WATER QUALITY ASSESSMENT OF HOT SPRINGS AND ITS DISCHARGES INTO THE TRIBUTARIES FED INTO THE BOGOTA RIVER

By

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WATER QUALITY ASSESSMENT OF HOT SPRINGS AND ITS DISCHARGES INTO THE TRIBUTARIES FED INTO THE BOGOTA RIVER

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This Ph.D thesis entitled, "**WATER QUALITY ASSESSMENT OF HOT SPRINGS AND ITS DISCHARGES INTO THE TRIBUTARIES FED INTO THE BOGOTA RIVER**" presented by Civil Engineer Yuly Andrea Sánchez Londoño, in compliance with the requirements demanded by the Colombian School of Engineering Julio Garavito University (in Spanish Universidad Escuela Colombiana de Ingeniería Julio Garavito) to qualify for the degree of Doctor of Engineering, approved by:

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To my parents, friends, hot springs and professors for their support in the completion of this thesis.

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Conference, article and poster

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Conference and abstract

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Conference

- Y. Sánchez. **Importancia de las Aguas Termales,** *Foro de Mujeres Empoderadas, Resilientes y Exitosas.* Sociedad Colombiana de Ingenieros 2023, Bogotá, Colombia, February 15, 2023. https://sci.org.co/wp-content/uploads/file/Agenda_V2.pdf.

YEAR 2022

Poster

- Y. Sánchez, M. Mehrvar, L. McCarthy, E. Quiñones, L.R. Cheu, J. Chacón, J. Romero. **Descarga directa de afluentes de agua termales en los ríos a ecosistemas acuáticos**, *3er Congreso Internacional de Investigación e Innovación Ambiental (CNIIA-2022)*, Bogotá, Colombia, November 9-11, 2022. http://congresoambiental.car.gov.co/agenda/. ISSN:2806-0784.

Conference, article and poster

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YEAR 2021

Conference and abstract

- Y. Sánchez, M. Mehrvar, L. McCarthy, L.R. Cheu, A. Reu ß, E. Quiñones, J. Romero. **Impact of the direct wastewater discharge from hot springs to rivers**, *9th International Conference of Swimming Pool and Spa*, *Virtual Conference*, November 19, 2021, Antalya – Turkey. http://www.9thicsps.com/en/2785-conference-programme.

Conference and article

- Y. Sánchez, M. Mehrvar, L. McCarthy, E. Quiñones, L.R. Cheu, J. Romero. **Preventive measures pertaining to COVID-19 in swimming pools and hot springs in Europe, Canada, United States, and Colombia**, *VII Congreso Internacional de Innovación y Tendencias de la Ingeniería (CONIITI 2021),* Virtual Conference, Bogotá D.C., Colombia, September 29 to October 1, 2021. https://ieeexplore.ieee.org/document/9619701/authors#authors. Indexed article in IEEE. DOI: 10.1109/CONIITI53815.2021.9619701.

Conference, article and poster

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  DOI: 10.26507/ponencia.1691.

Article

- I. Chaparro, Y. Sánchez. Mehrvar, L. McCarthy, E. Quiñones, G. Santos, E. Robles. **Mathematical Modelling Approach for Evaluation of Thermal Water Aquifers: A Case Study of the Paipa Geothermal System**, *Proceedings of World Geothermal Congress 2020+*, Reykjavik, Iceland, March to October 2021. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2020/15006.pdf.

Conference and abstract

- Y. Sánchez, M. Mehrvar, L. McCarthy, E. Quiñones, L.R. Cheu, J. Chacon. **Adverse Effect of Direct Discharge of Hot Spring Tributaries into Rivers on Life Aquatic Ecosystems**, *Proceedings of the 5th International Conference of Recent Trends in Environmental Science and Engineering* (RTESE 2021) Virtual

Conference, Niagara, Canada, May 17-19, 2021. https://avestia.com/RTESE2021_Proceedings/files/paper/RTESE_302.pdf. DOI: 10.11159/rtese21.302.

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Award

- Y. Sánchez. Women Science 2020, L'Oréal Colombia, December 2020.

Conference and article

- Y. Sánchez, M. Mehrvar, L. McCarthy, E. Quiñones, L.R. Cheu, J. Romero. **Scientific discussion of selected viruses including COVID-19 in hot springs**, *VI Congreso Internacional de Innovación y Tendencias de la Ingeniería (CONIITI 2020),* Virtual Conference, Bogotá D.C., Colombia, September 30 to October 2, 2020.: https://ieeexplore.ieee.org/abstract/document/9240267. Indexed article in IEEE. DOI: 10.1109/CONIITI51147.2020.9240267.

Conference, article and poster

- M. Rojas, Y. Sánchez. **Estado del arte de la Legionella Pneumophila en aguas termales**, Encuentro *Internacional de Educación en Ingeniería (ACOFI 2020),* Cartagena, Colombia, September 15-18, 2020. https://www.acofi.edu.co/eiei2020/wp-content/uploads/2020/09/Memorias-EIEI-ACOFI-2020.pdf. DOI: 10.26507/ponencia.790.

Conference, article and poster

- Y. Sánchez, M. Mehrvar, L. McCarthy, E. Quiñones, L.R. Cheu, J. Romero. **An Overview of the Management of Covid-19 in Swimming Pools, Beaches, and Hot Springs in Europe, Canada, and Colombia**, *Segundo Encuentro Nacional de Estudiantes de Doctorados en Ingeniería (ENEDI 2020), ACOFI*

2020, Cartagena, Colombia, September 16-18, 2020. https://www.acofi.edu.co/eiei2020/wp-content/uploads/2020/10/Memorias-ENEDI-2020.pdf. ISBN: 978-958-680-090-7. Digital Book.

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- M. Rojas. **Estado del Arte de *Legionella Pneumophila* en Aguas Termales.** Undergraduate Thesis. Colombian School of Engineering Julio Garavito University, 2020.
- I. Chaparro. **Aproximación a un Modelo Matemático para la Evaluación de Acuíferos Termales: Estudio de Caso del Sistema Geotérmico Paipa.** Master Thesis. Colombian School of Engineering Julio Garavito University, 2020.

YEAR 2019

Poster

- Y. Sánchez, L.R. Cheu. **Estado del arte del agua termal**, *Segundo Seminario de Investigación e Innovación*. Colombian School of Engineering Julio Garavito University, Bogotá, D.C, Colombia, October 30, 2019.

Conference, article and poster

- Y. Sánchez, L.R. Cheu. **Estado del arte de la calidad del agua termal**, *Primer Encuentro Nacional de Estudiantes de Doctorados en Ingeniería (ENEDI 2019), ACOFI 2019*, Cartagena, Colombia, September 10-13, 2019. https://acofipapers.org/index.php/eiei/article/view/267/263. ISSN: 2665-5918. DOI: 10.26507/ponencia.267.

Conference

- Y. Sánchez, L.R. Cheu. **Estado del arte de la calidad del agua termal**, *XXV Congreso Institucional de Investigación*. El Bosque University, Bogotá, D.C, Colombia, September 17-19, 2019. https://www.unbosque.edu.co/sites/default/files/2019-09/Programa%20XXV%20Congreso%20Institucional%20de%20Investigaciones%202019_FINAL.pdf.

Conference and abstract

- Y. Sánchez, L.R. Cheu. **State of the art the thermal water**, *8th International Conference of Swimming Pool & Spa*, March 18 - 22, 2019, Marseille – France. https://8thswimpoolspa.sciencesconf.org/program.

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Abstract

Water Quality Assessment of Hot Springs and Its Discharges into the Tributaries Fed into the Bogota River

Doctor of Engineering
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The hot springs are used for recreational, therapeutic, and medicinal purposes. Due to their mineralization and water temperature, they convey a feeling of well-being that makes them a great tourist attraction. However, bathers do not know the quality of the waters, so it is necessary to identify the possible risks to which bathers are exposed. In Colombia, hot springs are not disinfected before human use and their wastewater is discharged directly into rivers, nor is it customary to carry out monthly monitoring of their water quality. For this reason, it is important in Colombia to advance in the investigation of risk indicators for human health and the quality of aquatic ecosystems.

The disinfection of hot springs depends on whether one wants to preserve the physical-chemical properties of the water or not. Therefore, disinfectants such as Ultraviolet (UV) lights can be used, which do not affect the physical-chemical properties of the water, or disinfectants that can influence the properties of water chemicals such as chlorine or others. In countries such as Canada and Germany, chlorine is used to disinfect hot springs.

In this thesis, two types of hot springs that discharge to tributary water sources of the Bogotá river were studied. Its waters were monitored for six months to determine the physical, chemical, and microbiological quality of the water and to assess its compliance with drinking water, swimming pool, hot spring, and wastewater discharge standards. The results showed that each hot spring had its own unique water characteristics, with hot spring 1 being bicarbonate and hot spring 2 being ferruginous.

Parameter analysis revealed that hot spring 1 had high conductivities and pH values higher than 7.0, while hot spring 2 had lower conductivities and pH values between 6.0 and 7.7. Dissolved oxygen levels in both hot springs remained within acceptable ranges. Concentrations of heavy metals in the samples were found to be within the limits set by drinking water and swimming pool standards, except for the high iron values in hot spring 2, which posed mainly an aesthetic concern. Hot spring 2 exhibited high turbidity and color values due to the ferruginous properties of the water. Oil and fats were not quantifiable in any hot spring. Hot spring 1 presented calcium carbonate values above the regulatory limits for drinking water and swimming pools.

The values from the heavy metals analyzed (arsenic (As), chromium (Cr), mercury (Hg), lead (Pb), aluminum (Al), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), nickel (Ni), zinc (Zn), strontium (Sr), and calcium (Ca)) in the samples from hot springs 1 and 2 were compared with regulations for drinking water and swimming pools. These values were within the limits established by the regulation, with the exception of the hot spring 2 featuring high iron values, which becomes more of a water aesthetic problem.

The results also indicated the presence of fecal coliforms (*E. coli*), total coliforms, Enterococci, *L. pneumophila*, *P. aeruginosa*, molds, and yeasts in all samples, exceeding the permissible limits.

The use of UV for disinfection of hot springs without the use of chemicals has shown promising results. The tests conducted in the laboratory demonstrated high removal efficiencies, reaching up to 99.9% for bacteria such as E. coli. This method preserves the physical and chemical properties of the water, ensuring that it remains in its natural state. However, it is important to note that UV disinfection can be costly, particularly for smaller hot springs. In such cases, it may be necessary to consider alternative methods that not only preserve the chemical properties but also ensure the absence of pathogenic microorganisms. One such method is the use of disinfectants like chlorine, which may require determining the appropriate dosage depending on the type of hot spring. For example, the bicarbonate hot spring requires a dose of approximately 5 mg/L, while further research is needed to establish the dosage for ferruginous hot springs. To further advance knowledge in this field, it is recommended to replicate the methodology used in this study with different types of hot springs to assess the effectiveness of UV disinfection.

Additionally, the implementation of Constructed Wetlands (CW) in the treatment of wastewater from hot springs holds great potential. CW has proven effective in removing various contaminants, including heavy metals, and it offers the advantage of low operating costs. However, careful consideration should be given to the selection of plant species to be used in CW systems, considering the potential invasiveness of certain plants in different regions.

Overall, this study provides valuable insights into the water quality of the analyzed hot springs and highlights the need for appropriate regulations and treatment measures to ensure the safety and compliance of hot springs with respect to human health and environmental protection. Further research and implementation of effective management strategies are necessary to address the specific water characteristics and contamination issues associated with hot springs in order to safeguard public health and preserve the integrity of aquatic ecosystems.

Chapter 1

INTRODUCTION

The word thermal is relative to thermal baths, which comes from the Latin thermae (public baths) and the Greek θερμός (*thermo* = hot) (Evans, 1997). Hot springs are mineral waters whose emergent temperature must be 4ºC higher than the annual environmental average of the place from which they sprout, allowing the hot springs to take advantage of its thermal action (Cantabria (Spain), 1988). Although the literature refers to thermal waters, onsen or hot springs, from now on the term hot springs will be used in this thesis.

These waters come from underground layers of the earth that are at higher temperatures. These waters are rich in different mineral components and are used in therapies such as baths, inhalations, irrigation, and heating. They are usually found along fault lines, as groundwater can enter along the plane of the fault, heating to a certain depth, and rising later as steam (which can condense upon reaching the surface, forming a geyser) or hot water (Martinez et al., 2015).

Hot springs are also used for recreational, therapeutic, medicinal purposes (Sanchez and Cheu, 2019), and potentially benefit people's health by improving blood pressure and treating respiratory diseases, low-grade inflammation, stress-related pathologies (Galvez et al., 2018), pain, rheumatoid arthritis (Verhagen et al., 2015), osteoarthritis of the knee (Verhagen et al., 2007; Fioravanti et al., 2012), psoriasis, and atopic dermatitis (Ronni et al., 2003). On the other hand, hot springs also contain microorganisms that may contribute to other diseases. Matthew Miller, a professor of biochemistry at McMaster University in Hamilton, Canada, who studied the new coronavirus, stated that "*the risk of contracting the pool water virus is very low*" because respiratory viruses like COVID-19 are different from viruses like polio or other pathogens like cholera that are actually spread in water (CTV News Canada, 2020).

However, other studies suggest that it is necessary to identify health related potential chemical and microbiological risks (Yan et al., 2005). In Colombia, hot springs are not disinfected before human use and wastewater is discharged directly into rivers. Therefore, it is important in Colombia to advance research on indicators of risks to human health and the quality of aquatic ecosystems in hot springs.

According to the above context, the control of viruses and bacteria in recreational waters is achieved with adequate treatment and influenced by disinfection with chlorine or other disinfectants (WHO, 2006). It has been proven that viruses and bacteria in recreational waters could be properly treated and disinfected with chlorine or other disinfectants as well as other techniques (WHO, 2006). Disinfection has mainly been done using chlorine, ozone, or Ultraviolet (UV) radiation (with ozone and UV being used in combination with chlorine or bromine) (Barrera et al., 2012; WHO, 2006). New research is additionally examining the implementation of engineered wetlands in the control of bacteria and viruses, and recreational water.

However, most hot springs have lost their natural properties due to the addition of chlorine and other chemicals, with the exception of some natural hot springs pools that retain their natural physical and chemical properties (Valeriani et al., 2018). UV radiation does not produce the undesirable side effects normally found in classical chemical treatments, such as the generation of disinfection by-products (DBPs) for which studies have highlighted an association with carcinogenic effects (Sisti et al., 2014).

The European Center for Disease Prevention and Control (ECDC) reported the effectiveness of different disinfectants against different types of coronaviruses (ECDC, 2020). It concluded that although there were no specific studies on the efficacy of these agents of disinfection against SARS-CoV-2 (COVID-19), the data obtained against other coronaviruses such as SARSCoV (SARS), suggests that the use of a 0.1% sodium hypochlorite solution (equivalent to a 1:50 dilution of a household bleach solution at a concentration of 5%) is effective for virus inactivation.

Due to the importance of public health derived from the previous considerations, there are regulations for the disinfection of hot springs where recirculation systems are evident in countries such as Canada (Alberta, 2014) and Germany (Germany, 1997). The regions of Galicia and Murcia in Spain only allow water to be renewed for hot springs water treatment (Galicia, 1996; Murcia, 1997), and countries like Cuba do not specify any treatment of their waters (Cuba, 1998). It is worth noting that the specific case of the natural flow pools lined with natural rocks do not use chemicals, since the conditions of a natural body of water are purified by biological and physical treatment. Therefore, they are often not subject to regulations like health inspections (Alberta, 2014).

As a result of the nature of the research problem that is the objective of this thesis and within the framework of the previous considerations, it is important to highlight the Colombian regulations of hot springs, such as:

The Ministry of Health and Social Protection regulates hot springs in Colombia for the physical, chemical, and microbiological characteristics of the water, as established in the paragraph of article 6 of Decree 554 of 2015, "***The general physical, chemical, and microbiological parameters of water will not be required for ponds that store hot springs and therapeutic uses***" (Colombia, 2015).

However, the regulation of hot springs (Bill 62 of 2015) states that "***The hot springs is not a sterile resource and for therapeutic uses the hot springs and spas where this water is used, must be free of contamination- indicating microorganisms (fecal coliforms,***

Pseudomonas aeruginosa, and of the bacterium Legionella pneumophila), causing legionellosis, a lung disease that *can be fatal"* (Colombia, 2015).

Thus, to the best of the author's knowledge, hot springs regulations and minimum quality standards are needed in Colombia. Regarding this, there is only a draft law. Currently, the system of "disinfection" treatment in hot springs is only a water exchange, which consists of making a replacement of the hot springs in swimming pools.

In hot springs spas, monitoring of the water quality of microbiological organisms is not required. Only some physical and chemical parameters must be monitored. In the absence of regulations in Colombia, legislation is required to control water quality and measures in facilities with hot springs pools for recreational and medicinal use.

However, hot springs have traditionally been a tourist attraction in many parts of the world, such as: Japan, Canada, Taiwan, and other countries. During the peak tourist season, wastewater of hot springs is usually discharged into streams without treatment, which can affect the quality of the receiving water, causing negative impacts to the aquatic ecosystems (Lenart et al., 2016). Yang Wan Fa, a professor at National Taiwan University, investigated downstream ecological impacts of several major spa recreational sites. This author found that wastewater discharges of hot springs have adverse ecological effects (Taipei Times, 2004).

Hot springs are waters from the inner part of the earth that carry different chemical components, such as heavy metals, which may have an adverse effect on life in the aquatic ecosystem if found in excess concentrations when discharged directly into rivers (Itanna, 2019).

Despite the negative consequences on ecosystems derived from hot springs wastewater, it is interesting to note that there are regulations for wastewater discharges into rivers and sewers (Germany, 1997; Alberta, 2013), but not specifically for hot springs discharge. Therefore, the authorities must control the use of hot springs and the discharge of their untreated waters (Yan et al., 2005). The most common type of on-site treatment is the constructed wetland processes which are used to treat municipal sewage by removing Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS) (Johnson and Mehrvar, 2019; Zhang et al., 2010).

Regarding Colombia, Resolution 631 of 2015 (Colombia, 2015) regulates the discharge of wastewater into rivers and sewers. However, it does not consider parameters for the discharge specifically in hot springs.

1.1 RESEARCH PROBLEM STATEMENT

As evident by the literature and background review, there is a need to analyze pollutants and their effects on individual and collective health, in Colombia hot springs and their discharges to aquatic ecosystems. Identifying issues resulting from interaction between hot springs and people, and between hot springs wastewater discharges and aquatic ecosystems is critical.

Public decision-makers require scientific information to support their diagnoses, develop standards and control the quality of hot springs and their discharges into the rivers. Considering this currently, there are no regulations about wastewater discharges from hot springs in Colombia. For example, it is unknown: (i) the risk that the bather may be exposed to in hot springs pools; (ii) the presence of heavy metals that can affect the receiving water body and aquatic life negatively and pose risk to human health and aquatic ecosystem; (iii) presence of COVID-19 virus in hot springs wastewater, and (iv) operating conditions for the disinfection of hot springs on a prototype scale, including engineered wetlands.

