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Health Risk Management in Bottled Water: Integration of Physicochemical, Microbiological Indicators and Cyanobacterial Risks in Guayas.

Gestión del riesgo sanitario en agua embotellada: integración de indicadores fisicoquímicos, microbiológicos y riesgos por cianobacterias en Guayas.

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Abstract.
Bottled water quality represents a growing public health concern, particularly in contexts exposed to environmental pressures and emerging biological contaminants. This study aimed to evaluate bottled water quality and associated health risks using physicochemical and microbiological indicators, as well as conditions favoring cyanobacterial proliferation. Samples from different commercial brands in Guayaquil were analyzed using spectrophotometric methods, physicochemical measurements, membrane filtration for Escherichia coli, and enzymatic assays for microcystin detection. Results revealed significant inter-brand variability, characterized by low residual chlorine, moderate nutrient presence, and sporadic microbiological contamination events, indicating vulnerability in product sanitary stability. Furthermore, nutrient availability and environmental conditions suggest potential for cyanobacterial growth. Overall, findings demonstrate that compliance with physicochemical standards does not ensure safety, highlighting the need for an integrated risk management approach to improve bottled water quality control.

Keywords:
Bottled Water, Water Quality, Health Risk, Physicochemical Indicators, Escherichia Coli, Microbiological Safety, INEN 2200 Standard..

Resumen.
La calidad del agua embotellada representa un desafío creciente para la salud pública, especialmente en contextos con presión ambiental y riesgos emergentes asociados a contaminantes biológicos. El objetivo del estudio fue evaluar la calidad del agua embotellada y su riesgo sanitario mediante indicadores fisicoquímicos, microbiológicos y la identificación de condiciones favorables para cianobacterias. Se analizaron muestras de distintas marcas comercializadas en Guayaquil mediante espectrofotometría, medición de parámetros fisicoquímicos, filtración por membrana para Escherichia coli y detección de microcistinas mediante ensayo enzimático. Los resultados evidenciaron variabilidad significativa entre marcas, con niveles bajos de cloro residual, presencia moderada de nutrientes y eventos puntuales de contaminación microbiológica, lo que indica vulnerabilidad en la estabilidad sanitaria del producto. Además, la combinación de nutrientes y condiciones ambientales sugiere potencial para proliferación de cianobacterias. En conjunto, los hallazgos evidencian que el cumplimiento fisicoquímico no garantiza la inocuidad, destacando la necesidad de un enfoque integral de gestión del riesgo para fortalecer el control de calidad del agua embotellada.

Palabras clave:
Agua Embotellada, Calidad Del Agua, Riesgo Sanitario, Indicadores Fisicoquímicos, Escherichia Coli, Inocuidad Microbiológica, Norma INEN 2200.

1.- Introduction

Access to safe drinking water is one of the main public health challenges worldwide. The quality of water intended for human consumption must guarantee the absence of physical, chemical and microbiological contaminants that may pose health risks. In this context, the World Health Organization (WHO) establishes that the protection of public health depends on comprehensive risk management based on continuous monitoring of quality parameters and the implementation of water safety plans from source to consumer [1]

Water pollution poses a significant threat to human health and ecosystems. Microbiological contamination is mainly associated with waterborne infectious diseases, while chemical contamination can generate chronic effects such as neurological and reproductive alterations and various types of cancer. Although disinfection processes, particularly chlorination, have significantly reduced the incidence of waterborne infectious diseases, they can also produce chemical by-products that are potentially harmful to health when not properly controlled.[2]

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The relevance of microbiological control of water has been widely documented. reported an outbreak of gastroenteritis caused by *Shigella sonnei* associated with the consumption of contaminated public supply water, showing that failures in disinfection systems can trigger important public health problems. These findings highlight the need to implement continuous monitoring systems that allow for the timely detection of microbiological risks and the prevention of epidemic outbreaks.[3]

In recent decades, the perception of insecurity regarding mains water has driven a sustained growth in bottled water consumption worldwide. The global bottled water market mobilizes billions of dollars annually and continues to expand due to consumers' perception of greater purity and health safety. However, various studies have shown that the quality of bottled water can be affected by factors related to the source of catchment, treatment processes, bottling, storage and distribution conditions, generating variability between brands and production batches.[4]

In Ecuador, bottled water consumption has increased significantly due to limited reliance on some public supply sources. In the city of Guayaquil, 83.8% of consumers report using bottled water on a regular basis, associating this product with attributes of safety, purity and quality. However, research carried out in Quito showed that, although the physicochemical parameters of bottled mineral water generally comply with national and international regulations, some samples showed moderate concentrations of heterotrophic bacteria and microorganisms of the genus *Pseudomonas*, which shows the need to maintain periodic microbiological controls to guarantee the safety of the product [5]

Despite the abundance of water resources in Ecuador, significant challenges related to water quality remain. In particular, microbiological indicators continue to be fundamental tools for determining the health safety of water resources, since they allow the identification of the possible presence of pathogenic microorganisms associated with fecal contamination and other emerging risks. Among the latter, the proliferation of cyanotoxin-producing cyanobacteria stands out, currently considered a growing threat to public health and aquatic ecosystems. Factors such as the increase in nutrients, especially nitrogen and phosphorus, as well as the increase in temperature associated with climate change, favour eutrophication processes and the proliferation of potentially toxic microorganisms.[6]

Cyanobacteria have a secondary metabolism capable of producing toxic compounds such as microcystins, anatoxins and cylindrospermopsins, which have hepatotoxic, neurotoxic and dermatotoxic effects on aquatic organisms and humans. These toxins can be released into the environment during cellular senescence, increasing the risk of exposure through contaminated water consumption, recreational activities, and the food chain.[7]

The province of Guayas represents a scenario of special interest due to the growing anthropogenic pressure on its water resources. Recent studies have identified microbiological contamination in sources intended for human consumption. reported the presence of total coliforms and *Escherichia coli* in samples of bottled water marketed in different cantons of the province, while they detected genes associated with the production of microcystins and cylinspermopsins in samples from the Daule River. These findings show the existence of potential health risks even in the absence of visible cyanobacteria blooms.[8]

In addition, the Guayas basin faces limited availability of information on the factors that trigger harmful algal blooms and toxin production in tropical ecosystems. Recent research indicates that the specific thresholds of the physicochemical and climatic variables that favor these phenomena in the region are still unknown. This situation is particularly worrying considering that climate change could increase the frequency and intensity of toxic blooms, generating greater risks to human and environmental health.[9]

From a public health perspective, water quality management requires a comprehensive approach that considers both traditional microbiological risks and emerging threats associated with biological and chemical contaminants. Under the paradigm of "One Health" (*One Health*), it is essential to recognize the close interrelationship between human health, animal health and the health of aquatic ecosystems. In this context, the evaluation of physicochemical and microbiological parameters of water is a fundamental tool for the early identification of risks, the formulation of mitigation strategies and the protection of the health of the population.[10]

Therefore, the objective of this study is to evaluate water quality through the determination of physicochemical and microbiological indicators, with emphasis on the identification of health risks associated with indicator microorganisms and emerging contaminants, contributing to the strengthening of water quality surveillance and management systems in the province of Guayas.[11]

