, and knowledge acquisition related to safe water, hygiene and food handling, and domestic water treatment and storage. The proper operation and maintenance s LifeStraw® Community technology also contributed to raising baseline knowledge, which had initially been categorized as low. Following the implementation of the educational strategies, acquired knowledge was assessed as medium to high. Nevertheless, due to the complexity of certain content, particularly related to TANDAS, and the cultural characteristics of the participants, some learning outcomes remained limited, indicating the need for ongoing training and reinforcement.

The LifeStraw® Community technology met the technical specifications provided by the manufacturer, effectively removing turbidity, total coliforms, and Escherichia coli. However, in two municipalities, these parameters were negatively impacted due to inadequate operation and maintenance by institutional personnel, jeopardizing the delivery of safe drinking water to students.

The implementation of LifeStraw® Community in educational institutions led to a significant reduction in water-related health risks, decreasing WQRI levels from high to low, and in some cases, to no risk at all. This success supported the establishment of Agreement 1411-19, which recognizes the importance of this technology and its social adoption strategy in ensuring safe drinking water for the student population of the Obando subregion.

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