1.2 JUSTIFICATION OF THE RESEARCH PROBLEM

The literature includes information on the biological, physical, and chemical contamination of wastewater discharges from anthropic activities. At the same time, little attention is paid to the pollution of hot springs and the effects that these waters can have on peoples' health and the impact of the discharge on aquatic ecosystems. Moreover, in Colombia there is a lack of information about the study area in terms of hydro-chemical, biological, and physical parameters, the chemical changes in the constituents of hot springs and their wastewaters, as well as related impacts to peoples' health and environment.

Currently, Colombia is suffering from the absence of policy instruments in the field of hot springs management. Policies for managing the quality of hot springs on aquatic ecosystems and the health of people are of special importance to prevent and / or reduce the risks of diseases and environmental pollution. The disinfection of hot springs and their wastewater discharges to aquatic ecosystems represent a priority issue, particularly in Colombia. It is evident that there is very little research that can contribute information so that the authorities of this country can judge and elaborate standards and controls on this type of water resource.

In particular, the contribution to the impacts of aquatic ecosystems and their wastewater discharges must be properly regulated to avoid risks to human health and aquatic ecosystems.

On the other hand, according to Showers et al. (2020), some preliminary studies carried out by the University of Arkansas (Department of Civil Engineering) suggest that shortages of COVID–19 test kits could be necessary to estimate the spread of the disease in a community. Those asymptomatic and not assessed could also excrete fecal matter with SARS-CoV-2 and release it into wastewater, which in turn goes to the river. Based on these considerations, it is important to advance the research on detecting the COVID-19 viruses in hot springs by disinfecting their waters.

It is also important to highlight that this study is carried out in the context of the actions taken by the Aqueduct and Sewerage Company of Bogota (in Spanish Empresa de Acueducto y Alcantarillado de Bogotá E.A.B – E.S.P) towards decontamination of Bogota River. Therefore, considering the previously mentioned gaps in the research that the literature review and the antecedents have also evidenced, it is necessary to evaluate an urgent assessment to realize the dimensions of the problem, which could create a base for decision makers to rely on. This research study was conducted to assess these problems, fill these gaps, and open prospects for additional studies that evaluate the Colombian hot springs status.

The lack of regulation and scientific research on the contaminants and effects of hot springs and their wastewater discharges in Colombia has generated a significant knowledge gap on individual and collective health risks and ecological impacts on aquatic ecosystems. The absence of specific regulations on the quality of hot springs in Colombia and their wastewater discharges has resulted in limited information on the presence of contaminants, including heavy metals, and their possible negative effects on human health and the environment.

Therefore, the hypothesis is raised that the absence of quality and control standards in hot springs can compromise the health of users and have negative impacts on aquatic ecosystems. In addition, the lack of treatment measures and the discharge of raw wastewater from the hot springs are expected to affect the water quality in nearby rivers and streams, which could have detrimental consequences for the environment.

For these reasons, this study seeks to fill the research gaps and provide valuable information for decision makers for the development of policies and regulations for the management of hot springs in Colombia, ensuring the protection of public health and the conservation of aquatic ecosystems.

1.3 RESEARCH OBJECTIVES

1.3.1 Overall Objective

The overall objective is to study and assess the water quality of hot springs and its discharges into the tributaries fed into the Bogota river.

1.3.2 Specific Objectives

The following is the list of specific objectives of this study:

Objective 1. To assess physicochemical and microbial properties of two hot springs in the region of Cundinamarca and its discharges into the tributaries fed into the Bogota River (Chapter 5).

Objective 2. To study the operational conditions of disinfection for its applications in hot springs (Chapter 6).

Objective 3. To study a baseline concentration of limited parameters in hot springs as future potential indicators of risk to human health and aquatic ecosystems (Chapter 7).

Chapter 2

LITERATURE REVIEW

This chapter includes comments on the theoretical perspectives and methodological approaches found in previous studies, which are associated with the research problem statement (Sampiere et al., 2018). This part emphasizes the most important topics, outcomes, and gaps in the past and points out how this thesis expands the current literature in the field of hot springs quality and their wastewater discharges into aquatic ecosystems.

Hot springs are mineral water whose emergent temperature must be 4ºC higher than the annual environmental average of the place from which they sprout, allowing the hot springs to take advantage of its thermal action (Cantabria (Spain),1988). There are many uses for the hot springs, such as: i) Swimming, bathing, and balneology (therapeutic use); ii) Space heating and cooling; iii) Agriculture applications (mainly greenhouse heating and some animal husbandry); iv) Aquaculture applications (mainly fishponds and raceway heating); v) Industrial processes, and vi) Heat pumps (for heating and cooling) (Porowski, 2019).

The scope of this proposal is associated only the use of bathing, balneology, and the practice of using natural mineral water for the treatment and cure of diseases, such as: Osteoarthritis (Verhagen et al., 2007), rheumatoid arthritis (Verhagen et al., 2015), treating low-grade inflammation and stress-related pathologies (Garcia et al., 2012), treating psoriasis and atopic dermatitis. Therefore, the literature review will be addressed from this perspective.

2.1 CLASSIFICATION OF MINERAL WATERS AND HOT SPRINGS

- **Classification of mineral waters**

The classification of mineral waters for their mineralization and their use for therapeutic baths, medical treatment or human consumption, is shown in Table 2.1.

Table 2.1. Classification of mineral waters according to their mineralization and use.

Type	Mineralization	Use
Waters elevated mineralization	1 to 5 g/L	Consumed by drinking
Waters medium mineralization	5 a 15 g/L; osmotic concentration approaches that of blood plasma	Suitable waters in balneology and as medicine.
Water high mineralization	15 to 35 mg/L	Mainly for therapeutic baths.
Brines	15 to 150 mg/L	In natural form for exclusively for bathing purpose.

Source: (Komatina, 2004) cited in (Zachaira, 2016).

- **Classification of hot springs by their composition**

A classification of the mineral waters depending on their type, use and mineralization, is shown in Table 2.2.

Table 2.2. Types of mineral waters.

Type	Mineralization	Composition	Use
Medicinal mineral water without specific components and properties	150 g/L	Chloride and sulfate ions.	Balneological action on the human organism as a result of ionic composition and mineralization
Carbonated mineral waters	Fractions of 1 g / L to 90 g / L	High concentration of carbon dioxide as well as its ionic composition and mineralization value. Variable chemical composition HCO_3 dominant anion.	Treat diseases of the stomach, intestines, bile and urinary tract, etc.
Hydrogen sulfide mineral waters	>500 g/L	Free Hydrogen Sulfide and Hydrosulfide Ions. Diversity of chemical composition, mineralization and concentration of H_2S and HS.	In balneology, it is used to treat certain skin diseases, rheumatics, nervous disorders, etc.

Type	Mineralization	Composition	Use
Radioactive mineral waters	Ra > 1.10-11 g / L U > 3.10-5 g / L Rn > 1.852 Bq / L	They include hydrocarbonate, sulfate and chloride waters with high mineralization. High content of radioactive elements.	In balneology, they are used to treat diseases of the nervous system, cardiovascular, skin and gynecological diseases.
Iron waters, arsenic waters and waters with elevated content of Mn, Al, Cu, and Zn	Fe lower limit of 20 mg /L As lower limit of 0.7 mg / L and other metals.	-------	-------
Bromine and iodine waters	Br > 25 mg / L or I > 5 mg / L	------	Drink and bath.
Waters with high content of organic substance	From several mg / L to more than 400 mg / L	Mineral waters from peat bog, mud flats and petroleum deposits.	-----
Silicic water	If > 50 mg/L as H_2SiO_3	Represented by hot springs and highly thermal with temperatures over 35 ° C.	Bath.

Source: (Komatina, 2004) cited in (Zachaira, 2016).

As it is of interest to the research problem, it is pertinent to refer to waters for therapeutic use (*balneology)*. It is common to find compositions of water of hot springs, such as (Reyes et al., 2015):

- *Ferruginous waters*: Contains the ferrous ion (Fe^{+2}) or ferric (Fe^{+3}) in its composition.
- *Chlorinated waters:* Contains ion chloride (Cl^-).
- *Sulphurous waters:* Contains divalent sulfur anion composition ($S^=$).
- *Sulphated waters:* Contains the sulfate anion in its composition (SO_4^-).
- *Bicarbonated waters:* Contains bicarbonate anion (HCO_3^-). The waters may have a mixed composition and are always balanced with cations such as sodium (Na^+), calcium (Ca^{2+}) or magnesium (Mg^{2+}) in their composition.
- *Radiactive waters:* Contains ion Randon (Ra) ions.

- **Classification of hot springs by their temperature**

Classification of the hot springs based on their temperatures is shown in Table 2.3 (Armijo and San Martín, 1994).

Table 2.3. Classification of hot springs by temperature.

Type of hot springs	Classification
Cold	< 20°C
Hypothermal	20°C – 35°C
Mesothermal	35°C – 45°C
Hyperthermal	>45°C

2.2 LOCATIONS OF HOT SPRINGS

- **Worldwide**

There are hot springs on all continents worldwide. The ten best hot springs around the world due to their health benefits are Bains De Dorres (France), Wiesbaden (Germany), Waikite Valley Thermal Pools (New Zealand), Therme Vals (Switzerland), Myvatn Nature Baths (Iceland), Takaragawa Onsen (Japan), Strawberry Springs (Colorado, USA), Heviz (Hungary), Peninsula Hot Springs (Victoria, Australia), and Radium Hot Springs (British Columbia, Canada) (South Asian Post, 2013).

- **Latin America**

In Latin America, the best natural hot springs also due to medicinal properties are: Termas Papallacta (Ecuador), Laguna Verde (Bolivia), Baños Hot Springs (Ecuador), Tabacon Hot Springs (Arenal, Costa Rica), Baños Morales Hot Springs (Chile), Puritama Hot Springs (Atacama, Chile), Termas de Cacheuta (Mendoza, Argentina), and Deception Island (Antarctic) (Select Latin America, 2016).

- **Colombia**

In Colombia, the hot springs are mainly found in the Central Cordillera where there is greater volcanic activity. However, there are other hot springs in Cundinamarca, Boyacá and even on the Caribbean Coast that do not depend on volcanic activity (Hot springs, n.d). Colombia has five spring blocks as shown in Figure 2.1.

Figure 2.1. Spring blocks in Colombia (SGC, 2015).

Spring blocks:

1. Cundinamarca, Boyacá, Santander, and Norte de Santander.
2. Antioquia, Caldas, Risaralda, and Tolima.
3. Cauca and Huila.
4. Nariño and Putumayo
5. Non-Andean: Chocó, Atlántico, Cesar, Arauca, Meta, and Guaviare.

In Colombia, these hot springs are important for medicinal and curative properties: *Termales Los Volcanes* (Chocontá, Cundinamarca), *Reserva Termal San Vicente* (Santa Rosa de Cabal, Risaralda), *Los Ángeles Termal* (Rivera, Huila), *Termales Santa Rosa de Cabal* (Santa Rosa de Cabal, Risaralda), *Hotel Termales del Ruiz* (*Parque Nacional*

Natural de los Nevados), *Instituto Termal* (Paipa, Boyacá), and *D'Acosta Hotel Sochagota* (Paipa, Boyacá) (El Espectador, 2020).

- **Cundinamarca**

In a study carried out by INGEOMINAS in 2003, it was found that there were more than 40 hot springs sources in the department of Cundinamarca (INGEOMINAS, 2003).

The most important hot springs in Cundinamarca are: *Termas de Paratebueno*, *Termas de Guiterma, Termas de Tabio, Termas de Agua de Dios, Termas de Napoles, Termas de Gacheta, Termas de Chipaque, Termas de Pandi, Termas de Tocaima*, and *Termas de Choachi* (Lugares turísticos, n.d).

2.3 MICROBIOLOGICAL AND PHYSICOCHEMICAL PARAMETERS IN HOT SPRINGS SOURCES

There are studies on microbiological and physicochemical parameters in hot springs sources, in countries such as India (Badhai et al., 2015; Kumar & Ramesh, 2019), China (Yan et al., 2005), and Colombia (INGEOMINAS, 2003; Torres et al., 2019). Many hot springs have been characterized in the months of greatest influx of tourism activities to observe the variability in dry and rainy months. The main parameters measured were Water Temperature, Dissolved Oxygen (DO), pH, Conductivity, Free CO_2, Salinity, Total Dissolved Solids (TDS), Chloride, Total Alkalinity, Nitrates, Sulphates, Phosphates, Total Hardness, Calcium (Ca^{2+}), Magnesium (Mg^{2+}), and Sodium (Na^{+}).

In addition, other studies in Colombia (Torres et al., 2019), China (Yan et al., 2005), and Eritrea (Ghilamicael et al., 2017), consider parameters, such as: Sodium (Na), Potassium (K), Ammonia – Nitrogen, Fluoride, Bicarbonate, Silicate – Silicon, Iron (Fe), Copper (Cu), Lead (Pb), Cadmium (Cd), Zinc (Zn), and Arsenic (As). Erfurt and Cooper in their book “*Health and Wellness Tourism Spas and Hot Springs*”, describe others common minerals found in hot springs, as shown in Table 2.5.

Table 2.4. Most common chemical elements found in hot springs (Erfurt and Cooper, 2009).

Chemical compositions found in hot springs	Other substances occasionally present
Calcium	Bromine
Carbonates	Caesium
Chlorides	Cobalt
Fluoride	Iodine
Magnesium	Lithium
Sulphates	Radium
Sulphides	Silica

According to above studies, these microorganisms were found: Bacteria (*Brevibacillus borestelensis, Aeromonas veronii, Stenotrophomonas maltophilia, Paenibacillus dendritiformis, Bacillus cerus, Bacillus cibi, Streptococcus pyogenes, Bacillus subtilis, Brevibacillus parabrevis, Brevibacillus reuszeri, Geobacillus stearothermophilus*, Actinomycetes (*Thermoactinomyces candidus, Thermoactinomyces candidus, Thermoactinomyces thalpophilum, Streptomyces albus, Streptomyces canescens*) and Fungi (*Sclerotium rolfsii, Fusarium oxysporum, Sclerotinia sclerotiorum, Aspergillus tubingensis, Trichoderma harzianum*).

In the case of Cundinamarca, INGEOMINAS carries out measures of microbiological parameters of some hot springs, considering molds and yeasts, *Pseudomonas aeruginosa*, aerobic mesophiles, and fecal coliforms (INGEOMINAS, 2003).

2.4 MICROBIOLOGICAL AND PHYSICOCHEMICAL PARAMETERS HOT SPRINGS IN DISCHARGES TO RIVERS

The microbiological water quality of the rivers and the physicochemical parameters depend on the discharge they receive. The main parameters measured were temperature, pH, electrical conductivity, dissolved oxygen (DO), biochemical oxygen demand (BDO), chemical oxygen demand (COD), nitrates concentration, ammonia, and orthophosphates. The microbiological parameters include mesophilic and psychrophilic bacteria, *Staphylococcus spp.* and *Salmonella spp.*, and coliforms, thermotolerant (fecal) coliforms, *Escherichia coli* (*E. coli*), *E. faecalis*, and sulphate – reducing Clostridium (Lenart et al., 2016). Elevated concentrations of nitrogen, especially ammonia (NH_3), nitrate (NO_3^-), and nitrite (NO_2^-) and phosphorus, including Total Phosphorus (TP) and orthophosphate (PO_4^{3-}), have been observed in many urban rivers due to discharge from wastewater treatment plants and industrial processes (Schiliemann et al., 2020). Therefore, the scope of this thesis, the Bogota River is addressed as it is one of the most polluted in Colombia (Díaz et al., 2019).

2.5 WATER TREATMENT IN HOT SPRINGS

The control of viruses and bacteria in recreational waters is achieved with adequate treatment, influenced by disinfection with chlorine or other disinfectants (WHO, 2016).

Most hot springs have lost their natural properties due to the addition of chemicals like chlorine. Only some natural hot springs pools retain their natural physical and chemical properties (Valeriani et al., 2018).

In the case of chlorine application as a disinfectant, it is important to determine the chlorine demand to guarantee the disinfection of the water, as shown in Figure 2.2.

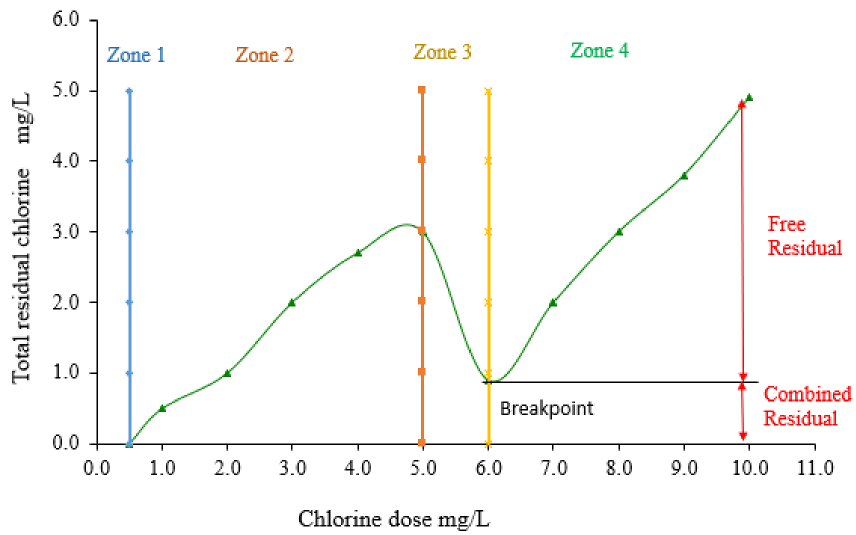


Figure 2.2. Breakpoint Chlorination Curve Interpretation, (Spon, R., 2008).

Zone 1: Initial chlorine demand is caused by reducing compounds that consume most of the chlorine.

Zone 2: Additional chlorine combines with total available ammonia and reactive organics compounds to form the maximum residual monochloramine. At the same time, the uncombined free ammonia is depleted to zero.

Zone 3: More doses of chlorine converts monochloramine to odorous dichloramine and nitrogen trichloride. The combined total residual chloramine decreases and the ammonia concentration approaches zero at the breakpoint.

Zone 4: True free chlorine residual is obtained and provides the least nuisance odor when free residuals make up 85 percent of the total chlorine concentration. Nuisance combined chlorine residuals survive and the potential for disinfection by-products (trihalomethane and haloacetic acid) formation remains, as more free chlorine residue develops.

The chemical disinfectants that are used most frequently include chlorine (hypochlorite or, chlorinated isocyanurates), chlorine dioxide, bromochlorodimethylhydantoin (BCDMH), ozone and Ultraviolet (UV) radiation (with ozone and UV usually being used in combination with a chlorine- or bromine-based disinfectant), and UV radiation alone (Barrera et al., 2012). Water treatment practices vary widely around the world, as do the levels of chemicals that are currently considered to be acceptable in order to achieve adequate disinfection while minimizing user discomfort (WHO, 2016).

The natural flow pools lined with natural rocks do not use chemicals, where the conditions of a natural body of water are purified by biological and physical treatment. They are often not subject to regulations like health inspections (Alberta, 2014).