1.1. Health risk management in water systems for human consumption.

Health risk management in water systems for human consumption is a comprehensive approach aimed at identifying, evaluating and controlling hazards that may compromise the health of the population. Various studies have indicated that the guarantee of safe water does not depend only on compliance with regulatory parameters, but also on the implementation of dynamic strategies that allow anticipating and mitigating risks throughout the supply chain, from the source to the final consumer. In this context, the concept of risk management has evolved from a reactive approach to preventive models, in which the early identification of hazards and the reduction of their probability of occurrence are prioritized. [12]

From a methodological perspective, recent literature suggests that risk management systems in drinking water should be based on tools such as Water Safety Plans, which integrate hazard analysis, vulnerability assessment, and the implementation of control measures at each stage of the process. This approach recognises that health risks can originate from microbiological contaminants as well as chemical compounds and, more recently, from emerging contaminants such as cyanotoxins. Likewise, the need to consider factors such as environmental variability, anthropogenic influence, and the operating conditions of treatment and distribution systems, which can act as critical determinants in the generation and propagation of risk, is emphasized.[13]

In relation to the variables analysed in this study, health risk management acquires particular relevance as it evidences the interaction between physicochemical and microbiological parameters as determinants of water quality. The literature has highlighted that suboptimal levels of disinfectants, such as residual chlorine, can reduce the capacity for microbiological control, while the presence of nutrients such as nitrates and phosphates can favor eutrophication processes and the development of potentially harmful microorganisms. In this sense, the integrated evaluation of these parameters allows not only to diagnose the current state of the water, but also to infer conditions that could increase the probability of health risks over time.[14]

Consequently, the adoption of a risk management approach in the analysis of bottled water is essential to transcend traditional schemes based on compliance with permissible limits and move towards predictive and preventive models. The identification of variability in the evaluated parameters and the detection of specific pollution events show the need to strengthen monitoring and control systems, incorporating indicators that allow anticipating emerging risks. In this way, this study is framed in a comprehensive perspective that seeks to contribute to the development of more robust strategies for the protection of public health in the province of Guayas.[15]

1.2. Physicochemical indicators as tools for assessing water quality.

Physicochemical indicators are fundamental tools for the evaluation of the quality of water intended for human consumption, since they allow characterizing its chemical and physical properties, as well as identifying possible alterations derived from natural processes or anthropogenic activities. Studies have shown that parameters such as pH, electrical conductivity, total dissolved solids, and nutrient concentration provide key information on the condition of water and its suitability for consumption. In this sense, these indicators not only reflect the intrinsic quality of the water resource, but also act as early signals of possible contamination or deterioration processes.[2]

From an analytical perspective, recent literature suggests that the interpretation of physicochemical indicators should be approached in an integrated way, considering the interactions between variables and their influence on the stability of the aquatic system. pH, for example, conditions the solubility of chemical compounds and biological activity, while conductivity and total dissolved solids are associated with the mineralization of water and the presence of dissolved ions. On the other hand, nutrients such as nitrates, nitrites and phosphates play a central role in eutrophication processes, acting as limiting factors for the growth of microorganisms. This systemic approach allows us to understand that water quality does not depend on a single parameter, but on the complex interaction between multiple variables that can amplify or mitigate health risks.[16]

In relation to the variables analysed in this study, physicochemical indicators acquire special relevance as they show patterns of variability that may be associated with both the origin of the water and the treatment and storage processes. Moderate concentrations of nitrates and phosphates, combined with low levels of residual chlorine, suggest potentially favorable conditions for the proliferation of microorganisms, including toxin-producing cyanobacteria. In addition, the observed variability in parameters such as electrical conductivity and total dissolved solids indicates differences in chemical composition between samples, which could influence water stability and the efficiency of disinfection processes. In this way, physicochemical indicators not only allow us to assess the current quality of the water, but also to infer underlying processes that could impact its safety over time.[17]

Consequently, although physicochemical indicators are widely used as control criteria in health regulations, their ability to guarantee water safety is limited when considered in isolation. The literature has highlighted that compliance with permissible values does not necessarily imply the absence of risk, especially in contexts where there are emerging contaminants or conditions that favor biological proliferation. Therefore, the analysis of these indicators must be integrated into a broader risk management approach, in which their interpretation is complemented by microbiological data and the evaluation of environmental and operational factors. In this framework, the present study aims to demonstrate the need for a multidimensional evaluation to improve the surveillance and control of bottled water quality in environments with high anthropogenic pressure.[18]

1.3. Microbiological indicators and risk associated with faecal contamination.

Microbiological indicators are one of the fundamental pillars in the evaluation of the sanitary quality of water for human consumption, due to their ability to evidence the possible presence of pathogenic microorganisms associated with fecal contamination. Several studies have indicated that the detection of indicator bacteria, particularly Escherichia coli, allows inferring the existence of recent contamination and, therefore, the potential presence of etiological agents responsible for waterborne diseases. In this sense, microbiological indicators not only fulfill a monitoring function, but also represent a direct criterion of safety, since their presence implies an immediate risk to public health. [19]

From a conceptual perspective, the scientific literature has consolidated the use of E. coli as a universal marker of fecal contamination due to its specificity, abundance in the intestinal tract of warm-blooded animals, and ease of detection by standardized methods. This approach is based on the premise that the introduction of fecal matter into water systems entails the possible presence of pathogens such as bacteria, viruses and protozoa, which may not be directly detected due to their analytical complexity. However, it is also recognized that microbiological indicators have limitations, as they do not always reflect the presence of all pathogens or fully capture the dynamics of emerging contaminants, reinforcing the need to complement their analysis with other parameters.[20]

In the context of the present study, microbiological evaluation is critically important as it reveals the presence of E. coli in certain bottled water samples, which is direct evidence of failures in the disinfection, packaging, or storage processes. The coexistence of contamination-free samples with others with high concentrations of colony-forming units suggests significant variability in sanitary quality between brands and batches. This heterogeneity, in combination with low levels of residual chlorine observed in the physicochemical analysis, indicates conditions conducive to microbial survival and proliferation, increasing the probability of exposure to pathogens. In addition, this scenario shows the vulnerability of the system to post-treatment contamination events, which can occur even when the water initially meets quality standards.[21]

Consequently, the interpretation of microbiological indicators in the framework of health risk management requires an approach that goes beyond the timely verification of regulatory compliance and is oriented towards understanding the dynamics of contamination and exposure. The presence of sporadic but significant fecal contamination events suggests a risk model characterized by low frequency and high severity, which is particularly relevant in terms of public health. Therefore, the integration of microbiological indicators with physicochemical and environmental variables is positioned as a fundamental strategy for the development of more robust surveillance systems, capable of anticipating risks and guaranteeing the safety of bottled water in contexts with high anthropogenic pressure.[22]