The treatment of hot springs without external chemical agents includes the following:

Water exchange: It consists of making a replacement of the hot springs in swimming pools (Sanchez and Cheu, 2019). This happens in regions of Galicia and Murcia in Spain (Galicia, 1996; Murcia, 1997). Where the aquifer is small, this treatment is unsustainable (Romano, 2017).

Ozone utilization: According to the World Health Organization 2016), it is an oxidizing and disinfecting agent for the treatment of swimming pool water; it is generated on-site and is potentially dangerous, especially for operators. Thus, it is not suitable for use as a residual disinfectant. In recreational water treatment, it is common to combine UV treatment and ozonation for disinfection (Cheema et al., 2017). The ozone that is generated by Ultraviolet (UV) radiation is used for the treatment of spa and swimming pool waters (mainly residential) and others by technology based on what is established in the German standard DIN 19643-1 "Treatment of water of swimming pools and baths," (Germany, 1997; Rip, 1995).

UV radiation: The UV radiation process purifies the circulating water, without leaving a residual disinfectant. It deactivates microorganisms and breaks down some contaminants. Ultraviolet light disinfection is a viable and beneficial alternative to chlorination for both water and wastewater treatment (Barrera et al., 2012; Fang et al., 2008).

There are many studies on hot springs that show the efficiency of using non-oxidative disinfection methods such as UV radiation for the inactivation of potential pathogenic species of dermatophyte fungi, including *T. mentagrophytes*, and *T. rubrum* (Sisti et al., 2014).

In the case of hot spring wastewater, the constructed wetlands process provides general COD, Total Suspended Solids (TSS), heavy metals, and human pathogen removal for sanitary wastewater naturally without the use of chemicals (Jhonson and Mehrvar, 2019; Wu et al., 2016; Zhang et al., 2010).

The control of viruses and bacteria in recreational waters is achieved with adequate treatment, influenced by disinfection with chlorine or other disinfectants (WHO, 2016). Most hot springs have lost their natural properties due to the addition of chemicals like chlorine. Only some natural hot springs pools retain their natural physical and chemical properties (Valeriani et al., 2018).

2.6 LAWS AND REGULATIONS ON HOT SPRINGS WATER TREATMENT

In Colombia, the regulations for hot springs are insufficient and do not have specific parameters for water quality. Article 6 of Decree 554 of 2015, of the Ministry of Health and Social Protection, establishes "*The general physical - chemical and microbiological parameters of the water will not be required of the ponds that store hot springs and therapeutic uses. The Ministry of Health and Social Protection will define these parameters*" (Colombia, 2015, p.1). At present, these regulations do not exist.

In countries, such as Canada and Germany, the disinfection of hot springs is carried out with recirculation systems (Alberta, 2014; Germany, 1997). The regions of Galicia and Murcia in Spain only allow water to be renewed for hot springs treatment, and countries like Cuba do not specify any treatment of their waters (Cuba, 1998; Galicia, 1996; Murcia, 1997). Chapters 3 and 4 go into more depth on the subject.

2.7 INDICATORS OF HUMAN HEALTH RISK ANALYSIS AND AQUATIC ECOSYSTEM IN HOT SPRING

- **Hot spring swimming pool**

Bacteria that can contaminate mineral-medicinal water are coliform, streptococci, and clostridia, which are considered indicators of lack of protection and the presence of *Escherichia coli (E. coli)*, *Salmonella* or *Pseudomonas aeruginosa* (*P. aeruginosa*) (Oliver and Clapes, n.d), of which are a health risk. Also, the concentration *P. aeruginosa* in wells and pools was found to be under 1.0 CFU / 100 mL for pH values under 7.0. For pH values above 7.0, the presence of the pathogen cannot be counted (Sanchez and Chivata, 2017). Based on Ossa, (2014) the presence of *P. aeruginosa* in hot springs is the main cause of infections with high morbidity and mortality in critical patients. In addition, it generates health complications for cancer patients and immunological or immunocompetent diseases. *P. aeruginosa* is widely distributed in nature, soil, water, plants, and animals. Its multiplication requires temperatures of 36 to 41 ℃ but not less than 4 ℃. It is able to survive in environments with few nutrients and minimal food needs (WHO, 2016). *P. aeruginosa* is an indicator of contamination, as it is an opportunistic pathogenic bacterium that can cause infections in immunosuppressed people. Its presence in hot springs is undesirable due to its epidemiological importance. This added to the fact that the characteristics of hot springs show favorable conditions for the development of this bacterium in water (De la Rosa Jorge and Mosso, n.d).

Clinical cases have been found where *P. aeruginosa* causes folliculitis due to the therapeutic or recreational use of hot tubs, spas, and occasionally swimming pools. In order to control the growth of *Pseudomonas* in hot tubs, spas or swimming pools, an adequate treatment of water is necessary to prevent this folliculitis (Ara et al., 2003).

Legionella pneumophila (L. pneumophila), transmitted by water, causes most cases of infection and epidemic outbreaks. *L. pneumophila* and other related species are found in lakes, rivers, streams, hot springs, and other water systems (Ara et al., 2003). Bacteria live and grow in aquatic environments at temperatures between 20 ℃ and 50 ℃ (with an optimum temperature of 35℃). *Legionella* bacteria can survive and proliferate by parasitizing free protozoa or within biofilms that form in water systems (WHO, 2016).

Fecal coliform bacteria are organisms found naturally in the feces of humans and animals. Their presence in sources and bodies of water indicates biological contamination and poor hygiene conditions. *E. coli O157* has been linked to outbreaks of illness associated with swimming in pools or similar environments (WHO, 2016).

According to the literature review of the article Health Risk in Hot Springs, the Pathogenic microorganisms identified in public hot springs are *Naegleria spp*, *Naegleria fowleri*, *Legionella pneumophila*, *Vittaforma corneae*, *Mycobacterium avium-intracellulare Complex* (MAC), *Pseudomonas aeruginosa*, and *Mycobacterium phocaicum*. These microorganisms can cause various health complaints in bath users, such as *Primary Amebic Meningoencephalitis* (PAM), *Legionella* pneumonia, *Pseudomonas* folliculitis, *Pseudomonas* mastitis, *Microsporadial* keratitis, Hot tub lung (HTL), and *P.aeruginosa* pneumonia (Rahel et al., 2021).

However, some countries have reported the presence of diseases caused by bacterial infections in hot springs, therefore, the presence of microorganisms is an important consideration to be used as an indicator to evaluate the quality of hot springs (Rahel et al., 2021).

- **Heavy metals in hot spring**

Exposure to some heavy metals has been associated with various adverse health effects, including cancer (US EPA, 2022). Although some elements are essential to humans, they can be dangerous at high levels of exposure. Considering the importance of their toxicological potential, arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg), and lead (Pb) are especially considered (García et al., 2012).

Some studies have found that geothermal water may contain toxic elements such as arsenic, cadmium, chromium, selenium, and mercury, and radioactive elements such as uranium (U), thorium (Th), and radon (Rn) (Durowoju et al., 2020).

Studies conducted at geothermal springs in Soutpansberg, Limpopo Province, South Africa found that trace metal concentrations of the geothermal springs and boreholes were within permissible drinking water guidelines by the South African National Standards (SANS) and World Health Organization (WHO), with the exception of mercury (Hg), which is high in the summer season. (Durowoju et al., 2020).

- **Hot springs discharges**

According to Yibas et al. (2011), it is necessary to determine the health-related risks of hot springs. It also seems there is a consensus that pollution of the aquatic ecosystems is considered a serious and growing problem (Dalzochio et al., 2016).

Based on the above considerations, some potential physical, chemical, and microbiological risks are associated with the physical (e.g., pH and temperature) and chemical compositions of the hot springs (e.g., antimony, mercury, selenium, and arsenic). For example, Lenart et al. (2016) suggests that the concentration of some components like K^+, Na^+, Ca^{2+}, Mg^{2+}, SO_2^-, HCO_3, F^-, Cl^-, SiO_2, HBO_2, CO_2, pH, Total Dissolved Solids (TDS), Hg, As, Sb, Be, Li, Rb, and Cs, could have negative effects in normal stream water.

For example, some studies have found that wastewater discharges from hot springs have a significant adverse impact on water quality during periods of minimal flow.

2.7.1 Methodologies for the Calculation of Risk Indicators

In the literature, methodologies of risk indicators for recreational waters are evidenced, such as:

Colombia

In Resolution 1618 of 2010 of the Ministry of Social Protection in the Article 17 establishes a Pool Pond Water Risk Index and Similar Structure – IRAPI (in Spanish). This corresponds to the degree of risk of occurrence of diseases related to the non-compliance with the physical, chemical, and microbiological characteristics of the water contained in pool, ponds, and similar structures (Colombia, 2010).

The procedure that must be carried out to calculate the Pool Pond Water Risk Index and similar structure - IRAPI, is:

$$\% \text{ IRAPI} = \text{VCM} + \text{VCR} + \text{VISL} + \text{VCOC} \quad (2.1)$$

Where:

VMC = Value of the microbiological characteristics of the water = 40%.

VCR = Residual concentration value of the disinfectant in the water = 30%.

VISL = Langelier Saturation index value = 20%.

VCOC = Value other physical and chemical characteristics analyzed = 10%.

The total mathematical sum of the scores assigned for each component of the equation is equal to 100%. The value of the Risk Index of Pool Pond Water and Similar Structure - IRAPI, is zero (0) points, which corresponds to no risk, when it meets the acceptable values of the microbiological characteristics, the disinfectant residual, Saturation Index de Langelier – ISL and other physical and chemical characteristics analyzed. The one hundred (100) points corresponds to high risk (Colombia, 2010).

Table 2.5. Compliance and non-compliance risk score (Sanchez,2011).

Description of the Components of the Equation	Component Criteria	Value to be Considered in the Equation for the Calculation of IRAPI
VCM (Value of the microbiological characteristics of the water)	When the acceptable values of all the microbiological characteristics indicated in this resolution are met.	Zero (0) %

Description of the Components of the Equation	Component Criteria	Value to be Considered in the Equation for the Calculation of IRAPI
	When (2) of the microbiological characteristics is not met.	Twenty (20) %
	When all the microbiological characteristics are not met.	Forty (40) %
VCR (Residual concentration value of the disinfectant in the water)	When the acceptable residual value of the disinfectant indicated in this resolution is met.	Zero (0) %
	When the residual value of the disinfectant is above the accepted value.	Fifteen (15) %
	When the residual value of the disinfectant is below the accepted value.	Thirty (30) %
VISL (Langellier Saturation index value)	When the value of the Langellier Index corresponds to fully balanced water, in accordance with what is indicated in this resolution.	Zero (0) %
	When the value of the Langellier Index corresponds to water with a corrosive or encrusting tendency.	Twenty (20) %
VOC (Value other physical and chemical characteristics analyzed)	When the acceptable values of all the physical and chemical characteristics indicated in this resolution are met.	Zero (0) %
	When some physical and chemical characteristics are not met.	Five (5) %
	When all the physical and chemical characteristics are not met.	Ten (10) %

Depending on the score, the risk classification is obtained (See Table 2.6).

Table 2.6. Compliance and non-compliance risk score.

Risk Index Classification for Swimming Pool Pond Water and Similar Structure – Absolute IRAPI (%) Risk Level	Risk Level
76 – 100	High risk
36 – 75	Medium risk
11 – 35	Low risk
0 – 10	Risk free

Argentina

Almeida et al. (2012) proposed an Index for Recreational Water Quality (RWQI) as a tool to ensure the health of swimmers and to take practical decisions. The RWQI was developed using epidemiological data and with different guidelines for recreational waters proposed by different organizations around the world, considering swimmer contact and the possibility of water ingestion during recreational activity. The index was applied to the data set on water quality of the Potrero de los Funes River (San Luis, Argentina), generated during 2 years (2009–2010).

The system uses a set of rating curves, one for each of the quality determinants: total coliforms, fecal coliforms, *E. coli*, enterococci, pH, turbidity, chemical organic demand, phosphorus, nitrate, and detergents. Weighted geometric mean arithmetic was used to calculate the RWQI (2.2).

$$\mathrm{RWQI} = \prod_{i=1}^{n} Q_i^{W_i} \qquad (2.2)$$

Where *Qi* is the rating value of parameter *i* and *Wi* is the weighting factors ($\sum Wi=1$). Therefore, each analytical value is transformed in a non-dimensional value or quality level (*Qi*) through a mathematical equation or through its corresponding graphic representation. *Wi* is the influence of each parameter in the total value of the index. To calculate each of them, their individual weight must be considered. Wi is calculated as (2.3):

$$W_i = \frac{\frac{1}{a_i}}{\sum \frac{1}{a_i}} \qquad (2.3)$$

The *ai* coefficient values vary from 1 (very important parameter) to 4 (less significant parameter) according to the importance assigned to each parameter involved in the index. In this way, the RWQI is calculated by the multiplication of all of the products of the parameter weights and sub-index values (Q_i^{Wi}) (2.2). RWQI is a number among 0 to 200, where values to 100 represent the best quality.

United States

The EPA proposes the Recreational Water Quality Criteria (RWQC) for Bacterial Indicators of Fecal Contamination. EPA research focuses on the development of new or improved analytical methods for high priority fecal indicators, such as rapid fecal indicator bacteria methods to support implementation of these methods in recreational waters (EPA, 2012).

Current RWQC rely on general fecal indicator bacteria, such as Enterococci and *E. coli,* to estimate potential public health risk associated with polluted waters (EPA, 2012).

2.8 COVID-19 IN HOT SPRINGS

When the Coronavirus pandemic started, authorities all around the world ordered the closure of all swimming pools, hot springs, and beaches for recreational use as a sanitary precautionary measure to prevent the spread of COVID-19. An example of these situations was an announcement of a temporary closure of the city's thermal parks, as a measure to prevent the spread of the Coronavirus in Colombia, Canada, and other countries (Sanchez et al., 2020).

According to the Centers for Disease Control and Prevention (CDCP, 2019), there is no evidence that the virus that causes COVID-19 can be transmitted to people through water in swimming pools, hot tubs, or playgrounds. Furthermore, the proper functioning of these aquatic sites and disinfection of the water (with chlorine or bromine) should deactivate the virus (CDCP, 2019). To the best of the author’s knowledge, there is no disinfection of hot springs wastewaters or disinfection before human use in Colombia. In addition to this number, I recommend reviewing the following publications:

Conference and article

- Y. Sánchez, M. Mehrvar, L. McCarthy, E. Quiñones, L.R. Cheu, J. Romero. **Preventive measures pertaining to COVID-19 in swimming pools and hot springs in Europe, Canada, United States, and Colombia**, *VII Congreso Internacional de Innovación y*

Tendencias de la Ingeniería (CONIITI 2021), Virtual Conference, Bogotá D.C., Colombia, September 29 to October 1, 2021. https://ieeexplore.ieee.org/document/9619701/authors#authors. Indexed article in IEEE. DOI: 10.1109/CONIITI53815.2021.9619701.

Conference and article

- Y. Sánchez, M. Mehrvar, L. McCarthy, E. Quiñones, L.R. Cheu, J. Romero. **Scientific discussion of selected viruses including COVID-19 in hot springs**, *VI Congreso Internacional de Innovación y Tendencias de la Ingeniería (CONIITI 2020),* Virtual Conference, Bogotá D.C., Colombia, September 30 to October 2, 2020. : https://ieeexplore.ieee.org/abstract/document/9240267. Indexed article in IEEE. DOI: 10.1109/CONIITI51147.2020.9240267.

Conference, article and poster

- Y. Sánchez, M. Mehrvar, L. McCarthy, E. Quiñones, L.R. Cheu, J. Romero. **An Overview of the Management of Covid-19 in Swimming Pools, Beaches, and Hot Springs in Europe, Canada, and Colombia**, *Segundo Encuentro Nacional de Estudiantes de Doctorados en Ingeniería (ENEDI 2020), ACOFI 2020,* Cartagena, Colombia, September 16-18, 2020. https://www.acofi.edu.co/eiei2020/wp-content/uploads/2020/10/Memorias-ENEDI-2020.pdf. ISBN: 978-958-680-090-7. Digital Book.

Chapter 3

HOT SPRINGS REGULATIONS AND LOCAL AND GLOBAL LEVEL

This chapter presents the existence of hot springs regulations at local and global level. The literature review presented in this chapter made it possible to find out that the regulations for hot springs, in Colombia are insufficient and do not have specific parameters for water quality. Article 6 of Decree 554 of 2015, of the Ministry of Health and Social Protection, establishes "the general physical – chemical, and microbiological parameters of the water will not be required of the ponds that store hot springs and therapeutic uses. The Ministry of Health and Social Protection will define these parameters" (Colombia, 2015, p.1). At present, these regulations do not exist. Canada and Germany do not possess specific regulations or standards for water from hot springs. Instead, the same microbial and chemical requirements as for swimming pool water according to the Alberta Government of Canadian Public Swimming Pool Regulations and the Standard Din 19643 of Germany apply for hot springs. Table 3.1 presents a compilation of international regulations for the treatment of hot springs, where water renewal or water disinfection is carried out.

Table 3.1. International regulations of some countries for hot springs treatment.

SPAIN			CUBA	WHO	CANADA		PORTUGAL	GERMANY
Galicia	***Cataluña***	***Murcia***	***State***	***World***	***Ontario***	***Alberta***	***National***	***National***
Order of November 5, 1996 (a)	Decree 271 of 2001, of October 9 (b)	Decree 55 of July 11, 1997 (c)	NC 93-09:85 NC 93-28:88 (d)	Guidelines for safe recreational water environments, volume 2, 2006. (e)	Recreational Water Reference Document, 2019 (f)	Alberta Regulation 204/2014 (g)	Ordinance No. 1220/2000 of December 29 (h)	DIN 19643-1 Treatment of water of swimming pools and baths (i)
The renewal of all water must be guaranteed in the appropriate time.	The products or methods used for disinfection must be stated.	Continuous water renewal	Does not establish treatment	In some natural spas utilizing thermal and mineral waters it may not be possible to treat the water in the usual way (i.e., by recycling or disinfection) because the agents believed to be of benefit, such as sulfides, would be eliminated or impaired. These natural spas, therefore, require non-oxidative methods of water treatment.	Adequate disinfection of water is one of the most important factors to help reduce risk of illness.	A pool must be operated and maintained by the owner or the owner's agent, if any, or the pool operator so that the water it contains is microbiologically, chemically and physically safe for use.	Preservation of the quality of the water up to the points of its use.	Disinfection with chemical agents.

[a] (Galicia, 1996). [b] (Cataluña, 2001). [c] (Murcia, 1997). [d] (Cuba, 1998). [e] (WHO, 2016). [f] (Ontario, 2019), [g] (Alberta, 2014). [h](Portugal Ministries of Economy and Health, 2000). [i](Germany, 1997).

Support for this topic is presented in the following publications:

Conference and abstract

Y. Sánchez, L.R. Cheu. **State of the art the thermal water**, 8th International Conference of Swimming Pool & Spa, March 18 - 22, 2019, Marseille – France. https://8thswimpoolspa.sciencesconf.org/program.

Conference, article, and poster

Y. Sánchez, L.R. Cheu. **Estado del arte de la calidad del agua termal**, *Primer Encuentro Nacional de Estudiantes de Doctorados en Ingeniería (ENEDI 2019), ACOFI*

2019, Cartagena, Colombia, September 10-13, 2019. https://acofipapers.org/index.php/eiei/article/view/267/263. ISSN: 2665-5918. DOI: 10.26507/ponencia.267.

Conference

Y. Sánchez, L.R. Cheu. **Estado del arte de la calidad del agua termal**, *XXV Congreso Institucional de Investigación.* El Bosque University, Bogotá, D.C, Colombia, September 17-19, 2019. https://www.unbosque.edu.co/sites/default/files/2019-09/Programa%20XXV%20Congreso%20Institucional%20de%20Investigaciones%202019_FINAL.pdf.

Poster

Y. Sánchez, L.R. Cheu. **Estado del arte del agua termal**, *Segundo Seminario de Investigación e Innovación.* Colombian School of Engineering Julio Garavito University, Bogotá, D.C, Colombia, October 30, 2019.

With respect to the quality of the water used by bathers from hot springs sources, in Colombia there is no culture of carrying out physical, chemical, and microbiological analysis samples of its waters, due to the fact that the control of these waters is not currently regulated the quality of the hot spring. From the bibliographical review, it was determined that countries such as Germany, Canada, and Chile use the same regulation of the quality of swimming pool water for hot springs to guarantee the health of the bather. Therefore, a comparison of limit parameters of drinking water and swimming pools for the water used by bathers was made.

In the article An Overview of Water Quality Regulation or Standards in Swimming Pools, Drinking Water, and Hot Springs in Germany, Canada, and Colombia, the analysis of this regulation is presented in more detail, which is summarized in Table 3.2.

Table 3.2. Main physical and chemical parameters.

PARAMETER	UNIT	DRINKING WATER						SWIMMING POOL					HOT SPRING
		CANADA			GERMANY	COLOMBIA	WHO	CANADA		GERMANY	CHILE	COLOMBIA	JAPAN
		ONTARIO Reg. 169/03 (a)	GUIDELINE FOR ONTARIO (b)	GUIDELINES FOR CANADIAN (c)	BGBl. I 2016, 476 (d)	Resolution 2115/07 (e)	A global overview of national regulations (f)	Alberta Reg. 204/2014 and Government (g)	Ontario Reg. 565/1990 (h)	DIN 19643 (i)	Decree 209 of 2002 (j)	Resolution 1618/10 (k)	Hot spring Law, 2014 (l)
Temperature	oC	-	15	<= 15	-	-		35-45	-	-	-	-	
Conductivity	uS/cm	-	-	-	2790 at 25 °C	1000	None specified	-	-	-	-	max 2400	
Odour and taste		-	Inoffensive	Inoffensive	3 - 23 °C as Ton/ Acceptable	Acceptable	None set	-	-	-	-	Acceptable	
ORP	mV	-	-	-	-	-		700 - 770	600 - 900	-	-	Min 700	
pH	pH Units	-	6.5 - 8.5	7.0 - 10.5	≥ 6,5 und ≤ 9,5	6,5 - 9,0	None set	6.8 - 7.6	7.2 - 7.8	6.5 - 7.2	7.2 - 8.2	7.0 - 8.0	
Alachlor	mg/L	0.005	0.005	-	-	-	0.02	-	-	-	-	-	
Aldicarb	mg/L	-	0.009	-	-	-	0.01	-	-	-	-	-	
Acrylamide	mg/L	-	-	-	0.0001	-	0.0005	-	-	-	-	-	
Aldrin +Dieldrin	mg/L	-	0.0007	-	-	-	0.00003	-	-	-	-	-	
Aluminum	mg Al/L	-	0.1	< 0.1	0.2	0.2	0,1 - 0,2	-	-	-	-	< 0,2	
Ammonium	mg/L NH_4	-	-	-	0.005	-	None set	-	-	-	-	< 1.5	
Antimony	mg Sb/L	0.006	0.006	0.006	-	0.02	0.02	-	-	-	-	-	
Arsenic	mg As/L	0.01	0.025	0.01	0,01	0.01	0.01	-	-	-	-	-	
Antrazine	mg/L	0.005	0.005	0.005	-	-	0.1	-	-	-	-	-	
Azinphos-methyl	mg/L	0.02	0.02	0.02	-	-		-	-	-	-	-	
Barium	mg Ba/L	1.0	1.0	2.0	-	0.7	0.7	-	-	-	-	-	5.0
Bendiocarb	mg/L	-	0.04	-	-	-		-	-	-	-	-	
Benzene	mg/L	0.001	0.005	0.005	0.001	-	0.01	-	-	-	-	-	
Benzo(a)pyrene	mg/L	0.00001	0.00001	0.00004	-	-	0.007	-	-	-	-	-	
Beryllium	mg/L	-	-	-	-	-	0.012	-	-	-	-		
Boron	mg B/L	5.0	5.0	5.0	1.0	-	2.4	-	-	-	-	-	
Bromide	mg Br-/L	-	-	-	-	-	-	-	-	-	-	-	>= 5
Bromate	mg/L	0.010	0.010	0.01	-	-	0.01	-	-	2	-	-	
Bromoxynil	mg/L	0.005	0.0050	0.005	-	-		-	-	-	-	-	
Cadmium	mg Ca/L	0.005	0.0050	0.007	0.003	0.003	0.003	-	-	-	-	-	
Carbaryl	mg/L	0.090	0.09	0.09	-	-		-	-	-	-	-	
Carbofuran	mg/L	0.090	0.09	0.09	-	-	0.007	-	-	-	-	-	
Carbon Tetrachloride	mg/L	0.002	0.005	0.002	-	-	0.004	-	-	-		-	
Copper	mg Cu/L	-	1.0	2.0	2.0	1	2.0	-	-	-	max 1.5	< 1,0	
Chromium	mg Cr/L	-	-	-	0.05	0.05		-	-	-	-	-	
Free and dissociable cyanide	mg CN/L	-	-	-	-	0.05		-	-	-	-	-	
Cyanazine	mg/L	-	0.01	-	-	-	0.0006	-	-	-	-	-	
Cyanide	mg/L	0.2	0.2	0.2	0.05	-	0.5	-	-	-	-	-	
1,2 Dichloromethane	mg/L	-	0.005	0.005	0.003	-		-	-	-	-	-	
2,4-Dichlorophenol	mg/L	0.05	0.9	0.9	-	-		-	-	-	-	-	
Fluoride	mg/L	1.5	1.5	1.5	1.5	-	1.5	-	-	-	-	-	
Hidrogen	mg/L H+										-		>= 1
Terbufos	mg/L	0.001	0.001	0.001	-	-		-	-	-	-	-	
Tetrachloroethylene (perchloroethylene)	mg/L	0.01	0.03	0.01	0.01	-		-	-	-	-	-	
Uranium	mg/L	0.02	0.02	0.02	0.01	-	0.03	-	-	-	-	-	
Iron	mg Fe/L	-	0.3	<= 0,3	0.2	0.3	None set	-	-	-	-	<0,3	>= 10
Magnesium	mg Mg/L	-	-	-	-	36	None specified	-	-	-	-	-	

PARAMETER	UNIT	DRINKING WATER						SWIMMING POOL					HOT SPRING
		CANADA			GERMANY	COLOMBIA	WHO	CANADA		GERMANY	CHILE	COLOMBIA	JAPAN
		ONTARIO Reg. 169/03 (a)	GUIDELINE FOR ONTARIO (b)	GUIDELINES FOR CANADIAN (c)	BGBl. I 2016, 476 (d)	Resolution 2115/07 (e)	A global overview of national regulations (f)	Alberta Reg. 204/2014 and Government (g)	Ontario Reg. 565/1990 (h)	DIN 19643 (i)	Decree 209 of 2002 (j)	Resolution 1618/10 (k)	Hot spring Law, 2014 (l)
Manganese	mg Mn/L	-	0.05	0.12	0.05	0.1	0.4	-	-	-	-	-	>= 10
Mercury	mg Hg/L	0.001	0.001	0.001	0.001	0.001	0.006	-	-	-	-	-	
Molybdenum	mg Mo/L	-	-	-	-	0.07	0.07	-	-	-	-	-	
Nickel	mg Ni/L	-	-	-	0.02	0.02	0.07	-	-	-	-	-	
Lead	mg Pb/L	0.01	0.01	0.005	-	0.01	0.01	-	-	-	-	-	
Selenium	mg Se/L	0.05	0.01	0.05	0.01	0.01		-	-	-	-	-	
Zinc	mg Cr/L	-	5	<=5	-	3	None set	-	-	-	-	-	
Litium	mg Li + /kg										-		>=1
Total Trihalomethanes	mg THMs/ L	0.1	0.1	0.1	-	0.2	<= 1	-	-	0.02	-	-	
Aromatic Hydrocarbons	mg PAH/L	-	-	-	-	0.01		-	-	-	-	-	
Strontium	mg Sr/L	-	-	7.0	-	-		-	-	-	-	-	> = 10
Barium	mg Ba/L										-		>= 5
Silver	mg Ag/L	-	-	-	-	-	None specified	-	-	-	-	< 0,1	-
Apparent color	TCU	-	5	<= 15	-	15		-	-	-	-	-	-
Turbidity	NTU	-	5	<= 0,3	1.0	2		-	-	0.5	-	2	-
Alkalinity	mg $CaCO_3$/ L		30 - 500	-	-	200		60 - 180	80 - 120	-	-	< 140	-
Calcium	mg Ca/L	-	-	-	-	60	None specified	-	-	-	-	-	-
Total Organic Carbon (TOC)	mg/L	-	5	-	without abnormal change	5		-	-	-	-	-	-
Oxidability	mg/L - O_2	-	-	-	5	-		-	-	-	-	-	-
Calcite dissolving capacity	mg $CaCO_3$/ L	-	-	-	5	-		-	-	-	-	-	-
Total Hardness	mg $CaCO_3$/ L	-	80 - 100	80 - 100	-	300	None set	-	-	-	-	< 400	-
Sodium	mg Na/L	-	-	<= 200	200	-	None set	-	-	-	-	-	-
Sulphide	mg S^2/L	-	0.05	<=0,05	-	250		-	-	-	-	-	-
Chlorides	mg/L	-	250	<= 250	250	-	None set	-	-	-	-	-	-
Fluorides	mg F- /L	-	1.5	1.5	-	1		-	-	-	-	-	-
Nitrates	mg NO_3- N/L	-	10	10	-	10	50	-	-	20	-	-	-
Nitrites	mg NO_3- N/L	-	1.0	1.0	0.5	0.1	3.0	-	-	-	-	-	-
Phosphates	mg PO4-/L	-	-	-	-	0.5		-	-	-	-	-	-
Sulfate	mg SO_4/L	-	500	<=500	250	250	None set	-	-	-	-	-	-
Free residual chlorine	mg/L - Cl_2	-	-	-	-	0,3 and 2	-	1,0 - 2,0	0,5 - 10	0.3 - 0.6 mg/L	-	1 - 3 mg/L	-
Combined Chlorine	mg/L	-	-	-	-	-	-	-	-	max 0,2	-	< 0,3	-
Cyanuric Acid	mg/L	-	-	-	-	-	-	50	Max 60	-	-	< 100	
Radon	mg/L Rn	-	-	-	-	-	-				-		20 μCu
Radium salts (as Ra)	mg/L Ra	-	-	-	-	-	-	-	-	-	-	-	100
Total dissolved solids	mg/L	-	500	<= 500	-	-	None set	-	-	-	-	-	

[a] (Ontario, 2003). [b] (Ontario, 2003).[c] (Health Canada, 2020). [d] (Germany, 2016). [e] (Colombia, 2015).). [f] (WHO, 2021). [g] (Alberta, 2014). [h] (Ontario, 1990). [i] (Germany, 1997). [j] (Chilean Ministry of Health, 2012). [K] (Colombia, 2007) and (Sanchez, 2011). [l] (Japan, 2014).

Countries that have specific regulations for hot springs focus more on regulating sanitary conditions, such as Galicia in Spain, which do not present limit values for the physical-chemical characteristics, but establish that *"the Medical Director must submit a report annually and in the first quarter to the Ministry of Health and Social Services of the permanence of the microbiological and physical-chemical characteristics of the different waters used for medicinal and/or thermal purposes for therapeutic uses"* (Galicia,1996, p.3).

With regard to the impact generated by the discharge of hot spring into rivers, the regulation of hot spring wastewater was reviewed.

In 2005, the Hot Spring Act was legislated in Taiwan to manage hot spring resources. Similar regulations are in force in Japan, Korea, and China. There are regulations for wastewater discharges – including backwash water from swimming pools – into rivers and sewers, for example, Germany and Canada, but not specifically an effluent standard for hot spring wastewater. Despite, the presumed negative consequences of the impacts on ecosystems derived from hot springs wastewater (Germany, 1997; Alberta, 2013).

Colombia specifically, does not have a specific regulation for the discharge of wastewater from hot springs. The Single National Decree 1076 of 2015 in Colombia establishes ***Article 2.2.3.3.9.7. Quality criteria for recreational purposes through primary contact. The admissible quality criteria for the destination of the resource for recreational purposes through primary contact,*** are established in Table 3.3.

Table 3.3. Quality criteria for recreational purposes (Colombia, 2015).

Reference	Expressed as	Value
Fecal coliforms	MPN	200 microorganisms/ 100 mL
Total coliforms	MPN	200 microorganisms/ 100 mL
Phenolic compounds	Phenol	0.002
Dissolved Oxygen	%	70% saturation concentration
pH	Units	5.0 – 9.0
Surfactants	Active substances to methylene blue	0.5

Paragraph 1. *Visible film of floating fats and oils, presence of floating material from human activity, toxic or irritating substances whose action by contact, ingestion or inhalation produce adverse reactions on human health are not accepted in the resource*.

Paragraph 2. *Nitrogen and phosphorus must be in a proportion that does not cause eutrophication.*

The United States Environmental Protection Agency has given special permission for that discharge of hot springs wastewater under the national pollutant discharge elimination system in a specific case (EPA, 2018).

Colombia has great hot spring resources, where many of the hot spring spas do not have their wastewater discharges to water sources regulated. Resolution 631 of 2015 regulates the discharge of wastewater into rivers and sewers. However, it does not consider parameters for the discharge of hot springs (Colombia, 2015).

Support for this topic is presented in the following publications:

Poster

- Y. Sánchez, M. Mehrvar, L. McCarthy, E. Quiñones, L.R. Cheu, J. Chacón, J. Romero. **Descarga directa de afluentes de agua termales en los ríos a ecosistemas acuáticos**, *3er Congreso Internacional de Investigación e Innovación Ambiental (CNIIA-2022),* Bogotá, Colombia, November 9-11, 2022. http://congresoambiental.car.gov.co/agenda/. ISSN:2806-0784.

Conference and abstract

- Y. Sánchez, M. Mehrvar, L. McCarthy, E. Quiñones, L.R. Cheu, J. Chacon. **Adverse Effect of Direct Discharge of Hot Spring Tributaries into Rivers on Life Aquatic Ecosystems**, *Proceedings of the 5th International Conference of Recent Trends in Environmental Science and Engineering* (RTESE 2021) Virtual Conference, Niagara, Canada, May 17-19,

2021. https://avestia.com/RTESE2021_Proceedings/files/paper/RTESE_302.pdf.
DOI: 10.11159/rtese21.302.

Conference, article and poster

- Y. Sánchez, M. Mehrvar, L. McCarthy, E. Quiñones, L.R. Cheu, J. Romero, A. Reuß, R. González, J. Chacón. **Impact of the Sewage Discharge from Hot Springs to Water Sources**, *Tercer Encuentro Nacional de Estudiantes de Doctorados en Ingeniería (ENEDI 2021), ACOFI 2021,* Cartagena, Colombia, September 16-18, 2021. https://acofipapers.org/index.php/eiei/article/view/1691/1557.
DOI: 10.26507/ponencia.1691.

Conference and abstract

- Y. Sánchez, M. Mehrvar, L. McCarthy, L.R. Cheu, A. Reu ß, E. Quiñones, J. Romero. **Impact of the direct wastewater discharge from hot springs to rivers**, 9th International Conference of Swimming Pool and Spa, Virtual Conference, November 19, 2021, Antalya – Turkey. http://www.9thicsps.com/en/2785-conference-programme.

Regarding the physical-chemical parameters of wastewater discharges to river water sources, a bibliographic review of the physical-chemical parameters was carried out, considering that there is no specific regulation for the discharge of wastewater from hot springs to river water sources.

Table 3.4 presents an analysis of regulations in Colombia, a specific case of the Bogota River and regulations from Germany, Canada, and Japan.

Table 3.4. Main physical and chemical parameters.