1.4. Cyanobacteria and cyanotoxins as emerging contaminants.

Cyanobacteria, also known as blue-green algae, are a group of photosynthetic microorganisms widely distributed in aquatic ecosystems, whose health relevance has increased significantly in recent decades. Various studies have indicated that, under certain environmental conditions, these microalgae can proliferate massively, generating harmful algal blooms that compromise water quality. This phenomenon, known as eutrophication, is mainly associated with the enrichment of nutrients such as nitrogen and phosphorus, as well as climatic factors such as the increase in temperature and the stability of the water column. In this context, cyanobacteria have been recognized as emerging contaminants due to their ability to alter the physicochemical conditions of water and to produce toxic compounds with direct implications for public health.[23]

From a toxicological perspective, the scientific literature has documented that many species of cyanobacteria are capable of synthesizing secondary metabolites known as cyanotoxins, among which microcystins, anatoxins and cylinspermopsins stand out. These compounds have a wide variety of adverse effects, including liver toxicity, neurotoxicity, and dermatological effects, depending on the route of exposure and the dose ingested. At the molecular level, microcystins, for example, act as potent inhibitors of phosphatase enzymes, disrupting critical cellular processes and causing tissue damage. The complexity of these toxins lies in their chemical stability and in their ability to persist in water even after cell death of cyanobacteria, which amplifies the risk of exposure in both raw and treated water.[24]

In relation to the variables analyzed in the present study, the presence of nutrients such as phosphates and nitrates acquires a central role as limiting factors in the proliferation of cyanobacteria. Recent literature suggests that moderate concentrations of these compounds may be sufficient to trigger algal growth processes in aquatic systems, especially in favorable thermal conditions such as those observed in tropical environments. Likewise, the low concentration of residual chlorine identified in some samples could limit the inhibition capacity of these microorganisms in long-term storage systems. Although the initial analysis did not show significant presence of cyanotoxins, the observation of growth under subsequent experimental conditions suggests the existence of a latent proliferation potential, which reinforces the hypothesis of vulnerability of the system to this type of contaminants. [25]

Consequently, the inclusion of cyanobacteria and their toxins in the water quality analysis responds to the need to expand the traditional approach towards an emerging risk perspective. The literature has highlighted that conventional monitoring systems, focused on classic physicochemical

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and microbiological parameters, may be insufficient to detect these risks early. Therefore, the integration of indicators associated with eutrophication and the specific surveillance of cyanotoxins is positioned as a critical component in health risk management. In this sense, the present study contributes to evidence the importance of considering these emerging contaminants in the evaluation of the quality of bottled water, particularly in regions with environmental conditions that favor their proliferation. [26]

1.5. Bottled water: perception of quality, real risks and control challenges.

Bottled water consumption has experienced sustained growth globally, driven mainly by the perception of greater purity, health safety and organoleptic quality compared to mains water. Various studies have indicated that this preference responds both to factors of institutional trust and to previous experiences related to the quality of public supply. In urban contexts with high pressure on supply systems, as is the case in several cities in Latin America, the choice of bottled water is associated with the search for a reduction in perceived health risk, positioning itself as an apparently safer alternative for human consumption.[27]

However, recent literature suggests that there is a significant gap between the perception of quality and the actual risks associated with bottled water. Despite being subject to specific regulations, its quality can be compromised by multiple factors along the value chain, including the source of capture, treatment processes, bottling conditions, as well as storage and distribution. The absence of an adequate disinfectant residual, together with exposure to variable environmental conditions, can favor the proliferation of microorganisms or the alteration of the physicochemical characteristics of the water. This set of factors shows that bottled water is not an inherently risk-free product, but that its safety depends on systematic and continuous control.[28]

Within the framework of this study, the evaluation of physicochemical and microbiological parameters reveals the existence of variability between brands and batches, which reinforces the hypothesis that quality control systems are not homogeneous in practice. The detection of low levels of residual chlorine, together with the presence of nutrients and specific events of microbiological contamination, suggests that production and management conditions can generate scenarios conducive to the deterioration of water quality. In addition, the possible interaction between these factors and the proliferation of emerging contaminants, such as cyanobacteria, introduces an additional dimension of risk that is not always considered in traditional surveillance systems.

Consequently, the challenges in the control of bottled water quality require the adoption of more comprehensive approaches based on health risk management, which incorporate the simultaneous monitoring of physicochemical, microbiological and emerging variables. The literature has emphasized the need to strengthen traceability systems, improve disinfection protocols, and ensure adequate storage and distribution conditions to minimize the likelihood of contamination. In this context, this study contributes to evidence the importance of rethinking bottled water quality assessment models, promoting a more critical and evidence-based view that effectively protects the health of consumers in environments with high demand and potential exposure.[29]

2.- Materials and methods.

The present study opted for a quantitative methodological design that integrated laboratory analysis with the collection of contextual information on the consumption of bottled water in the province of Guayas.

1. Sample collection

Bottled water samples were taken from various distribution points in the city of Guayaquil, including supermarkets, neighborhood stores, and street vendors. The sample included different brands and production batches, which were determined by a survey applied to consumers using Google Forms as a digital platform to determine the most consumed brands in order to obtain a representative view of the quality of the water that reaches the population. The sample size was defined by means of probability sampling, considering the accessibility and availability of the products in the market.[30]

2. Parameters analyzed

In the laboratory, analyses of physicochemical and microbiological parameters and the proliferation of cyanobacteria were carried out, using the following equipment and supplies:

- Nutrients (phosphates, nitrites and nitrates): They were determined with the Hach DRY 900 spectrophotometer equipment, using specific reagents for each of these parameters.
- Residual free chlorine: This was measured with the Hach DRY 900 spectrophotometer, following the protocols indicated by the manufacturer.
- pH: It was quantified with a digital pH-meter.
- *Eschericha coli* was performed by filtration method and cyanobacteria (Microcystin- RL)

3. Analysis procedure

Each sample was properly processed to ensure the reliability of the results. The values obtained were compared with the maximum permissible limits established by the Ecuadorian Technical Standard NTE INEN 2200:2017 – Bottled Purified Water, as well as with the recommendations of the World Health Organization (WHO, 2017) for water intended for human consumption.

4. Microbiological Methods

The detection of microcystins in the water samples was performed using the MicroCystest® kit (Zeulab, Spain), a method based on the inhibition of the enzyme protein

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phosphatase 2A (PP2A), the biological mechanism responsible for the toxicity of microcystins and nodularins. This methodology allows the real potential toxicity of the samples to be determined, detecting different variants of microcystins present in the water.
The procedure consisted of adding 50 µL of sample or standard in each well of a microplate, followed by the incorporation of the phosphatase solution and the chromogenic substrate. The samples were then incubated at 37 °C for 30 minutes. At the end of the incubation period, the stop solution was added and the spectrophotometric reading was performed at a wavelength of 405 nm. The concentration of microcystins was determined by means of a calibration curve elaborated with microcystin-LR standards.

The analytical validation of the method included the determination of the limit of detection (0.09 µg/L) and the limit of quantification (0.23 µg/L), as well as the evaluation of precision and accuracy by means of repeatability, intermediate precision and recovery tests.

For the determination of *Eschericha coli*. It has been performed by 100 mL membrane filtration, the filter is taken and placed in the selective medium for *E. coli* in blue, and the m-TEC agar, used in EPA method 1103.2, which consists of: a) Filtration: A known volume of water sample is filtered through a filtration membrane (usually with a pore size of 0.45 µm), retaining bacteria on the surface; b) Culture: The membrane is placed on a Petri dish with mTEC agar. c) Incubation: It is incubated at a high temperature (usually 44.5 °C for 24 hours) to inhibit unwanted bacteria d) Counting: After incubation, E . *coli* forms yellow-green colonies, which are counted directly as colony-forming units (CFUs) per 100 mL of sample.

3.- Results.

The results obtained are presented in the following tables of the parameters determined by the physical, chemical and microbiological analyses

Table 1. Water analysis using the HACH DRY 900

Sample	March	Free chlorine (mg/L)	Phosphate (mg/L)	nitratos (mg/L)	nitrites (mg/L)
ACB	Pure Water	0,02	1,6	1,2	0,001
ACF	Thessaly	0,03	2,0	2,0	0,007
ACF	Mountain	0,02	1,2	1,5	0,002
ANA	Ok	0,04	1,8	0,3	0,004
ASG	Ok	0,03	0,9	0,9	0,006
ACB	Ok	0,04	1,0	0,7	0,004
SCB	Aqua Premium	0,03	1,0	1,1	0,004
SNA	Omizu	0,02	1,4	4,7	0,004
SCB	Alive	0,01	1,1	1,3	0,002
SSG	Aqua Premium	0,01	1,5	1,2	0,007
SSG	Omizu	0,02	1,1	3,8	0,006
SSD	Thessaly	0,03	2,6	2,3	0,003
SSD	Alive	0,01	0,9	1,0	0,004
SSG	Pure Water	0,02	1,8	1,6	0,001
SSD	Sky	0,04	1,1	0,7	0,005
SSD	All Natural	0,03	1,7	1,3	0,001
SSD	Dasani	0,02	1,3	1,1	0,004
TCF	Mountain	0,02	1,3	1,6	0,001
TNA	Alive	0,02	0,9	1,3	0,002
TNA	Pure Water	0,07	1,5	1,1	0,005
TNA	Sky	0,06	1,0	0,4	0,006
TNA	All Natural	0,03	1,3	1,1	0,002
TNA	Dasani	0,03	1,1	0,9	0,009
TNA	Omizu	0,03	1,3	3,5	0,004
TNA	Thessaly	0,05	2,7	2,8	0,008
TNA	Aqua Premium	0,03	1,4	0,8	0,005
TSG	Mountain	0,02	1,5	1,4	0,021
ACB	All Natural	0,04	1,3	1,1	0,009
ACB	Sky	0,03	0,9	0,6	0,007
ACB	Dasani	0,03	1,4	0,8	0,004

The physicochemical characterization presented in Table 1 shows a relevant inter-brand variability in the main parameters associated with both water quality and the potential development of sanitary risks, which reflects heterogeneity in the collection, treatment and control processes in the bottled water industry in the province of Guayas. In terms of residual free chlorine, values ranged from 0.01 to 0.07 mg/L, consistently below the range recommended by the World Health Organization (0.2–0.5 mg/L) to ensure effective disinfection during storage and distribution. This condition implies a limited persistence of the disinfectant effect, which increases the probability of post-bottling microbiological recontamination, especially under inadequate handling conditions or prolonged environmental exposure. The wide range observed also suggests inconsistencies in chlorination protocols between different brands and batches, which constitutes a factor of uncertainty in health risk management.

Regarding dissolved nutrients, phosphates had concentrations between 0.9 and 2.7 mg/L, while nitrates varied between 0.3 and 4.7 mg/L. Although these values are below the maximum permissible limits established by international regulations for human consumption, their presence in relatively high concentrations in certain

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samples, particularly in brands such as Thessaly and Omizu, suggests contributions of anthropogenic origin associated with agricultural runoff or urban influences. From an ecological and health perspective, these nutrients are a key limiting factor in eutrophication processes, and can promote the proliferation of cyanobacteria in aquatic systems, including in treated water supply chains. In this sense, the coexistence of moderate levels of nitrogen and phosphorus increases the probability of generating trophic conditions favorable for the development of harmful algal blooms and the eventual production of cyanotoxins, which represents an emerging risk that transcends conventional physicochemical controls.

In relation to nitrites, the concentrations recorded were generally low (0.001–0.021 mg/L), however, the presence of high punctual values, as in the sample corresponding to the Montaña brand (0.021 mg/L), can be interpreted as an indicator of recent processes of contamination or incomplete transformation of nitrogen, reflecting possible deficiencies in the quality of the treatment or in the storage conditions. From the point of view of health risk, although the concentrations do not reach acute toxicity levels, the detection of nitrites acquires epidemiological relevance as it is associated with the formation of potentially harmful compounds, such as nitrosamines, and with adverse effects in vulnerable populations.

In an integrated manner, the analysis of Table 1 shows that, although the parameters evaluated are within permissible ranges in most cases, the variability observed and the combination of factors such as low chlorine residual and the presence of nutrients generate a scenario conducive to an increase in health risk. In particular, the convergence of conditions that favor both microbial survival and nutrient availability poses a potential risk of deterioration of water quality during its useful life, evidencing the need to strengthen control systems, implement continuous monitoring strategies and adopt a preventive approach based on comprehensive risk management.

Table 2. Results of the samples analyzed according to descriptive statistics

Numerical variable	# of data	Media	Standard Deviation	Medium	Cropped average (10%)
Cloro_libre (mg/L)	29	0,030	0,0138	0,03	0,0284
pH	30	7,141	0,4249	7,29	7,1958
Phosphates (mg/L)	30	1,387	0,4508	1,3	1,3167
Nitrates (mg/L)	30	1,470	1,0154	1,15	1,2833
Nitrites (mg/L)	30	0,005	0,0038	0,004	0,0044
uS/cm	30	221,667	216,8998	198,5	179,54
T_°C	30	25,047	0,5829	25,1	25,125
ppm	30	110,800	108,5247	99,5	89,750
mV	30	334,367	34,4528	330	333,541

The analysis of the descriptive statistics presented in Table 2 allows us to evaluate the central tendency, dispersion and stability of physicochemical parameters, providing an inferential basis for interpreting water quality and its implication in health risk. In the case of residual free chlorine, a mean of 0.030 mg/L with a standard deviation of 0.0138 is observed, indicating low relative variability but consistently reduced levels in most samples. The coincidence between the mean, median (0.03 mg/L) and trimmed mean (0.0284 mg/L) suggests an approximately symmetrical distribution with no influential extreme values, reinforcing the evidence of a systematic trend towards suboptimal concentrations of residual chlorine. From a health perspective, this homogeneity at low levels implies a generalized scenario of insufficient disinfectant capacity, consistently increasing the probability of survival or reintroduction of microorganisms during the distribution chain.