PARAMETER	UNIT	WASTEWATER GOING TO RIVERS								
		COLOMBIA						GERMANY	CANADA	JAPAN
		Agreement No. 20 of December 23, 2020 (a)					Resolution 631 of 2015 (b)	Wastewater statute (c)	By-Law No. 457-2000 (d)	National Effluent Standards (e)
		Bogota River					National	Hannover	Toronto	National
		Class I	Class II	Class III	Class IV	Class V				
Temperature	°C	-	-	-	-	-	-	35	-	-
Conductivity	µS/cm	-	-	-	-	-	-	-	-	-
pH	pH units	6.5 - 8.5	5.0 - 9.0	5.0 - 9.0	4.5 - 9.0	4.5 - 9.0	6.0 - 9.0	6.5 - 10	6.0 - 9.0	5.8 - 8.6
Dissolved Oxygen	mg/L – O_2	4	>4	>4	-	-	-	-	-	-
Aluminum	mg Al/L	5	-	-	5	5	Analysis and Report	-	50	-
Antimony	mg Sb/L	-	-				-	-	5.0	-
Arsenic	mg As/L	0.05	0.05	0.05	0.1	0.1	-	1.0	1.0	0.1
Barium	mg Ba/L	0.1	1	1			-	2.0	-	-
Boron	mg B/L	0.3 - 0.4	-	-	0.3 - 0.4	0.3 - 0.4	-	-	-	10.0
Cadmium	mg Cd/L	0.01	0.01	0.01	0.01	0.01	-	0.2	0.7	0.03
Cobalt	mg Co/L	0.05	0.05	0.05	0.05	0.05	-	-	5.0	-
Copper	mg Cu/L	0.1	0.2	0.2	0.2	0.2	1.0	2.0	2.0	3.0
Chrome	mg Cr/L	0.05	0.05	0.05	0.1	0.1	0.5	1.0	2.0	2.0
Hexavalent Chromium	mg Cr^{-6}/L	0.01	-	-	-	-	-	0.1	2.0	0.5
Iron	mg Fe/L	0.1	-	-	5	5	Analysis and Report	-	-	10
Magnesium	mg Mg/L	-	-	-	-	-	-	-	-	-
Manganese	mg Mn/L	0.1	-	-	0.2	0.2	-	-	5.0	10
Molybdenum	mg Mo /L	-	-	-	0.01	0.01	-	-	5.0	-
Mercury	mg Hg/L	0	-	0	0.01	0.01	0.02	0.05	0.01	0.005
Nickel	mg Ni/L	0.01	-	-	0.2	0.2	0.5	0.5	2	-
Lead	mg Pb/L	0.01	0.05	-	0.1	0.1	0.5	0.5	1.0	0.1
Selenium	mg Se/L	0.01	0.05	0.01	0.02	0.02	-	1.0	1.0	0.1
Zinc	mg Zn/L	0.01		2	2	2	3.0	3.0	2.0	-
Silver	mg Ag/L	0.01	0.05	0.05	-	-	-	1.0	5.0	2.0
Strontium	mg Sr/L	-	-	-	-	-	-	-	-	-
Tin	mg Sn/L	-	-	-	-	-	-	5.0	5.0	-
Titanium	Ti mg/L	-	-	-	-	-	-	-	5.0	-
Vanadium	Va mg/L	0.1	0.1	0.1	0.1	0.1				
Phenolics (4AAP)	mg/L	-	-	-	-	-	-	1.0	-	5.0
Color	CPU	-	75	75	-	-				
Apparent color	TCU	-	-	-	-	-	Analysis and Report	-	-	-
Turbidity	NTU	-	-	-	-	-	-	-	-	-
Oils and fats	mg/L	0.01	-	-	-	Absent	10	250	15 - 150	-

PARAMETER	UNIT	WASTEWATER GOING TO RIVERS								
		COLOMBIA						GERMANY	CANADA	JAPAN
		Agreement No. 20 of December 23, 2020 (a)					Resolution 631 of 2015 (b)	Wastewater statute (c)	By-Law No. 457-2000 (d)	National Effluent Standards (e)
		Bogota River					National	Hannover	Toronto	National
		Class I	Class II	Class III	Class IV	Class V				
Total volatile halogenated hydrocarbons	mg/L	-	-	-	-	-	-	0.5	-	-
Adsorbable organically bound halogens (AOX)	mg/L	-	-	-	-	-	Analysis and Report	1.0	-	-
Separation of light liquids further removal of hydrocarbons is required total hydrocarbons	mg/L	-	-	-	-	-	-	20	-	-
Total hydrocarbons	mg/L	-	-	-	-	-	Analysis and Report	100	-	-
Benzene	mg/L	-	-	-	-	-	Analysis and Report	-	0.01	0.1
Sulphate	mg/L	400	400	400	-	-	-	600	-	-
Phosphate-Phosphorus:	mg PO^{4} - P/L	-	-	-	-	-	-	50	-	-
Fluoride	mg F/L	-	-	-	-	-	-	60	10	8
Cyanide, readily releasable	mg CN/L	-	-	0.2	-	-	-	0.2	-	-
Cyanide, total	mg CN/L	-	-	-	-	-	-	5.0	2.0	1.0
Sulfide, easily releasable	mg S/L	-	-	-	-	-	-	2.0	-	-
Ammonium nitrogen	mg NH4-N/L	-	-	-	-	-	-	100	-	100
Phenol index	mg C6H5 OH/L	-	-	-	-	-	-	100	-	-
Alkalinity	mg $CaCO_3$ /L	-	-	-	-	-	Analysis and Report	-	-	-
Calcium	mg Ca/L	-	-	-	-	-	-	-	-	-
Total Inorganic Carbon (TIC)	mg/L	-	-	-	-	-	-	-	-	-
Total Organic Carbon (TOC)	mg/L	-	-	-	-	-	-	-	-	-
Biological Oxygen Demand (BOD)	mg O_2/L	7	7	20	50	70	70	-	300	160 (Daily Average 120 mg/L)
Chemical Oxygen Demand (COD)	mg O_2/L	-	-	-	-	-	150	500 to 2000	-	160 (Daily Average 120 mg/L)
Calcium Hardness	mg $CaCO_3$ /L	-	-	-	-	-	Analysis and Report	-	-	-
Total Hardness	mg $CaCO_3$ /L	-	-	-	-	-	Analysis and Report	-	-	-
Soluble Phosphorus	mg P/L	-	-	-	-	-	-	-		-
Total Phosphorus	mg P/L	-	-	0.1	-	-	Analysis and Report	-	10	16 (Daily Average 8 mg/L)
Ammoniacal Nitrogen	mg NH_3-N/L	-	-	0.3	-	-	Analysis and Report	-	-	120 (Daily Average 60 mg/L)
Total Kjeldahl Nitrogen	mg N/L	-	-	-	-	-	Analysis and Report	-	100	-
Active substance to methylene blue	mg detergents/L calcula	-	-	-	-	-	Analysis and Report	-	-	-

PARAMETER	UNIT	WASTEWATER GOING TO RIVERS								
		COLOMBIA						GERMANY	CANADA	JAPAN
		Agreement No. 20 of December 23, 2020 (a)					Resolution 631 of 2015 (b)	Wastewater statute (c)	By-Law No. 457-2000 (d)	National Effluent Standards (e)
		Bogota River					National	Hannover	Toronto	National
		Class I	Class II	Class III	Class IV	Class V				
	te LAS 288,37 g/mol									
Sodium	mg Na/L	-	-	-	-	-	-	-	-	-
Settleable solids	mg SS/L	-	-	-	-	-	5	-	-	-
Total Suspended Solids	mg SST/L	10	10	20	40	50	70	-	350	200 (Daily Average 150 mg/L)
Total Solids	mg /L	-	-	-	-	-	-	-	-	-
Sulphide	mg S^2/L	-	-	-	-	-	Analysis and Report	-	-	-
Acidity	mg $CaCO_3$ /L	-	-	-	-	-	Analysis and Report	-	-	-
Chlorides	mg Cl-/L	250	-	250	-	-	Analysis and Report	-	-	-
Fluorides	mg F-/L	-	-	-	-	-	-	-	-	-
Reactive phosphorus	mg PO_4/L	-	-	-	-	-	-	-	-	-
Nitrates	mg NO_3-N/L	10	10	1	-	-	Analysis and Report	-	-	-
Nitrites	mg NO_3-N/L	10	10	0.5	10	-	Analysis and Report	-	-	-
Nitrite - Nitrogen	mg NO2-N/L	-	-	-	-	-	-	10	-	-
Sulphate	mg SO_4/L	-	-	-	-	-	Analysis and Report	-	-	-
Total dissolved solids	mg/L	-	-	-	-	-	-	-	-	-
Surfactants	mg/L	0.5	-	0.5	-	-	-	-	-	-

[a] (RAC of Colombia, 2020), [b] (Ministry of Environment and Sustainable Development of Colombia, 2015), [c] (Hannover, 2016), [d] (Toronto, 2000), [e] (Ministry of the Environment Government of Japan, 2015).

3.1 METHODOLOGY

The search strategy for this systematic review was focused on various references such as international magazines, Google Scholar, state of the art books were consulted with the following search criteria: i) hot springs discharge regulations, ii) quality of hot springs, iii) hot springs discharge regulations, and iv) hot spring treatment.

Likewise, an Excel Sheet of only regulations about the quality of hot springs was built that included the country and the name of the standard parameter.

3.2 CONCLUSIONS

Natural thermal baths are an important component of health and wellness tourism, as well as for recreational use that has become particularly important in countries with bathing traditions, where sustainable tourism is important (Erfurt and Cooper, 2021). Therefore, it is necessary to advance in the investigation on the contamination of the wastewaters coming from hot springs, where the authorities increase control over the use of hot springs and the discharge of their untreated waters. It is also important to think about sustainable tourism, where the consumption of hot springs is an important factor. The contamination of hot springs must be minimized by reducing anthropogenic pollution and suitable water treatment.

Chapter 4

PATHOGENIC MICROORGANISMS IN THE SOURCE AND DISCHARGES OF HOT SPRINGS

This chapter presents to assess the pathogenic microorganisms in the source and discharges of hot springs at local and global level, including COVID–19 virus (SARS – CoV-2).

The bibliographical review presented in this chapter allowed us to evaluate the pathogenic microorganisms that are regulated in recreational waters, considering that in many countries, they regulate the quality of hot springs in the same way as the quality of swimming pool water based on drinking water regulations. Therefore, the article ***An Overview of Water Quality Regulation or Standards in Swimming Pools, Drinking Water, and Hot Springs in Germany, Canada, and Colombia***, presents in detail the parameters that are regulated in countries such as Colombia, Canada, and Germany. In view of the above, Table 4.1 summarizes the regulated microbiological parameters in drinking water and swimming pools.

Table 4.1. Main microbiological parameter in drinking water and swimming pools.

PARAMETER	UNIT	DRINKING WATER						SWIMMING POOL				
		CANADA			GERMANY	COLOMBIA	WHO	CANADA		GERMANY	CHILE	COLOMBIA
		ONTARIO Reg. 169/03 (a)	GUIDELINE FOR ONTARIO (b)	GUIDELINES FOR CANADIAN (c)	BGBl. I 2016, 476 (d)	Resolution 2115/07 (e)	A Global Overview of National Regulations (f)	Alberta Reg. 204/2014 and Government (g)	Ontario Reg. 565/1990 (h)	DIN 19643 (i)	Decree 209 of 2002 (j)	Resolution 1618/10 (k)
Enterococci	MPN/ 100 mL	-	-	-	0	-	None specified	-	-	-	-	-
Escherichia coli	CFU/ 100 cm^3	Not detectable	Not detectable	Not detectable	0	0	Must not be detectable in any 100ml sample	-	-	0 CFU/ 100 mL	Absence	-
Total coliforms	CFU/ 100 cm^4	Not detectable	Not detectable	Not detectable	-	0	None specified	-	-	-	< 20	-
Pseudomonas aeruginosa	MPN/ 100 mL	-	-	-	-	-	-	Not present	-	0 CFU/ 100 mL	-	0 UFC / 100 cm^3
Legionella	MPN/ mL	-	-	-	-	-	-	-	-	0 CFU/ mL	-	Studies will be carried out

PARAMETER	UNIT	DRINKING WATER						SWIMMING POOL				
		CANADA			GERMANY	COLOMBIA	WHO	CANADA		GERMANY	CHILE	COLOMBIA
		ONTARIO Reg. 169/03 (a)	GUIDELINE FOR ONTARIO (b)	GUIDELINES FOR CANADIAN (c)	BGBl. I 2016, 476 (d)	Resolution 2115/07 (e)	A Global Overview of National Regulations (f)	Alberta Reg. 204/2014 and Government (g)	Ontario Reg. 565/1990 (h)	DIN 19643 (i)	Decree 209 of 2002 (j)	Resolution 1618/10 (k)
Giardia and Cryptosporidium	cysts and oocysts	minimum removal or inactivation	minimum removal or inactivation	removal and/or inactivation of	-	0	-	-	-	-	-	by the person in charge of the pool
Virus and protozoos		-	It is desirable that no virus or protozoa be present		-	-	-	-	-	-	Absence	

[a] (Ontario, 2003), [b] (Ontario, 2003), [c] (Health Canada, 2020), [d] (Germany, 2016), [e] (Colombia, 2015), [f] (WHO, 2021), [g](Alberta, 2014), [h](Ontario, 1990), [i](Germany, 1997), [j] (WHO, 2016), [k] (Colombia, 2007) and (Sanchez, 2011).

With respect to countries that have their own hot spring regulations, such as the case of Galicia – Spain (Galicia, 1996), it establishes that "*water intended for showers and medicinal baths or collective baths and pools for therapeutic use, will be free of microorganisms indicating fecal contamination (Escherichia coli and fecal streptococci) as well as pathogenic microorganisms and parasites*".

In the case of Catalonia – Spain (Catalonia, 2001), "*A program to monitor the sanitary conditions of the water used in balneotherapy and hydrotherapy services is established to ensure the absence of pathogenic microorganisms, especially Legionella pneumophila, and which includes monitoring of microorganisms that indicate fecal contamination".*

Regarding the management of microbiological microorganisms in wastewater, the main indicator for the control of microorganisms corresponds to *E. coli*, as shown in Table 4.2.

Table 4.2. Main microbiological parameter in wastewater.

PARAMETER	UNIT	WASTEWATER GOING TO RIVERS				
		CANADA	**GERMANY**	**COLOMBIA**		**JAPAN**
		Ontario	**Hannover**	**Bogota River**	**National**	**National**
		Water Pollution Control Plant serving the City of Thunder Bay (a)	**Wastewater statute (b)**	**Agreement No. 20 of December 23, 2020, River (c)**	**Decree 1076 of 2015 (d)**	**National Effluent Standards (e)**
E. coli / Fecal coliforms	MPN/ 100 mL	150 to 200 organisms / 100 mL	-	-	200 microorganisms / 100 mL	
Total coliforms	MPN/ 100 mL	-	-	5000 Class I and III 20000 Class II and IV	200 microorganisms / 100 mL	Daily Average 3000/cm^3

[a] (Ministry of the Environment and Climate Change of Ontario, 2014; Simhon, et al, 2019), [b] (Hannover, 2016), [c] (RAC of Colombia, 2020), [d] (Ministry of Environment and Sustainable Development of Colombia, 2015), and [e] (Ministry of the Environment Government of Japan, 2015).

Regarding the COVID-19 virus (SARS-COV-2), several publications were made about the virus in the hot springs and the preventive measures for the management of COVID–19, such as:

Conference, article and poster

- Y. Sánchez, M. Mehrvar, L. McCarthy, E. Quiñones, L.R. Cheu, J. Romero. **An Overview of the Management of Covid-19 in Swimming Pools, Beaches, and Hot Springs in Europe, Canada, and Colombia**, *Segundo Encuentro Nacional de Estudiantes de Doctorados en Ingeniería (ENEDI 2020), ACOFI 2020*, Cartagena, Colombia, September 16-18, 2020. https://www.acofi.edu.co/eiei2020/wp-content/uploads/2020/10/Memorias-ENEDI-2020.pdf. ISBN: 978-958-680-090-7. Digital Book.

Conference and article

- Y. Sánchez, M. Mehrvar, L. McCarthy, E. Quiñones, L.R. Cheu, J. Romero. **Scientific discussion of selected viruses including COVID-19 in hot springs**, *VI Congreso Internacional de Innovación y Tendencias de la Ingeniería (CONIITI 2020),* Virtual Conference, Bogotá D.C., Colombia, September 30 to October 2, 2020. : https://ieeexplore.ieee.org/abstract/document/9240267. Indexed article in IEEE. DOI: 10.1109/CONIITI51147.2020.9240267.

Conference and article

- Y. Sánchez, M. Mehrvar, L. McCarthy, E. Quiñones, L.R. Cheu, J. Romero. **Preventive measures pertaining to COVID-19 in swimming pools and hot springs in Europe, Canada, United States, and Colombia**, *VII Congreso Internacional de Innovación y Tendencias de la Ingeniería (CONIITI 2021),* Virtual Conference, Bogotá D.C., Colombia, September 29 to October 1, 2021. https://ieeexplore.ieee.org/document/9619701/authors#authors. Indexed article in IEEE. DOI: 10.1109/CONIITI53815.2021.9619701.

According to the United States Center for Disease Control and Prevention (CDC), there is no evidence that the COVID-19 virus can be transmitted to people through water in swimming pools, hot tubs, or playgrounds.

4.1 METHODOLOGY

For the development of the articles referring to this chapter, these search criteria were focused on: COVID-19 in hot springs, water treatment, preventive measures for controlling COVID-19 in swimming pools and hot springs, Colombian COVID-19 regulations, regulation or standards in swimming pools, drinking water, and hot springs and regulation in wastewater.

4.2 CONCLUSIONS

Countries such as Canada and Germany do not possess specific regulations or standards for water from hot springs. Instead, the same microbial and chemical requirements as for swimming pool water according to Public Swimming Pools Regulation of Canada and the Standard Din 19643 of Germany apply for hot springs.

In order for the hot springs to guarantee the elimination of bacteria and viruses from fecal and non-fecal derivatives and the COVID-19 virus, a monitoring scheme is required to identify the effective disinfection of the water to control pathogens.

Frequent replacement of hot springs is the most common treatment in Colombia to preserve the quality of the hot springs, due to the constant outcrop of the water, which controls the microbiological quality of the water, which is not yet regulated.

With respect to pathogenic microorganisms, *E. coli* is controlled in swimming pool water, as well as in drinking and residual water. Bathers, due to having direct contact with the water, must be free of *P. aeruginosa*, *Legionella*, *E. coli*, Enterococci, and Total Coliform bacteria as established by the WHO.

Chapter 5

PHYSICAL, CHEMICAL, AND MICROBIOLOGICAL PROPERTIES

This chapter shows the fulfillment of the first objective of the doctoral *" To asses physicochemical and microbial properties of two hot springs in the region of Cundinamarca and its discharges into the tributaries fed into the Bogota River".*

To determine the quality of the hot springs chosen for the study, physical, chemical, and microbiological parameters were chosen according to the bibliographic review carried out in section **2.3 MICROBIOLOGICAL AND PHYSICOCHEMICAL PARAMETERS IN HOT SPRINGS SOURCES**, which are described below.

5.1 IN SITU AND MICROBIOLOGICAL CONTROL PARAMETERS

Table 5.1 presents the parameters chosen to monitor in the hot springs.

Table 5.1. In situ and microbiological parameters to monitor.

PARAMETERS			
IN SITU	Flow Temperature Conductivity pH Dissolved Oxygen	**MICROBIOLOGICAL**	Total Coliforms Fecal Coliforms (*E. coli*) Enterococci *Legionella* *Pseudomonas aeruginosa* Molds Yeasts

- **In situ parameters**

Flow (L/s): Determines the amount of water in a source or discharge that is intended to be gauged. In the case of the present study, the volumetric method was used, which required a stopwatch and a volumetric container (10 L bucket with 1 L graduations).

The container was placed under the discharge, collecting the entire flow of water, with the simultaneous activation of the timer. The volume of the sample was measured depending on the speed of filling and the time from when the container was introduced to the discharge and stopped when it was withdrawn (IDEAM, n.d).

The flow was calculated with the following equation:

$$Q = V / t \qquad (5.1)$$

Where: Q = Flow, L/s.
V = Volume, L.
T = Time, s.

Temperature (°C): Water temperature tolerance can vary considerably from individual to individual (Government of Canada, 2012). In the case of hot springs, they are considered cold < 20°C, their classification is presented in Table 3 of Chapter 2 (Armijo and San Martín, 1994).

Conductivity (µS/cm): The ability of water to transmit electrical current. It increases with the amount of dissolved electrolytes. An increase in conductivity reflects an increase in the concentration of dissolved solids; residues of products used in water treatment or increased chlorides from urine, which can constitute a risk to the health of bathers (Bayona, 2005).

pH (units of pH): used to express how acidic or alkaline the water is (Bayona, 2005). The pH must be in a range of 7.2 to 7.6, values below 7.2 can cause eye irritation, opacity in the tiles, and detachment of coatings and corrosion of all metal parts. A high pH value decreases the efficiency of free residual chlorine, decreasing the biocidal capacity, as the hypochlorite ion predominates over hypochlorous acid, as observed in Figure 5.1 (Bayona, 1993).