The pH has a mean of 7.141 with a moderate standard deviation (0.4249), indicating a relatively stable distribution around neutrality. The difference between the mean and the median (7.29) suggests a slight asymmetry towards lower values, although without critical deviations from the recommended range. The proximity between the arithmetic mean and the trimmed mean shows the absence of significant outliers, indicating relatively homogeneous chemical conditions between the samples. Although these values do not represent a direct risk to health, their stability contributes to maintaining favorable physicochemical conditions for biological processes, which becomes relevant in the presence of other factors such as the availability of nutrients.

In relation to phosphates, the mean of 1.387 mg/L and the standard deviation of 0.4508 reflect moderate variability, with a slight difference from the median (1.3 mg/L), indicating a slight positive asymmetry. This characteristic suggests the presence of some samples with relatively high concentrations that increase the average. From an environmental point of view, the persistence of phosphorus levels in this range can favor trophic enrichment processes, particularly when combined with appreciable concentrations of nitrogen, generating conditions conducive to the proliferation of cyanobacteria and increasing the potential risk of cyanotoxin production.

The behavior of nitrates shows a mean of 1.470 mg/L with a high standard deviation (1.0154), which shows a high dispersion of the data. The difference between the mean and the median (1.15 mg/L), as well as the reduction in the cut mean (1.2833 mg/L), suggest the presence of extremely high values that induce a positive asymmetry in the distribution. This pattern implies that, although most of the samples have moderate levels, there are specific cases with significantly higher concentrations that may be associated

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with specific sources of contamination. From the perspective of risk, this heterogeneity indicates that certain batches or brands are more likely to contribute to eutrophication processes or to show failures in the control of the quality of the source water.

Nitrites have a mean of 0.005 mg/L and a standard deviation of 0.0038, reflecting a relatively high variability compared to their mean value. The median (0.004 mg/L) and the trimmed mean (0.0044 mg/L) indicate a slight asymmetry towards higher values, which can be interpreted as evidence of specific events of recent contamination. Although concentrations remain low in absolute terms, their relative variability suggests instability in nitrogen oxidation processes, which could imply indirect risks associated with the formation of potentially harmful by-products.

The parameters associated with water mineralization, such as electrical conductivity (221.667 µS/cm) and total dissolved solids (110.800 ppm), have high standard deviations (216.8998 and 108.5247 respectively), indicating considerable dispersion and marked heterogeneity between samples. The difference between the mean and the median in both cases suggests the presence of extreme high values that significantly influence the distribution. This behavior is consistent with differences in water origins and treatment processes, which has implications for both sensory quality and chemical stability of the product. From a risk perspective, this variability could affect the interaction between chemical compounds and microorganisms, indirectly influencing the viability of certain pathogens or the persistence of potentially toxic compounds.

Finally, the temperature (mean of 25.047 °C) and the redox potential (334.367 mV) show low variability, which indicates relatively stable conditions during the analysis. However, thermal stability around values close to 25 °C may favor microbial growth in the absence of adequate disinfectant control, while redox potential values reflect a moderately oxidizing environment that, although it contributes to microbiological control, may not be sufficient in combination with low levels of residual chlorine.

Overall, inferential analysis of the descriptive statistics evidences that while parameter means are within acceptable ranges, dispersion and asymmetry of several key variables, particularly nutrients and mineralization parameters, reveal significant heterogeneity in bottled water quality. This variability, added to consistently low levels of residual chlorine, configures a latent health risk scenario, in which apparent chemical stability can mask conditions conducive to microbiological contamination and the proliferation of potentially harmful organisms.

Table 3. Microbiological analysis results

March	Codig	Presentation	Production	Expiration	UFC/100mL
AQUA	TNA	500 ml	26/05/25	26/07/25	0
	SSD	500 ml	26/05/25	26/07/25	0
	ACB	500 ml	26/05/25	26/07/25	0
ALL NATURE	TNA	625 ml	06/06/25	04/10/25	0
	SSD	625 ml	22/05/25	12/09/25	0
	ACB	625 ml	15/05/25	12/09/25	0
TESALI	TNA	625 ml	15/05/25	11/09/25	0
	SSD	625 ml	15/05/25	11/09/25	800
	ACB	625 ml	15/05/25	11/09/25	0
ALIVE	TNA	600 ml	06/05/25	03/10/25	0
	ACB	600 ml	19/05/25	16/10/25	0
	SSD	600 ml	16/04/25	13/09/25	0
PURE	TNA	500 ml	11/05/25	07/11/25	0
	ACB	500 ml	27/05/25	23/11/25	0
	SSD	500 ml	15/03/25	11/09/25	0
SKY	TNA	625 ml	11/05/25	07/11/25	0
	ACB	625 ml	11/05/25	07/11/25	0
	SSD	625 ml	11/05/25	07/11/25	0
OK	TNA	600 ml	23/05/25	20/10/25	0
	ACB	600 ml	23/05/25	20/10/25	0
	SSD	600 ml	23/05/25	20/10/25	0
MANY	TNA	500 ml	19/04/25	20/09/25	350
	ACB	500 ml	19/04/25	20/09/25	200
	SSD	500 ml	19/04/25	20/09/25	650
DASSANI	TNA	600 ml	19/05/25	20/08/25	0
	ACB	600 ml	19/05/25	20/08/25	0
	SSD	600 ml	19/05/25	20/08/25	0
OMIZU	TNA	500 ml	19/02/25	20/05/25	0
	ACB	600 ml	19/05/25	20/08/25	0
	SSD	600 ml	19/05/25	20/08/25	0

The microbiological analysis presented in Table 3 shows a heterogeneous behavior in the sanitary quality of bottled water, with direct implications in the assessment of risk to public health. In general terms, it is observed that most of the samples analyzed (24 out of 30) did not present detectable growth of Escherichia coli, which suggests that, under normal conditions, a significant proportion of the brands comply with the microbiological standards established by current regulations, which require the total absence of this indicator in water intended for human consumption. The consistency of negative results across multiple brands and batches indicates the partial implementation of proper disinfection and sanitary control practices during the treatment and packaging processes.

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However, the detection of E. coli in four samples introduces a critical element in the evaluation of the system, since its presence constitutes an unequivocal indicator of recent faecal contamination and, therefore, of a failure in the microbiological integrity of the product. The concentrations recorded, which reach values of up to 800 CFU/100 mL in the Tesalia brand (SSD code) and range from 200 to 650 CFU/100 mL in different lots of the Mountain brand, reflect significantly high levels compared to the permissible limit (0 CFU/100 mL). From an inferential perspective, these values do not represent simple marginal deviations, but critical events that show conditions of substantial contamination, with a high microbial load that considerably increases the probability of the presence of enteric pathogens.

The distribution of the positive results also shows a specific pattern associated with certain sample codes, particularly SSD and to a lesser extent other codes in the Mountain brand, which suggests the possible existence of systematic factors related to specific stages of the production process or the distribution chain. This behavior points to the hypothesis of localized failures, either in disinfection systems, in storage conditions or in post-bottling handling. The coincidence of production dates in contaminated batches reinforces the possibility of specific contamination events in the plant or adverse environmental conditions in certain periods, which introduces a temporal dimension in the risk dynamics.

From the health risk management approach, the coexistence of a high percentage of compliant samples with a small but significantly contaminated subset suggests a non-uniform risk scenario, characterized by a low frequency of events but with high severity. This type of distribution is particularly relevant in drinking water systems, since the occurrence of microbiological contamination events, although sporadic, can have disproportionate consequences in terms of public health, including outbreaks of gastrointestinal diseases. The magnitude of the observed values indicates that, in positive cases, the potential exposure far exceeds the safety thresholds, which increases the probability of infection in consumers.

Additionally, the interpretation of these results must be integrated with the previously observed physicochemical conditions, particularly the low levels of residual chlorine, which limit the microbial inhibition capacity during storage. This interaction suggests that the initial absence of contamination does not guarantee the safety of the product over time, as suboptimal disinfection conditions can facilitate bacterial growth in later stages. Consequently, the microbiological evidence presented not only reflects point contamination events, but also the structural vulnerability of the system to failures in quality control.

Overall, the results in Table 3 highlight the need to strengthen microbiological quality assurance systems through the implementation of stricter controls, continuous monitoring and traceability of production batches. They also highlight the importance of adopting a preventive approach based on comprehensive risk management, which is not limited to compliance with physicochemical parameters, but systematically incorporates microbiological surveillance as a central axis to guarantee the safety of bottled water.

Table 4. Results of the samples analyzed according to absolute deviation

Numerical variable	# of data	Absolute Deviation from the Median	Minimum	Maximum	Range
Free chlorine (mg/L)	29	0,015	0,0100	0,07	0,0600
pH	30	0,222	6,2600	7,62	1,3600
Phosphates (mg/L)	30	0,297	0,9000	2,7	1,8000
nitratos_ (mg/L)	30	0,519	0,3000	4,7	4,4000
Nitrites (mg/L)	30	0,003	0,0010	0,021	0,0200
uS/cm	30	203,116	0,0000	792	792,000
T_°C	30	0,593	23,4000	25,8	2,4000
Ppm	30	102,299	0,0000	396	396,000
mV	30	37,065	247,000	398	151,000

The analysis based on the absolute deviation from the median (MAD) and the dispersion statistics presented in Table 4 allows us to delve into the robustness and heterogeneity of the physicochemical parameters, providing relevant inferential evidence for the evaluation of health risk. Unlike the standard deviation, the MAD offers a less sensitive measure to extreme values, so its interpretation is particularly useful to identify the structural stability of the data and detect the presence of outliers with a potential impact on water quality.

In the case of residual free chlorine, the absolute deviation from the median (0.015 mg/L) together with a range of 0.060 mg/L reveals a moderate dispersion around consistently low values, confirming that the low chlorine concentration does not respond to point outliers, but to a systematic condition in most samples. This pattern reinforces the hypothesis of insufficient control of the disinfectant residue throughout the sample, uniformly increasing vulnerability to microbiological recontamination processes and compromising the sanitary stability of the product during storage.

The pH has a MAD of 0.222 and a relatively limited range (1.36 units), indicating considerable chemical stability between the samples. This low dispersion, both in absolute and robust terms, suggests that pH is not a relevant differentiating factor in terms of direct health risk; However, its homogeneous behavior within the neutral to

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slightly alkaline range may facilitate the persistence of certain microorganisms in the absence of effective disinfectant mechanisms, especially when combined with other limiting factors such as low residual chlorine.

Regarding phosphates, the MAD of 0.297 mg/L and the range of 1.8 mg/L show an intermediate variability with the presence of relatively high values. This behavior suggests that, even though most of the samples have concentrations close to the median, there are significant increases in certain conditions that could favor trophic enrichment processes. In this context, phosphorus continues to position itself as a critical factor in the assessment of ecological risk, since small variations in its concentration can trigger substantial changes in biological dynamics, particularly in systems susceptible to the proliferation of cyanobacteria.

The analysis of nitrates shows a MAD of 0.519 mg/L and a wide range of 4.4 mg/L, which shows a high heterogeneity in the distribution of this nutrient. The combination of a relatively high robust dispersion with a wide range suggests the coexistence of two behaviors: a majority group of moderate values and a fraction of samples with significantly higher concentrations. From the health risk approach, this non-uniform distribution implies that certain batches present more favorable conditions for eutrophication processes or reflect possible influences from external sources of contamination, increasing uncertainty in water quality.

In the case of nitrites, the MAD is low (0.003 mg/L), but its range (0.020 mg/L) indicates the presence of extreme values that, although rare, are relevant due to their health significance. This discrepancy between central stability and range amplitude suggests recent pollution events or failures in complete nitrogen oxidation. From an epidemiological perspective, even small concentrations of nitrites can have implications in vulnerable populations, reinforcing the need to consider not only the magnitude but also the variability of this parameter.

Parameters associated with mineralization, such as electrical conductivity and total dissolved solids, have the highest dispersion values, with MAD of 203.116 µS/cm and 102.299 ppm respectively, and extremely wide ranges (792 µS/cm and 396 ppm). This high variability confirms a marked heterogeneity in the origin of the water and in the treatment processes applied by the different brands. From a health point of view, this compositional diversity can influence the chemical stability of the water and the interaction between microorganisms and the aqueous matrix, indirectly affecting the persistence of contaminants and the efficiency of disinfection processes.

Finally, the temperature and redox potential present relatively low MAD values compared to their ranges, which indicates conditions of operational stability during sampling, although with a certain amplitude that could respond to variations in storage and handling. Temperature around 25 °C, combined with moderate values of redox potential, can contribute to microbial viability in the absence of adequate chemical control, thus reinforcing the interaction between physicochemical and microbiological variables in the construction of the health risk.

Overall, the robust dispersion analysis confirms that the quality of bottled water depends not only on the average values of the parameters, but also on its structural variability and the presence of extreme values. The coexistence of stability in some parameters and high heterogeneity in others configures a complex scenario in which the health risk is not homogeneous, but is unevenly distributed between samples, brands and batches. This behavior highlights the need for monitoring approaches that incorporate robust variability metrics and allow for early identification of critical conditions that may compromise product safety.

Table 5. Results of samples tested for bias

Numerical variable	# of data	Bias	Curtosis	Standard Mean Error
Cloro_libre (mg/L)	29	1,014	1,0780	0,002554
pH	30	-1,093	-0,2706	0,0775693
Fosfatos_(mg/L)	30	1,357	1,5780	0,0823133
nitratos_(mg/L)	30	1,656	2,1482	0,1853949
nitritos_(mg/L)	30	2,376	7,7043	0,000698
uS/cm	30	1,459	1,5211	39,600312
T_°C	30	-1,185	1,1433	0,1064293
Ppm	30	1,457	1,5122	19,813812
mV	30	-0,039	-0,2561	6,290201

The analysis of the coefficients of asymmetry (bias) and kurtosis presented in Table 5 allows us to delve deeper into the shape of the distributions of the physicochemical parameters, providing critical inferential evidence on the presence of extreme values and their implication in the assessment of health risk. In general terms, the predominance of positive biases in several variables indicates asymmetrical distributions to the right, which implies the existence of high values that, although they do not represent the central trend, have a significant impact on the quality of the system and on the interpretation of risk.