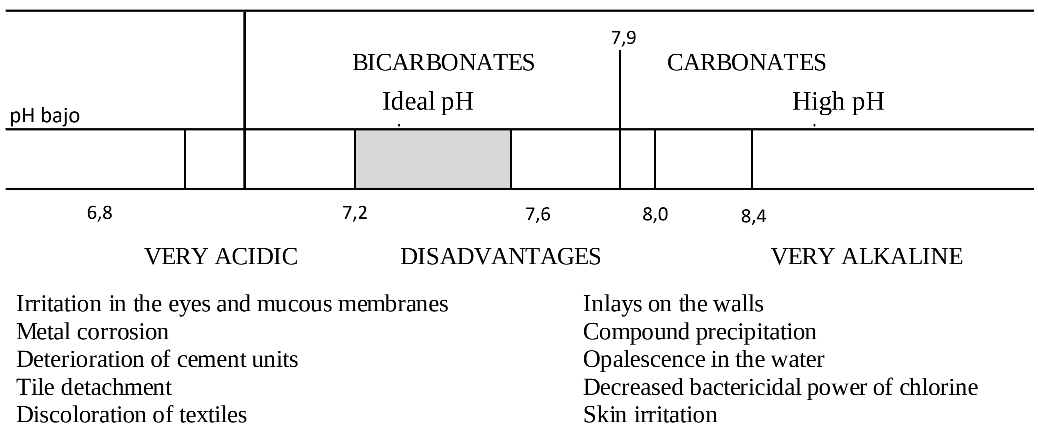


Figure 5.1. Influence of pH in pool water (Bayona, 1993).

Dissolved Oxygen (DO): a measure of the amount of gaseous oxygen contained in water. The DO concentration determines the quality of the water source (HACH, n.d).

- **Microbiological parameters**

The most common microbiological tests to determine the sanitary quality in a swimming pool have been tests for fecal coliforms, total coliforms, and heterotroph counts. Other bacteria suggested as indicators of recreational water quality include *Pseudomonas aeruginosa*, fecal streptococci, enterococci, and *staphylococci* (APHA, AWWA, WEF, 2017).

Considering its ease of isolation and cultivation in the laboratory, being relatively innocuous for humans and animals, and being directly related qualitatively and quantitatively, with the presence of pathogenic microorganisms, Total Coliform counts were used for the microbiological evaluation in the hot springs. Fecal Coliforms (*E. coli*), Enterococci, *Pseudomonas aeruginosa*, *Legionella*, Molds and Yeasts.

Total and fecal coliforms (CFU/100mL): Coliforms are Gram-negative, non-spore-forming, oxidase-negative, rod-shaped bacteria that can grow aerobically and facultatively, anaerobically in the presence of bile salts and are capable of fermenting lactose with 48 h production of acid and aldehyde when incubated at a temperature of 35 +/- 2 ºC (APHA, AWWA, WEF, 2017). Coliform bacteria possess the enzyme β-galaclosidase and belong to the Enterobacteriaceae family. The genera that make up the coliform group are *Escherichia*, *Klebsiella*, *Enterobacter*, *Serratia*, *Citrobacter* and *Edwardsiella* (Health Canada, 2020).

Fecal coliform bacteria are gram-negative, non-spore-forming rods that are found in the intestines and feces of humans and other warm-blooded animals. The predominant fecal coliform is *E. coli*. *E. coli O157* is one of the bacteria linked to outbreaks of illnesses associated with swimming in swimming pools (WHO, 2006).

Among all the coliforms, only the genus *Escherichia*, and occasionally *Klebsiella*, have the ability to ferment lactose at 35-37 °C and also at 44.5°C. Therefore, the coliform assay at 44.5 °C makes it possible to determine the existence of *E. coli* and to determine fecal microbiological contamination (MILLIPORE, 2005).

Enterococci: are bacteria that live in the intestinal tracts of warm-blooded animals and humans (EPA, n.d.). They are readily culturable and predict human health risks from exposure to polluted recreational waters (Byappanahalli et al, 2012).

Legionella**:** are Gram-negative, non-spore-forming, motile, aerobic bacilli, which may be free-living or living within amoebae and other protozoa or within biofilms. *Legionella spp*. are heterotrophic bacteria found in aquatic environments and can reproduce at temperatures above 25 °C. *Legionella spp.* can cause legionellosis, a range of pneumonic and non-pneumonic diseases (WHO, 2006).

Pseudomonas aeruginosa **(UFC/100mL):** a Gram-negative bacillus, grows on a selective medium with cetrimide and produces pyocyanin, is oxidase positive, fluoresces under UV light (360 +/- 20nm), and is capable of producing ammonia from acetamide (MILLIPORE, 2005). It is an opportunistic human pathogen that causes infections, capable of growing in water with low nutrient concentrations and are resistant to chlorination. In swimming pools, the primary health effect associated with *P. aeruginosa* is otitis externa or swimmer's ear (WHO, 2006).

In the article ***State of the art of Legionella Pneumophila in hot springs***, it is shown in more detail about this bacterium.

Molds and Yeasts: grow very easily in damp and wet conditions inducing acute health effects (Berivan A., et al, 2017).

5.2 PHYSICAL AND CHEMICAL CONTROL PARAMETERS

Table 5.2 shows the parameters chosen to monitor in the hot springs that were chosen in agreement with the EAAB and the bibliographic review.

Table 5.2. Physicochemical parameters to monitor.

Physicochemical parameters	
Apparent colour	Aluminum
Turbidity	Arsenic
Oils and fats	Boron
Alkalinity	Copper
Calcium	Chrome
Total Inorganic Carbon (TIC)	Iron
Total Organic Carbon (TOC)	Magnesium
Biochemical Oxygen Demand (BOD)	Manganese
Chemical Oxygen Demand (COD)	Mercury
Total Kjeldahl Nitrogen	Nickel
Total Solids	Lead
Sulphides	Selenium
Acidity	Zinc
Chlorides	Strontium
Fluorides	Sodium
Reactive phosphorus	Settleable solids
Nitrates	Nitrites
Total dissolved solids	Sulphate
Total Suspended Solids	Total Phosphorus
Calcium Hardness	Ammoniacal Nitrogen
Total Hardness	Methylene Blue Active Substances (MBAS)

Apparent colour: includes colour of dissolved materials and the colour of suspended matter (HACH, n.d.).

Turbidity: it constitutes an indicator of the aesthetic appearance of the pool, generated by the presence of solids in suspension in the water. Turbidity can be of organic origin (algae, insects, threads) or inorganic (soil, clay, hair, etc.) (Bayona, 2005).

Oils and Fats: are a group of substances that are insoluble in water. When these are discharged into bodies of water, they can form films on the surface that interfere with the passage of light and gas exchange between the water and the atmosphere (ECOQUIMSA, n.d.).

Alkalinity: the total content of dissolved alkaline substances (carbonates, bicarbonates, and hydroxides). Indicates the buffering ability of water to neutralize acids and provides guidance in maintaining proper pH to control itchy eyes and irritated skin in bathers (Bayona, 2005; Government Canada, 2009).

Total Inorganic Carbon (TIC): used to detect inorganic carbon, found in the form of bicarbonate anion, carbonate anion, carbonic acid, and dissolved carbon dioxide, in a sample (Lenart, n.d).

Total Organic Carbon (TOC): allows measurement of organic material in most waters. Sources of organic carbon in fresh and marine waters include living materials, waste materials, and effluents (British Columbia, 1998).

Alternatively, TOC can be determined by difference between total carbon (TC) and total inorganic carbon (TIC).

Biochemical Oxygen Demand (BOD): is the amount of oxygen consumed by decomposition of the sample during the incubation period (Cole- Parmer, n.d.).

Chemical Oxygen Demand (COD): is the amount of dissolved oxygen that must be present in water to oxidize chemical organic materials (HACH, n.d.; Encyclopedia of Analytical Science, 2005).

Total Kjeldahl Nitrogen: is the sum of free-ammonia and organic nitrogen compounds which are converted to ammonium sulfate ($(NH_4)_2SO_4$) (EPA, 1993).

Total Solids: are dissolved solids plus suspended and settleable solids in water (EPA, n.d.).

Sulphides: it is a product of the anaerobic decomposition of sulfur-containing organic matter, and other sulfur compounds (Government of Canada, 2014).

Acidity: is its quantitative capacity to neutralize a strong base to a selected pH level (APHA, AWWA, WEF, 2017).

Chlorides: are very common water pollutants. Usually come from urine and can impart a brackish taste to water. Bathers in pools bring in chlorides, not only from sweat but also from urine. They are controlled by replacing the water with another water without chlorides (Bayona, 2005).

Fluoride: is a mineral. A moderate amount of fluoride ions (F^-) in drinking water contributes to good dental health (Government of Canada, n.d.; APHA, AWWA, WEF, 2017).

Reactive phosphorus: is a corresponding method-based term that describes what you are actually measuring when you perform the test for orthophosphate (EPA, n.d.).

Nitrates and Nitrites: they are naturally produced by the oxidation of nitrogen by microorganisms and, to a lesser extent, by lightning (Government of Canada, 2014).

Total dissolved solids: comprise of inorganic salts and small amounts of organic matter that are dissolved in water. The principal constituents are usually the cations calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and potassium (K^+) and the anions carbonate, bicarbonate, chloride, sulfate, and particularly in groundwater, nitrate (from agricultural use) (Government of Canada, 1991).

Total Suspended Solids: harmful in excess and listed as a conventional pollutant in the Clean Water Act, it can indicate the quality of any water specimen, from ocean water to wastewater (HATCH, n.d.).

Calcium Hardness: calcium is one of the principal cations associated with hardness in drinking water (Government of Canada, n.d.).

Total Hardness: is primarily caused by the presence of calcium and magnesium in the water (Government of Canada, 2014). When rushing, they can cause incrustations on the bottom and on the walls of the pool (Bayona, 2005).

Metals: refers to any metal and metalloid element that has a relatively high density ranging from 3.5 to 7 g/cm^3 and is toxic or poisonous at low concentrations. Few metals, such as Iron (Fe), Zinc (Zn), Cooper (Cu), Cobalt (Co), Chrome (Cr), Manganese (Mn), and Nickel (Ni) are required for biological metabolism in trace amounts. However, their higher dose may cause toxic effects. Others, such as Lead (Pb), Mercury (Hg), Cadmium (Cd), and Arsenic (As) are not suitable for biological functions and are possibly toxic (Kumar et al., 2014).

Settleable solids: means the volume of solid particles in a water sample. Measured by the Imhoff cone volumetric method (APHA, AWWA, WEF, 2017).

Sulfate: is a potentially harmful contaminant in freshwater environments (Government of British Columbia, n.d.).

Total Phosphorus: it is a measure of all the phosphorus found in a sample (orthophosphate, condensed phosphate, and organic phosphate), whether dissolved or particulate phosphorus (EPA, n.d.; Zhang, 2012).

Ammoniacal Nitrogen: is a measure of the amount of ammonia in a sample of water. Their presence in freshwater sources can cause eutrophication and pollution (Gonzales, et al., 203).

Methylene Blue Active Substances (MBAS): indicate the presence of detergents (anionic surfactants) in a sample of water (Wyrmas et al., 2013).

5.3 METHODOLOGY

The two hot springs were chosen for the study for the following factors:

1. **Less transport time of the sample to the laboratory:** in this case, the laboratories are the Bogota Water and Sewerage Company and the Colombian School of Engineering Julio Garavito University.
2. **Located in the department of Cundinamarca and with discharge to tributaries that feed the Bogota River:** the National Inventory of Hydrothermal Manifestations of the platform of the Colombian Geological Service in the Cundinamarca region was consulted, where 50 hot springs were reported, of which only 16 discharge into the tributaries that feed the Bogota River. Two hot springs were chosen for this study (Colombian Geological Service, n.d.) (See Figures 5.2 and 5.3).

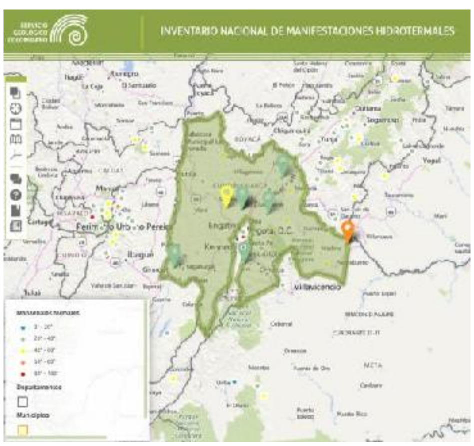


Figure 5.2. Scheme of the National Inventory of Hydrothermal Manifestations (Colombian Geological Service, n.d.).

Figure 5.3. Hot springs that discharge into the tributaries that feed the Bogota River (Google maps, 2022).

A total of 6 samplings were carried out in 2 hot springs (one private and the other public) in the department of Cundinamarca, with a sampling frequency of one sample per month for each hot spring for a period of six months, at the source and at the outlet of the hot spring pool, as shown in Figure 5.4.

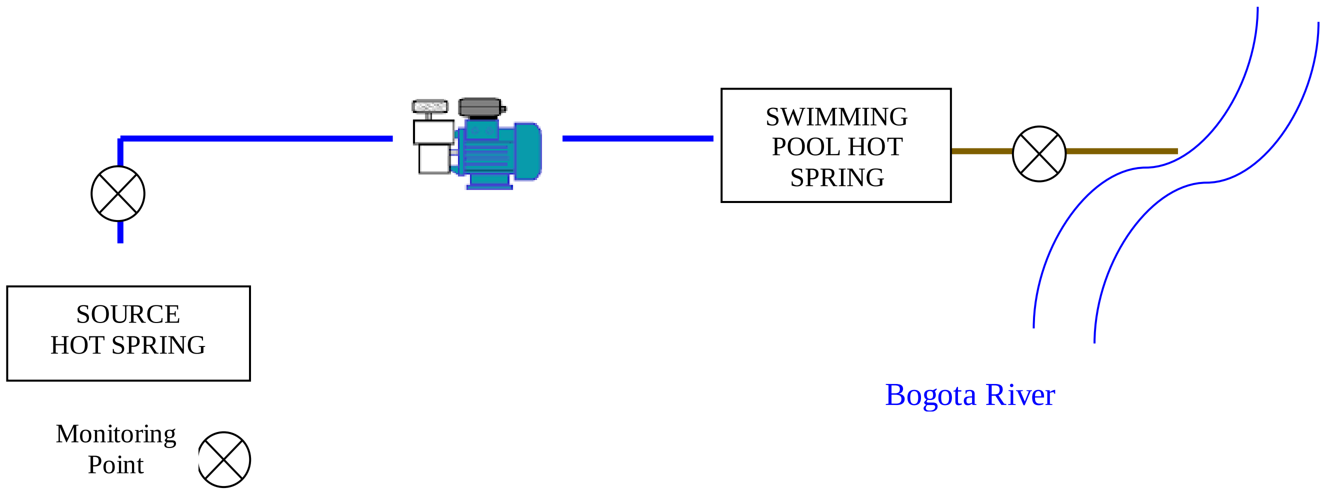


Figure 5.4. Scheme of hot springs monitoring point.

For each sampling of the physical-chemical parameters, both at the input and output of the hot springs, the materials described in Table 5.3 were required, which were appropriately washed with distilled water for sterilization.

Table 5.3. Materials for sampling.

Analysis	Volume (mL)	Material	Quantity (units)
Oils and fats	1000	Normal glass wide mouth	4 jar
Inorganic Carbon	250	Amber glass – Teflon cover	4 jar
TOC	250	Amber glass- Teflon cover	4 jar
Alkalinity - Acidity	500	Amber glass	4 jar
Metals - Total Hardness	1000	Plastic	4 jar
Nutrients - COD- Total Phosphorus	2000	Plastic	4 jar
BOD_5 -ST- Sulfates - Turbidity- Silicates- Apparent color - Nitrites - Nitrates- Chlorides - Fluorides	4000	Plastic	4 jar
Sulphides	500	Plastic	4 jar

The collection of the sample for the analysis of the microbiological parameters was arranged in properly sterilized 100 mL bottles manufactured by IDEXX and 10 vials were required for each sampling.

The sampling schedule was carried out in the period from July to December of the year 2021, as shown in Table 5.4.

Table 5.4. Sampling Schedule.

HOT SPRINGS	JUNE			JULY			AUGUST			SEPTEMBER				OCTOBER			NOVEMBER				DECEMBER			
	Mo	Tu	We	Mo	Tu	We	Su	Mo	Tu	We	Th	Fr	Sa	Fr	Sa	Su	Th	Fr	Sa	Su	Mo	Tu	We	Th
	28	29	30	26	27	28	29	30	31	1	2	3	4	1	2	3	4	5	6	7	13	14	15	16
1			X			X					X					X				X			X	
2			X			X					X					X				X			X	

In each of the monitoring, the water sample was taken, considering the protocols established by the EAAB (in Spanish Empresa de Acueducto y Alcantarillado de Bogotá). In situ, the physical parameters described in Table 5.5 were measured.

Table 5.5. Physical parameters measured in situ.

Parameter	Unit	Equipment
Flow	L/s	Bucket and stopwatch
Temperature	°C	Multiparameter meters
Conductivity	µS/cm	Multiparameter meters
pH	pH units	Multiparameter meters
Dissolved Oxygen	mg/L	Multiparameter meters

After taking the samples with their respective chain of custody, they were transferred to the laboratory. The samples of physical-chemical parameters were analyzed in the laboratory of the Bogota Water and Sewerage Company and the microbiological ones by the Colombian School of Engineering Julio Garavito University.

Table 5.6 shows the test methods for the physical-chemical parameters according to standard methods.

Table 5.6. Physical – Chemical test methods.

Parameters	Unit	Method	Standard Methods (APHA, AWWA, WEF, 2017).
Aluminum	mg Al/L	Inductively Coupled Emission Spectroscopy - Nitric Acid Digestion	SM 3030 E and 3120 B - Al
Arsenic	mg As/L	Inductively Coupled Emission Spectroscopy - Nitric Acid Digestion	SM 3030 E and 3120 B - As
Boron	mg B/L	Inductively Coupled Emission Spectroscopy - Nitric Acid Digestion	SM 3030 E and 3120 B - B
Copper	mg Cu/L	Inductively Coupled Emission Spectroscopy - Nitric Acid Digestion	SM 3030 E and 3120 B - Cu
Chrome	mg Cr/L	Inductively Coupled Emission Spectroscopy - Nitric Acid Digestion	SM 3030 E and 3120 B - Cr
Iron	mg Fe/L	Inductively Coupled Emission Spectroscopy - Nitric Acid Digestion	SM 3030 E and 3120 B-Fe
Magnesium	mg Mg/L	Digestion Nitric Acid-ICP	SM 3030 E and 3120 B - Mg
Manganese	mg Mn/L	Inductively Coupled Emission Spectroscopy - Nitric Acid Digestion	SM 3030 E and 3120 B-Mn
Mercury	mg Hg/L	Atomic Absorption - Cold Vapor	SM 3112 B - Hg
Nickel	mg Ni/L	Inductively Coupled Emission Spectroscopy - Nitric Acid Digestion	SM 3030 E and 3120 B-Ni
Lead	mg Pb/L	Inductively Coupled Emission Spectroscopy - Nitric Acid Digestion	SM 3030 E and 3120 B-Pb
Selenium	mg Se/L	Inductively Coupled Emission Spectroscopy - Nitric Acid Digestion	SM 3030 E and 3120 B-Se

Parameters	Unit	Method	Standard Methods (APHA, AWWA, WEF, 2017).
Zinc	mg Zn/L	Inductively Coupled Emission Spectroscopy - Nitric Acid Digestion	SM 3030 E and 3120 B-Zn
Strontium	mg Sr/L	Inductively Coupled Emission Spectroscopy - Nitric Acid Digestion	SM 3030 and 3120 B-Sr
Apparent color	TCU	Spectrophotometric	M4FC 0304I58
Turbidity	NTU	Nephelometric	SM 2130 B
Oils and fats	mg/L	Gravimetric Partition	SM - 5520 B
Alkalinity	mg $CaCO_3$/L	Titrimetric	SM-2320 B
Calcium	mg Ca/L	Inductively Coupled Emission Spectroscopy - Nitric Acid Digestion	SM 3030 E y 3120 B - Ca
Total Inorganic Carbon (TIC)	mg/L	High Temperature Combustion	SM 5310 B
Total Organic Carbon (TOC)	mg/L	High Temperature Combustion	SM 5310 B
Biochemical Oxygen Demand (BOD)	mg O2/L	5-Day BOD Assay - Luminescence Optical Sensor Method	SM 5210B, SM 4500-O-H
Chemical Oxygen Demand (COD)	mg O2/L	Open Reflux	SM - 5220 B
Calcium Hardness	mg $CaCO_3$/L	Volumetric - EDTA	SM 3500 - Ca B
Total Hardness	mg $CaCO_3$/L	Volumetric - EDTA	SM 2340 C
Soluble Phosphorus	mg P/L	Ascorbic Acid	SM 4500-P B, E
Total Phosphorus	mg P/L	Ascorbic Acid	SM 4500 -P B, E
Ammoniacal Nitrogen	mg NH_3-N/L	Distillation and Volumetric	SM 4500-NH3 B and C
Total Kjeldahl Nitrogen	mg N/L	Determination of Nitrogen - Total Kjeldahl	M4FC034I29-04
Active Substance to Methylene Blue	mg detergents/L calculate LAS 288,37 g/mol	Active Substances to Methylene Blue - SAAM	SM 5540 C
Sodium	mg Na/L	Inductively Coupled Emission Spectroscopy - Nitric Acid Digestion	SM 3030 E and 3120 B-Na
Settleable Solids	mg SS/L	Volumetric - Imhoff Cone	SM 2540 F
Total Suspended Solids	mg SST/L	Dried at 103 ºC - 105 ºC	SM 2540 D
Total Solids	mg /L	TS Dried at 103 ºC - 105 ºC	SM - 2540 B

Parameters	Unit	Method	Standard Methods (APHA, AWWA, WEF, 2017).
Sulphides	mg S^2/L	Iodometric	SM 4500-S- 2 F
Acidity	mg $CaCO_3$/L	Volumetric	SM 2310 B
Chlorides	mg Cl-/L	Ion Chromatography with Chemical Suppression of Conductivity Effluent	SM 4110 B
Fluorides	mg F-/L	Ion Chromatography with Chemical Suppression of Conductivity Effluent	SM 4110 B
Reactive Phosphorus	mg PO_4/L	Ascorbic acid	SM 4500-P B, E
Nitrates	mg NO_3-N/L	Ion Chromatography with Chemical Suppression of Conductivity Effluent	SM 4110 B
Nitrites	mg NO2-N/L	Ion Chromatography with Chemical Suppression of Conductivity Effluent	SM 4110 B
Sulfate	mg SO_4/L	Ion Chromatography with Chemical Suppression of Conductivity Effluent	SM 4110 B
Total Dissolved Solids	mg/L	Dried at 180 ºC	SM 2540 C

Table 5.7 lists the microbiological tests carried out on the samples from the hot springs, indicating the culture medium, test method, and incubation period.

Table 5.7. Microbiological test methods.

Parameters	Unit	Method	Culture medium	Incubation period
Total Coliforms	MPN/ 100 mL	Defined Substrate Technology	Colilert	35 ± 0,5 °C for 24 hours
Fecal Coliforms (*E. coli*)	MPN/ 100 mL		Colilert	35 ± 0,5 °C for 24 hours
Enterococci	MPN/ 100 mL		Enterolert	41 ± 0.5 °C for 24 hours
Legionella	MPN/ mL		Legiolert	37 ± 0.5 °C for 7 days
Pseudomonas aeruginosa	MPN/ 100 mL		Pseudalert	38 ± 0.5 °C for 24 to 28 hours
Molds	CFU/ mL	MC - Media Pad	Yeast and Molds	25 ± 1 °C for 48 to 72 hours
Yeasts	CFU/mL		Yeast and Molds	25 ± 1 °C for 48 to 72 hours

Defined Substrate Technology Method (DST): developed by IDEXX. It has been U.S EPA approved and was included in the U.S Standard Methods for Examination of Water and Wastewater.

It was the basis for testing for total coliforms, *E.coli*, *Pseudomonas aeruginosa*, *Legionella pneumophila*, and Enterococci. Enzyme-specific nutrient indicators produce definitive, easy-to-read results. DST tests can produce presence/absence or quantitative results. They were sensitive to one organism in 100 mL. The tests did not require media preparation, filtering, or additional confirmations, and their processing took less than one minute.

The samples were incubated on the culture media described in Table 5.7, to count the colonies later directly.

The photographic record shows the preparation sequence of the plates seeded for total coliforms, *E. coli*, *Pseudomonas aeruginosa*, *Legionella Pneumophila*, and Enterococci, a procedure that was carried out as established by IDEXX standard ISO 9308-2:2012.

Materials:

To determine the colonies of each of the measured parameters, the following assembly was obtained:

- Refrigerator
- Autoclave ST-65G series
- 2 incubators IB – 01 E
- UV camera
- Biobase BBS-DDC laminar flow cabinet (refer to Figure 5.5)
- Quanti-Tray Sealer PLUS (refer to Figure 5.6)
- Colony counter
- Culture media: Colilert, Enterolert, Legiolert, Pseudalert, Molds and Yeasts

- 100 Quanti-Tray and Quanti-Tray/2000

Figure 5.5. Laminar flow cabinet.

Figure 5.6. Quanti-Tray Sealer**.**

5.3.1 Culture media

- **Colilert:** Simultaneously detects total coliforms and *E. coli* in water. It is based on IDEXX's proprietary Defined Substrate Technology (DST).

Quanti-Tray Enumeration Procedure (IDEXX, 2019)

1. Added contents of one pack to a 100 mL water sample in a sterile vessel.
2. Capped vessel and shook until dissolved.
3. Poured sample/reagent mixture into a Quanti-Tray and sealed in a Quanti-Tray Sealer.
4. Placed the sealed tray in a 35±0.5°C incubator for 24 hours.
5. Read results according to Table 5.8. Counted the number of positive wells and referred to the Most Probable Number (MPN) table provided with the trays to obtain an MPN (See Appendix B).

Table 5.8. Results interpretation.

Appearance	Results
Less yellow than the comparator	Negative for total coliforms and *E. coli*
Yellow equal to or greater than the comparator	Positive for *total coliforms*
Yellow and fluorescence equal to or greater that the comparator.	Positive for *E. coli*

In Figures 5.7 and 5.8, an example of total coliform and *E. coli* colonies are presented.

Figure 5.7. *Total coliform* colonies.

Figure 5.8. *E. coli* colonies.

- **Enterolert:** Detects *enterococci*, such as *E. faecium* and *E. faecalis*, in fresh and marine water. It is based on IDEXX's proprietary Defined Substrate Technology (DST).

Quanti-Tray Enumeration Procedure

1. Added contents of one pack to a 100 mL water sample in a sterile vessel.
2. Capped vessel and shook until dissolved.
3. Poured sample/reagent mixture into a Quanti-Tray and sealed in an IDEXX Quanti-Tray Sealer.
4. Placed the sealed tray in a 41±0.5°C incubator for 24 hours.
5. Read results according to Table 5.9. Counted the number of positive wells and referred to the Most Probable Number (MPN) table provided with the trays to obtain an MPN.

Table 5.9. Results interpretation.

Appearance	Results
Lack of fluorescence	Negative for enterococci
Blue fluorescence	Positive for enterococci

In Figures 5.9 and 5.10, an example of the negative and positive colonies for *enterococci* is presented.

Figure 5.9. Negative for *enterococci*, lack of fluorescence.

Figure 5.10. Positive for *enterococci*, blue fluorescence.

- **Legiolert:** It is a test that detects *L. pneumophila* in water samples. This test is based on a bacterial enzyme detection technology that signals the presence of *L. pneumophila* through utilization of a substrate present in the Legiolert reagent.

No potable Water Sample Preparation (for use with environmental samples only) - 1.0 mL Protocol

1. Added 100 mL of sterile diluent (e.g., deionized water, phosphate/Butterfield's buffer, or 0.1% peptone) to a sterile vessel without sodium thiosulfate.
2. Added contents of Legiolert blister pack to vessel.
3. Shook until contents were dissolved. Solution may remain cloudy.
4. Added 2.0 mL of Legiolert pretreatment into a sterile tube.
5. Added 2.0 mL of nonpotable water sample to the same tube and mixed well.
6. Incubated the tube at room temperature for 60 seconds (±5 seconds).

7. Mixed the tube contents, immediately transferred 2.0 mL to the vessel containing Legiolert, and mixed well.

Quanti-Tray Enumeration Procedure for Quality Control (QC) and Proficiency Test (PT) samples only:

1. Added contents of Legiolert blister pack to sample.
2. Shook until contents were dissolved. Sample remained cloudy.

For all test samples:

3. Poured sample/reagent mixture into a Quanti-Tray/Legiolert tray. Tapped or flicked the tray to remove air bubbles.
4. Immediately sealed tray in an IDEXX Quanti-Tray Sealer PLUS.
5. Incubated the sealed trays for all nonpotable water incubated at 37±0.5°C for 7 days.
6. Quanti-Tray/Legiolert was incubated paper side down with the wells facing up in an environment that would minimize Quanti-Tray water loss (either in high humidity or in an enclosure that traps moisture). Stacked trays in alternating directions for added stability. Did not remove trays completely from incubator prior to final read.
7. Read results according to Table 5.10. Counted the number of positive wells and referred to the Legiolert Most Probable Number (MPN) table provided with the trays to obtain an MPN. Multiplied results by the dilution factor for the final MPN.

Table 5.10. Results interpretation.

Appearance	Results
Any brown color (with or without turbidity)	Positive for *L. pneumophila*
Any turbidity (With or without any brown color change)	Positive for *L. pneumophila*
No brown color change and no turbidity	Negative for *L. pneumophila*

• Legiolert quantitative results are definitive at 7 days. In addition, positive wells observed before 7 days and negative wells observed after 7 days are also valid.

• Turbidity alone indicates growth of *L. pneumophila* when the indicator may not develop as quickly or strongly.

In Figures 5.11 and 5.12, an example of the positive or negative for *L. pneumophila* colonies is presented.

Figure 5.11. Negative for *L. pneumophila,* no brown color change and no turbidity.

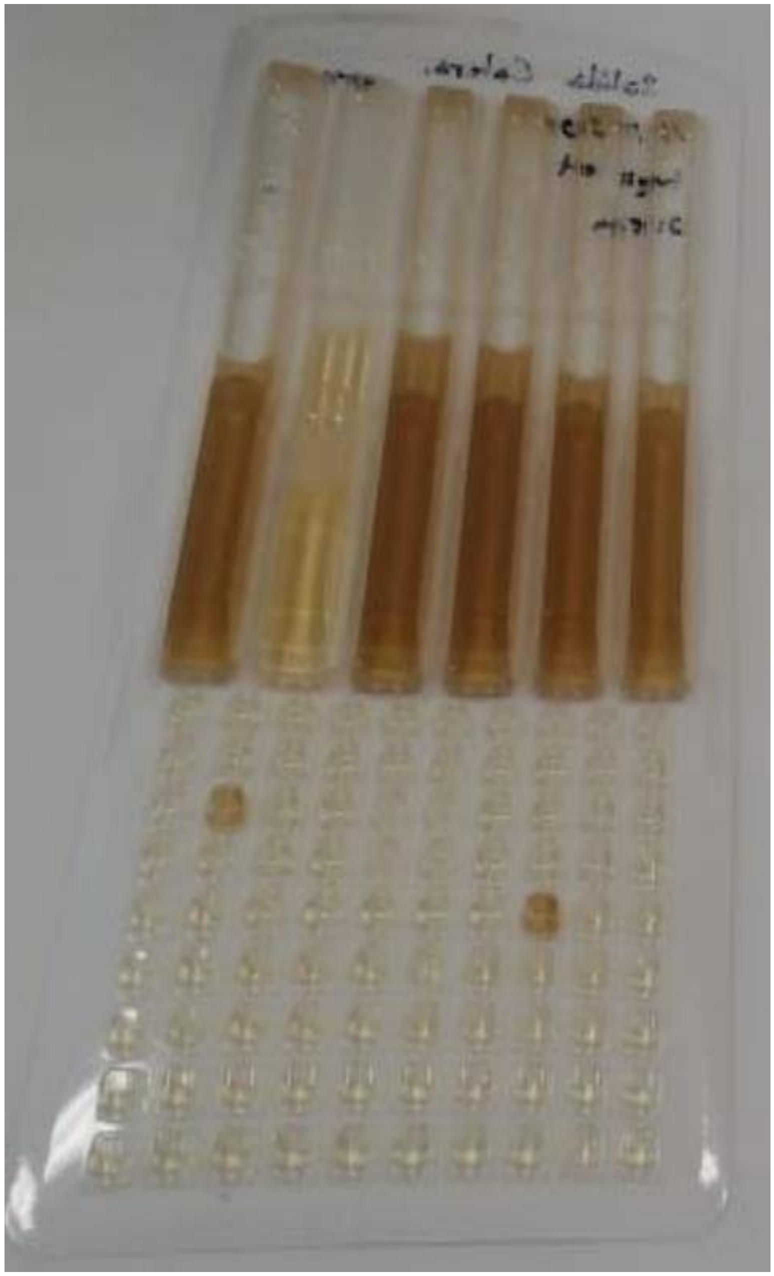


Figure 5.12. Positive for *L. pneumophila*, brown color.

- **Pseudalert:** Detects the presence of *P. aeruginosa* in water samples. The test is based on a bacterial enzyme detection technology that signals the presence of *P. aeruginosa* through the hydrolysis of a substrate present in the Pseudalert reagent.

Quanti-Tray Enumeration Procedure (100 mL Samples Only)

1. Added contents of one pack to a 100 mL water sample in a sterile vessel.
2. Capped vessel and shook until dissolved.
3. Added 2 drops of IDEXX Antifoam Solution to the sample/reagent mixture.
4. Poured sample/reagent mixture into a Quanti-Tray and sealed in a Quanti-Tray Sealer.
5. Placed the sealed tray in a 38±0.5°C incubator for 24 to 28 hours.
6. Read results according to Table 5.11. Counted the number of positive wells and referred to the Most Probable Number (MPN) table provided with the trays to obtain an MPN.

Table 5.11. Results interpretation.

Appearance	Results
No blue fluorescence	Negative for *P. aeruginosa*
Blue fluorescence *	Positive for *P. aeruginosa*

* Presence of blue fluorescence greater than the amount present in a negative control sample.

In Figures 5.13 and 5.14, an example of the negative and positive colonies for *Legionella pneumophila* is presented.

Figure 5.13. Negative for *L. pneumophila*, no blue fluorescence.

Figure 5.14. Positive for *L. pneumophila*, blue fluorescence.

MC-Media Pad® Yeast and Mold: is a pre-sterilized, ready-to-use dry culture device. The MC-Media Pad® is coated with selective medium and chromogenic substrates for specific detection. Once the liquid sample is inoculated onto the test pad, the sample diffuses through the whole pad by capillary action. The medium re-constitutes automatically.

Yeasts and Molds Procedure:

1. Opened the aluminum bag, and removed the MC-Media Pad®. Wrote information on the cover film.
2. Lifted the transparent cover film and pipetted 1.0 mL of sample solution onto test pad. (It was recommended to lift the cover film diagonally for easy and secure re-sealing.).
3. Closed the cover film and lightly pressed the edges of film to seal.
4. Incubated test plate at 25 ±1 °C for 48-72 hours.
5. Re-sealed the opened bags and stored at 2–15 °C for up to 4 weeks.
6. Read results counted all reddish colored colonies. Yeasts were small colonies with a defined border and molds were large colonies with fuzzy borders.

In Figures 5.15 and 5.16, an example of yeasts and molds are presented.

Figure 5.15. Molds present with fuzzy borders.

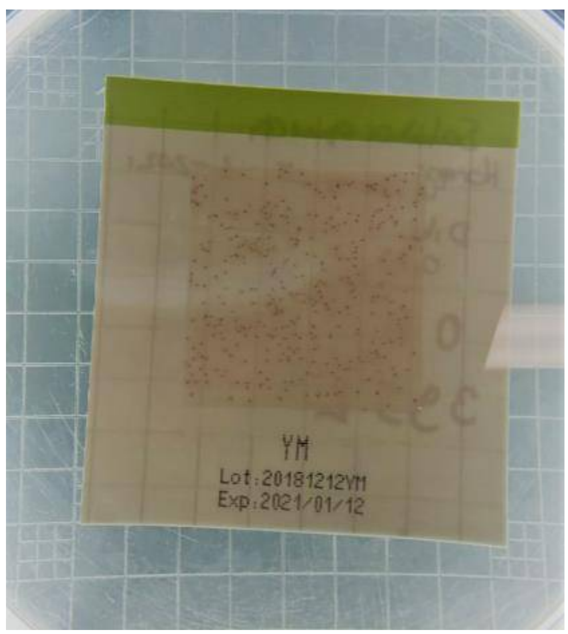


Figure 5.16. Yeasts present with defined border.

5.4 ANALYSIS RESULTS

Below are the results of the monitoring campaigns carried out during a period of six months, from June to December of 2021. In appendix D, the field work of the monitoring campaigns is presented in detail and appendix E, the results of laboratory of EAAB (in Spanish).

Considering that the study was developed with two types of hot springs and a maximum of six data points for each parameter, the student's t-test statistical analysis was applied, as shown in appendix F.

5.4.1 Input Parameter Results

The results of the input parameters of each one of the hot springs are presented in Appendix E, which were analyzed by the laboratory of the Bogota Water and Sewerage Company (in Spanish EAAB).

Results Parameters In Situ

Table 5.12 presents the results of the parameters measured in the field of hot springs 1 and 2.