In the case of residual free chlorine, positive bias (1.014) and slightly elevated kurtosis (1.078) show an asymmetric distribution with the presence of isolated high values, although most samples are concentrated at low levels. This behavior confirms that higher chlorine values, although they exist, do not represent the dominant condition of the system. From a health perspective, this reinforces the interpretation that microbiological protection is insufficient in most cases, and that events with greater chlorinated residual do not compensate for the generalized disinfection deficit.

The pH has a negative bias (-1.093) and a kurtosis close to zero (-0.2706), which indicates a slight concentration of values towards the upper part of the range with a relatively flattened distribution. This pattern suggests a structural stability of the parameter, with low presence of extreme values. Although pH does not represent a direct risk in the observed ranges, its uniform distribution confirms consistent physicochemical conditions that could favor the persistence of microorganisms in the absence of adequate disinfectant barriers.

Phosphates show a positive bias (1.357) and high kurtosis (1.578), indicating a tailed distribution towards high values and a certain concentration of data around the mean with the presence of peaks. This behavior is consistent with the existence of samples with significantly higher concentrations that can act as critical points in the dynamics of the system. From the risk approach, these high values become relevant by enhancing eutrophication processes, increasing the probability of cyanobacteria proliferation and, consequently, of cyanotoxin generation.

The nitrate analysis shows a more pronounced positive bias (1.656) and high kurtosis (2.1482), reflecting a highly asymmetric and leptocurtic distribution. This pattern shows that, although most of the samples are concentrated in moderate values, there are high concentrations that significantly increase the mean. The presence of these extreme values suggests localized sources of contamination that generate heterogeneity in water quality. From a health point of view, this distribution implies that certain batches have a greater potential to contribute to trophic enrichment processes and, therefore, to associated environmental and health risks.

The behavior of nitrites is particularly relevant, with a very high bias (2.376) and extremely high kurtosis (7.7043), indicating a highly concentrated distribution at low values but with the presence of infrequent extreme peaks. This pattern suggests specific events of recent contamination or treatment failures, which, although statistically unrepresentative, have a high health relevance. From a risk perspective, this type of distribution characterizes scenarios where the frequency of events is low but their potential severity is high, which is consistent with systems vulnerable to sporadic failures.

Mineralization parameters, such as conductivity (bias 1.459; kurtosis 1.5211) and total dissolved solids (bias 1.457; kurtosis 1.5122), exhibit similar behaviors, with positive asymmetry and high kurtosis, indicating high heterogeneity in water composition. This pattern confirms the existence of samples with significantly higher levels of mineralization, which can influence the chemical stability of the system and the interaction with microorganisms. From a risk point of view, this variability can affect bacterial survival dynamics and the effectiveness of disinfection processes.

In contrast, the temperature shows a negative bias (-1.185) and a positive kurtosis (1.1433), indicating a slight concentration of values at the upper end with some central accumulation. This behavior, together with the low variability previously observed, suggests relatively stable thermal conditions, but in ranges that may favor microbial growth. On the other hand, the redox potential (mV) has a bias close to zero (-0.039) and a negative kurtosis (-0.2561), which indicates a practically symmetrical and homogeneous distribution, without significant presence of extreme values.

The joint analysis of the bias coefficients, kurtosis and standard error of the mean allows us to infer that, although some parameters have relatively stable distributions, others show marked asymmetries and long tails that show the presence of critical values. This statistical configuration is indicative of a non-homogeneous system, in which water quality can vary significantly between samples and where the presence of extreme events, although rare, has a disproportionate impact on the health risk assessment. In this context, the identification and control of these outliers is essential for the design of monitoring and management strategies, as they constitute the main determinants of emerging risks associated with bottled water quality.

4.- Discussion

4.1. Interpretation of the results

The results obtained show that the quality of the bottled water evaluated cannot be interpreted only under a regulatory compliance approach, but requires a comprehensive analysis based on health risk management. Although most physicochemical parameters remain within permissible ranges, the presence of significant variability between brands and batches suggests the existence of heterogeneity in the processes of capture, treatment and quality control. This behavior confirms that water quality is not a static condition, but the result of complex operational dynamics that can generate scenarios of sanitary vulnerability, even in regulated systems.

A particularly relevant finding is the consistency of suboptimal levels of residual chlorine, which represents a critical factor from the point of view of disinfection. From a technical perspective, residual chlorine acts as a secondary barrier that ensures the microbiological stability of water during storage and distribution. The literature has established that concentrations below the recommended ranges reduce the efficacy of this barrier, increasing the probability of post-treatment contamination. In this context, the results suggest that the analyzed system has a limited microbiological control capacity over time, which could explain the appearance of specific contamination events detected in the microbiological analysis.[31]

In relation to nutrients, the presence of nitrates, nitrites and phosphates in moderate concentrations, although within acceptable limits, acquires relevance when considered from an ecological and emerging risk approach. Recent literature suggests that the simultaneous availability of nitrogen and phosphorus can favor eutrophication processes, even in apparently controlled systems, particularly in tropical conditions characterized by high temperatures. In this sense, the coexistence of nutrients with low levels of disinfectant configures a scenario conducive to the development of microorganisms, including cyanobacteria potentially producing toxins, which transcends traditional quality assessment approaches.

Finally, the detection of microbiological contamination in a small but significant number of samples introduces a critical dimension in the interpretation of the results. From the point of view of risk management, this behavior is consistent with systems characterized by low frequency of events but high severity, where the occurrence of punctual failures can generate disproportionate impacts on public health. Overall, the findings show that apparent physicochemical conformity does not guarantee health safety, which reinforces the need to adopt comprehensive approaches that consider the interaction between chemical, microbiological and environmental variables.

4.2. Comparison with previous studies

The results obtained are relevant in line with previous research that has documented the variability in bottled water quality and the limitations of control systems based exclusively on conventional parameters. Various studies have reported that, although bottled water usually meets established physicochemical criteria, microbiological inconsistencies may occur associated with failures in disinfection processes or inadequate storage conditions. This pattern coincides with observed findings, where most samples meet regulatory requirements, but isolated fecal contamination events persist.[32]

In particular, the microbiological results are consistent with what has been reported in regional studies, such as the one carried out in the province of Guayas, where the presence of Escherichia coli in commercialized bottled water was evidenced. This coincidence reinforces the hypothesis that, in local contexts, quality assurance systems present structural weaknesses that allow the occurrence of pollution events. Likewise, recent research has indicated that the perception of safety associated with bottled water does not always correspond to its actual microbiological quality, which positions these findings within a broader problem of trust and regulation in alternative supply systems.[33]

In relation to physicochemical parameters, the results are consistent with studies that have shown the influence of factors such as the source of uptake and treatment processes on the variability of parameters such as conductivity, dissolved solids and nutrients. However, the present study provides an additional element by integrating these parameters with the health risk approach, showing how the presence of nutrients, even in moderate concentrations, can become relevant in terms of eutrophication processes and biological proliferation. This integration allows us to move beyond the description of quality to a functional interpretation of the system.[34]

Additionally, the findings related to the potential for cyanobacteria proliferation align with recent research that has documented the presence of genes associated with the production of cyanotoxins in bodies of water in the region, such as the Daule River. This convergence of evidence suggests that the area's water systems present favorable conditions for the development of emerging contaminants, and that these risks may extend to treated water systems if adequate controls are not in place. In this sense, the study contributes to expanding existing knowledge by linking bottled water quality to regional environmental dynamics and emerging risks.[35]

4.3. Theoretical and practical implications

From a theoretical point of view, the results of the study provide evidence that reinforces the need to move from traditional quality control approaches to comprehensive models based on health risk management. The literature has indicated that the evaluation of water quality must consider not only compliance with maximum permissible limits, but also the probability of occurrence of adverse events and their possible consequences. In this context, the present study contributes to consolidate a multidimensional approach that integrates physicochemical, microbiological and environmental variables, expanding the conceptual framework for the evaluation of bottled water systems.

The study also provides a relevant perspective by incorporating the analysis of emerging contaminants, such as cyanobacteria and their toxins, within the context of bottled water. This approach allows the discussion to be extended beyond traditional indicators, evidencing the need to include variables associated with eutrophication and ecological dynamics in monitoring systems. In this way, it contributes to the development of more complete conceptual models that consider the interaction between chemical, biological and environmental processes in the generation of health risk.

In practical terms, the results have direct implications for the bottled water industry and for regulatory entities. Evidence of low levels of residual chlorine suggests the need to review and optimize disinfection processes to ensure the microbiological stability of the product during its life cycle. Likewise, the variability observed between brands highlights the importance of strengthening quality control systems, including periodic audits, real-time monitoring and batch traceability, in order to reduce the occurrence of contamination events.
Additionally, from an applied perspective, the findings open the possibility of developing technological innovation strategies aimed at improving treatment and storage systems, such as the use of alternative disinfectants, intelligent sensors for continuous monitoring or predictive models of water quality. Likewise, in the field of

environmental management, the results suggest the need to implement integrated policies that address water quality from source to consumption, incorporating the "One Health" approach as a framework for decision-making.

4.4. Limitations and future projections

Despite the relevance of the findings obtained, the study has certain limitations that must be considered in the interpretation of the results. First, the sample size, while representative of the most consumed brands, may not fully capture the variability of the bottled water market in Guayas province, which could limit the generalizability of the results. Likewise, the selection of samples was made based on availability and accessibility, which introduces a possible bias associated with the commercial distribution of the products.

From a methodological point of view, the analysis focused on a specific set of physicochemical and microbiological parameters, implying that other potentially relevant pollutants, such as heavy metals, microplastics or emerging organic compounds, were not considered. This limitation restricts the scope of the study in terms of comprehensive characterization of water quality and suggests the need to broaden the spectrum of analysis in future research.

In relation to cyanotoxins, although a validated detection method was used, the results obtained reflect the apparent absence of these substances under initial conditions, but show their possible development under controlled experimental conditions. However, the study does not incorporate a longitudinal analysis that allows the evaluation of the temporal evolution of these pollutants in real storage conditions, which limits the understanding of their dynamics in consumption scenarios. This restriction highlights the need for more in-depth studies that integrate temporal analyses and variable environmental conditions.

In this context, future research should be oriented towards the development of predictive risk models that integrate physicochemical, microbiological and environmental variables, allowing contamination scenarios to be anticipated. It is also recommended to incorporate advanced analysis techniques, such as molecular tools for the detection of toxigenic genes or real-time sensors for quality monitoring. These lines of research would not only make it possible to overcome the identified limitations, but would also contribute to the development of more robust and adaptive management systems, capable of responding to emerging challenges in the quality of water for human consumption.

5.- Conclusion.

5.1. Synthesis of findings

The present study made it possible to comprehensively evaluate the quality of bottled water marketed in the province of Guayas through the application of physicochemical and microbiological indicators, showing that, although most of the samples comply with the limits established by current regulations, there are significant variations between brands and batches that condition the sanitary stability of the product. In particular, it was identified that the physicochemical parameters present heterogeneous behaviors, characterized by the presence of nutrients in moderate concentrations and consistently low levels of residual chlorine, which limits the ability to control microbiological quality during storage.

Likewise, the microbiological results revealed the presence of specific fecal contamination events, which shows that compliance with physicochemical parameters does not guarantee the safety of the water by itself. This evidence confirms that bottled water quality responds to complex dynamics involving both treatment processes and subsequent handling conditions. In this sense, the objectives of the study were met by evidencing the need to integrate multiple indicators for a more robust assessment of health risk in water systems for human consumption.

5.2. Scientific and technical contributions

From a scientific point of view, the study contributes to strengthening the conceptual framework of health risk management in bottled water systems, by demonstrating that the evaluation based on traditional parameters is insufficient when analyzed in isolation. The integration of physicochemical and microbiological variables, together with the consideration of factors associated with emerging pollutants, allows us to move towards a multidimensional approach that broadens the understanding of the processes that determine water quality.

In the technical field, the work provides relevant empirical evidence on the variability in the quality of bottled water in a tropical context, identifying conditions that can favor the proliferation of microorganisms and the deterioration of quality during the supply chain. Likewise, the incorporation of cyanotoxin analysis, even when they were not initially detected in the samples, represents a methodological advance by considering the potential for the development of emerging risks under specific environmental conditions, thus contributing to closing gaps in the conventional assessment of water quality.

5.3. Theoretical implications and practical applications

The findings of the study have relevant implications for the theoretical development of water quality assessment models, as they demonstrate the need to adopt risk-based approaches that integrate chemical, microbiological and ecological variables. This perspective allows us to move towards more robust conceptual frameworks, in which water quality is understood as a dynamic system influenced by multiple interrelated factors, thus overcoming traditional approaches focused exclusively on regulatory compliance.

From the applied point of view, the results highlight the importance of strengthening quality control systems in the bottled water industry, particularly in relation to the optimization of disinfection processes, the continuous monitoring of critical parameters and the implementation of traceability systems that allow identifying and correcting failures in the supply chain. Likewise, the need to incorporate emerging contamination indicators and preventive strategies to mitigate risks associated with the proliferation of cyanobacteria, especially in regions with favorable environmental conditions for their development, is evident.

5.4. Projections and lines of future research

Based on the results obtained, several lines of future research are identified aimed at deepening the understanding of the factors that condition the quality of bottled water. Firstly, it is recommended to develop longitudinal studies to evaluate the temporal evolution of physicochemical and microbiological parameters during storage, in order to determine the stability of the product throughout its shelf life. It is also pertinent to incorporate the analysis of other emerging pollutants, such as heavy metals, microplastics and organic compounds, which could influence water quality and the health of consumers.

Additionally, it is suggested to move towards the development of predictive risk models that integrate environmental, operational and water quality variables, allowing anticipating pollution scenarios and optimizing management systems. Finally, the implementation of advanced monitoring techniques, including molecular tools for the detection of toxigenic microorganisms and real-time sensors, represents a promising line to strengthen health surveillance and contribute to the design of safer and more resilient supply systems in contexts of high anthropogenic pressure.

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8.- Appendix.

Not applicable.

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