Table 5.12. Results of parameters measured in situ hot springs 1and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
			ENTRY	ENTRY	ENTRY	ENTRY	ENTRY	ENTRY
Hot spring 1	Flow	L/s	1.66	2.07	0.51	2.38	0.94	0.66
	Temperature	°C	31.1	24.3	30.2	34.9	25.2	20.5
	Conductivity	µS/cm	8978	6342	6085	6987	6235	5386
	pH	pH units	8.1	7.8	7.3	7.5	7.2	7.3
	Dissolved Oxygen	mg/L – O_2	4.1	4.1	4.4	4.3	4.6	4.4
H o	Flow	L/s	1.63	3.66	N. D	1.38	3.13	3.54

PARAMETER	UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
		30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
		ENTRY	ENTRY	ENTRY	ENTRY	ENTRY	ENTRY
Temperature	oC	29.2	32.3	34	38.9	30.2	26.3
Conductivity	µS/cm	102	89	74	102	87	108
pH	pH units	7.7	6.8	6.4	6.2	6.7	6.8
Dissolved Oxygen	mg/L – O_2	3.3	4.3	4.4	4.4	4.3	4.5

N.D: No data.

Once the student's t-tests of the in-situ parameters of the input data were determined, the results shown in Appendix E were obtained.

Flow

In Figures 5.17 and 5.18, the distribution of the values of each flow of the hot spring is shown, which conform to a normal distribution, with an average value of 1.37 L/s for hot spring 1 and an average value of 2.67 L/s for hot spring 2 in probability paper. According to the student's t-test, there was no statistically significant difference between the samples, with a confidence level and a probability of 95% (See Appendix E).

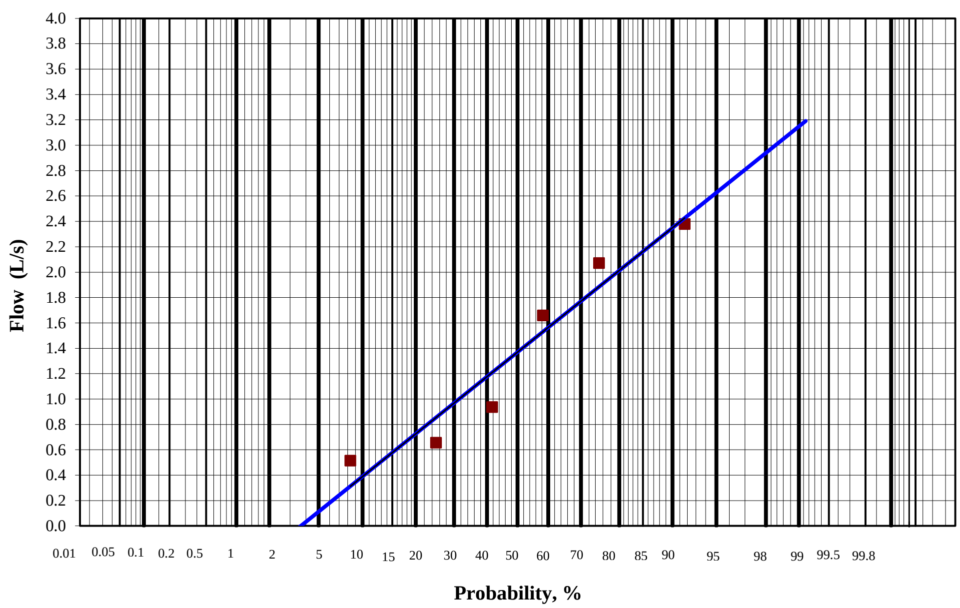


Figure 5.17. Probability of flow occurrence - hot spring 1.

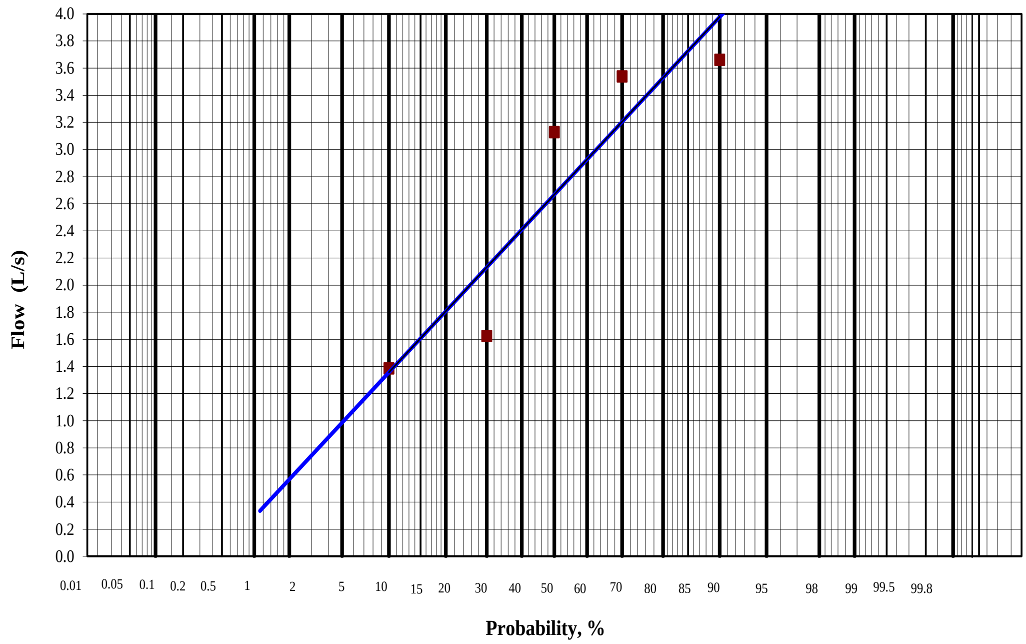


Figure 5.18. Probability of flow occurrence - hot spring 2.

Temperature

In Figure 5.19, the temperature results of each of the hot springs are shown. It is observed that hot spring 1 corresponds to type of hypothermal water, with temperatures between 20 and 35 °C and with an average value of 27.7 °C. In the case of hot spring 2, most of the data corresponds to hypothermal water with a mean value of 31.82 °C.

The statistical analysis of student's t-test was performed between hot springs 1 and 2. The results revealed no statistically significant difference between the samples with a confidence level of 95%. Comparing the values with the Alberta recreational water regulation, the temperature was below 35 °C, considering that the hot springs' temperatures were natural.

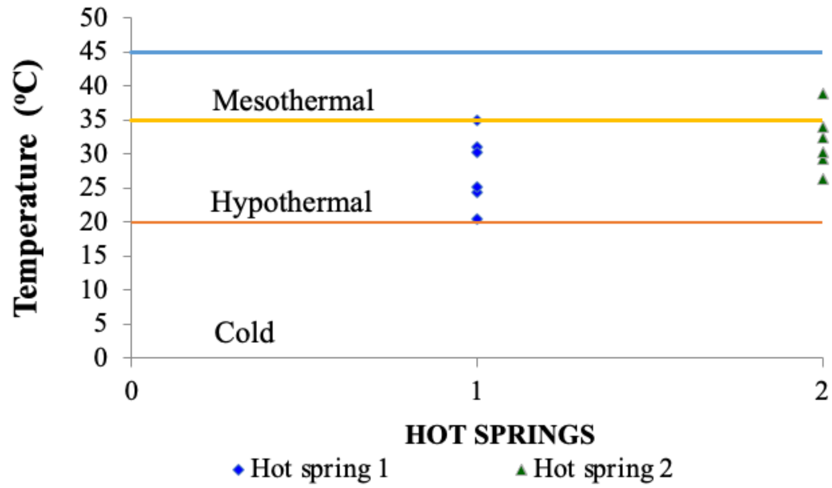


Figure 5.19. Temperature input data results.

Conductivity

The student's t-test of the conductivity results for each of the hot springs showed that there was a strong statistical difference in the samples, for which the null hypothesis was rejected. This is due to the properties of each of the hot springs. Hot spring 1 is bicarbonate water and hot spring 2 is ferruginous water. In hot spring 1, the average conductivity was 6668.8 µS/cm and in hot spring 2 it was 93.67 µS/cm.

Colombia regulates a maximum value of 2400 µS/cm for recreational waters and 1000 µS/cm for drinking water. Germany regulates 2790 µS/cm at 25 °C for drinking water. In Figure 5.20, it can be seen that no data from the hot springs were found in this interval.

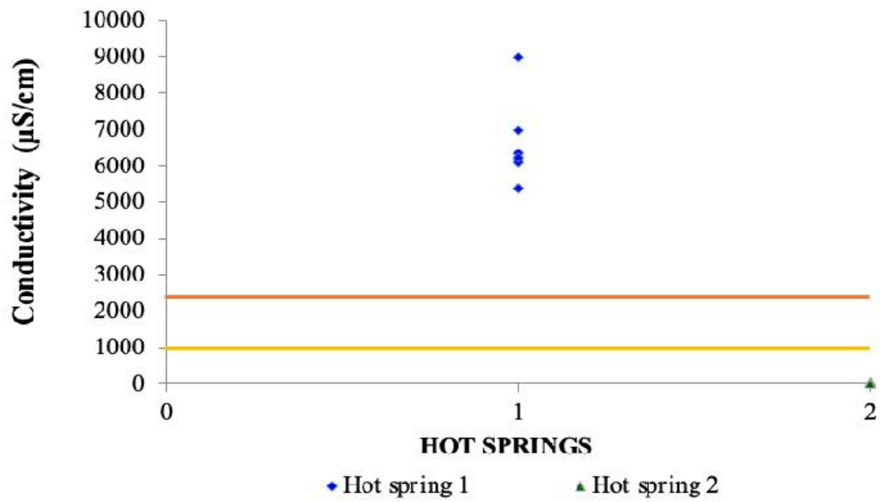


Figure 5.20. Conductivity input data results, where it was observed that according to the Colombian swimming pool regulations, hot spring 1 exceeds the values.

pH

The pH values of the different standards are compared in Table 3.2. It was observed that the regulations for drinking water and swimming pool water were in a range of 6. 5 to 10.5 units of pH, as shown in Figure 5.21.

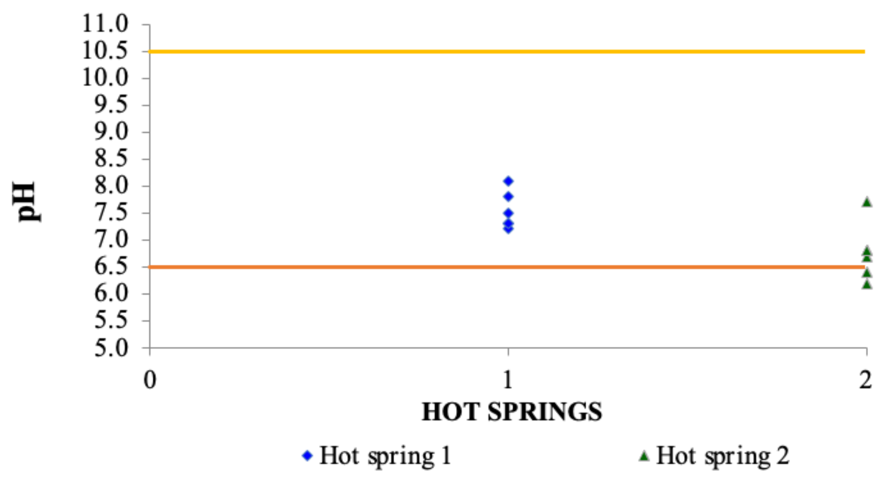


Figure 5.21. pH input data results, where it was observed that the data from hot spring 2 were below the value of 6.5 units of pH.

The student's t-test of the pH results for each of the hot springs showed that there was a strong statistical difference in the samples, for which the null hypothesis was rejected. In hot spring 1, the average pH was 7.53 and in hot spring 2 was 6.77 units of pH.

Dissolved Oxygen (DO)

The DO data was analyzed according to the student's t-test, there was no statistically significant difference between the samples with a confidence level of 95%. The regulations are shown in Table 6, in drinking water and swimming pools there are no limit values for DO. Figure 5.22 shows the DO results of each hot spring.

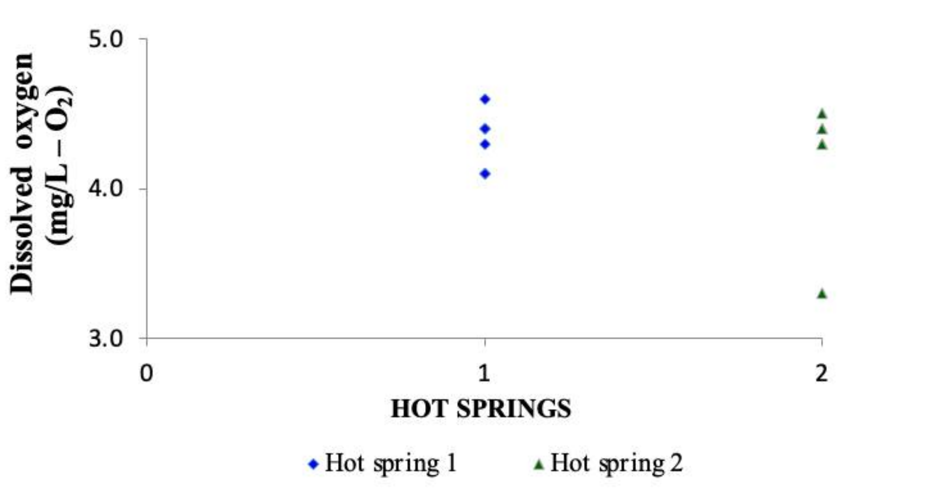


Figure 5.22. Results of the input data DO, where it was observed that the data remains between 3.0 and 5.0 mg O_2/L.

5.4.2 Results of physical-chemical parameters

- **Aluminum (Al), Arsenic (As), Boron (B), Copper (Cu), and Chromium (Cr)**

Table 5.13 presents the results of the parameters Aluminum (Al), Arsenic (As), Boron (B), Copper (Cu), and Chromium (Cr).

Table 5.13. Results of parameters Al, As, B, Cu, and Cr in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
			ENTRY	ENTRY	ENTRY	ENTRY	ENTRY	ENTRY
Hot spring 1	Aluminum	mg Al/L	N.Q	N.Q	0.02	N. Q	0.01	0.03
	Arsenic	mg As/L	N.Q	N.Q	N.Q	N.D	N.Q	N.Q
	Boron	mg B/L	0.07	0.07	0.07	0.06	0.09	0.11
	Copper	mg Cu/L	N.Q	N.D	N.D	N.D	N.Q	N.Q
	Chromium	mg Cr/L	N.Q	N.D	N.D	N.D	N.D	N.D
Hot spring 2	Aluminum	mg Al/L	0.01	N.Q	0.02	0.05	0.05	0.02
	Arsenic	mg As/L	N.Q	N.Q	N.Q	N.Q	N.Q	N.Q
	Boron	mg B/L	N.Q	N.Q	N.Q	N.Q	N.Q	0.03
	Copper	mg Cu/L	N.Q	N.D	N.D	N.D	N.Q	N.Q
	Chromium	mg Cr/L	N.D	N.D	N.D	N.D	N.D	N.D

N.Q = Not quantifiable, N.D = No data.

Once the student's t-tests of the Al, As, B, Cu, and Cr parameters of the input data were determined, the results shown in Appendix E were obtained.

Aluminum

The student's t-test for the aluminum data did not present significant statistical differences between the samples with a confidence level of 95%. The different standards compared in Table 6, in drinking water and swimming pools there are a maximum value for Al of 0.1 and 0.2 mg Al/L. In hot spring 1, the average Al was 0.02 mg Al/L and in hot spring 2 was 0.03 mg Al/L. In Figure 5.23, the aluminum results of each hot spring are presented.

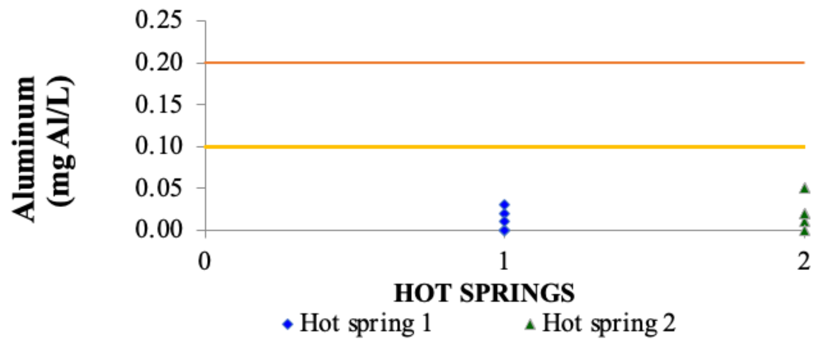


Figure 5.23. Results of the input data Al, where it was observed that the data from the hot springs complied with the regulations.

Arsenic

The regulations are shown in Table 3.2, the maximum value is 0.01 mg As/L for drinking water. In swimming pool is not regulate. The results obtained from each of the hot springs were not quantifiable, which complied with the regulations of drinking water.

Boron

The student's t-test of the Boron results of each of the hot springs showed that there was a strong statistical difference in the samples, for which the null hypothesis was rejected.

The regulations are show in Table 3.2, the values have a maximum value of 1.0 and 5.0 mg B/L for drinking water, in swimming pool water was not regulated. The results obtained from hot spring 1 presented an average value of 0.08 mg B/L and for hot spring 2 was not quantifiable, only a measurement of 0.03 mg B/L was achieved. In Figure 5.24, the Boron results of each hot spring are presented.

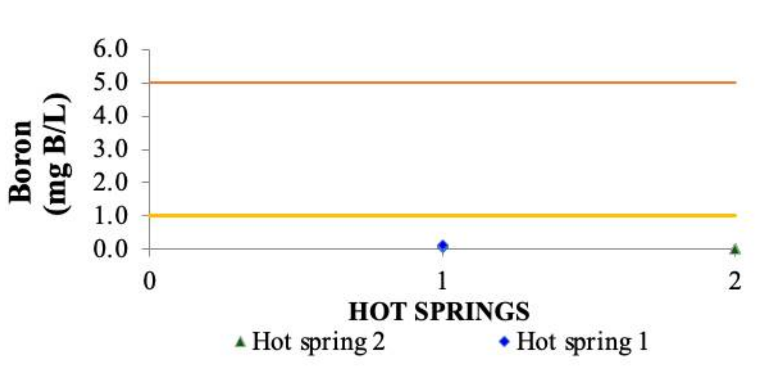


Figure 5.24. Results of the Boron input data, where it was observed that the data from the hot springs complied with the regulations.

Copper

The regulations are shown in Table 3.2, the maximum values oscillate between 1.0 and 2.0 mg Cu/L for swimming pool water and drinking water. The results obtained from each of the hot springs were not quantifiable, which complied with the provisions of the limit of the standards.

Chromium

The regulations are shown in Table 3.2, the limit value for drinking water is 0.05 mg Cr/L and in swimming pool water are not regulated. Only one data from hot spring 1 was not quantifiable. The other data did not have measurements of hot springs 1 and 2.

- **Iron (Fe), Magnesium (Mg), Manganese (Mn), Mercury (Hg), and Nickel (Ni)**

Table 5.14 presents the results of the parameters Fe, Mg, Mn, Hg, and Ni.

Table 5.14. Fe, Mg, Mn, Hg, and Ni parameter results in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY 30/06/2021 ENTRY	JULY - AUGUST 28/07/2021 ENTRY	AUGUST - SEPTEMBER 2/09/2021 ENTRY	SEPTEMBER - OCTOBER 3/10/2021 ENTRY	OCTOBER - NOVEMBER 17/11/2021 ENTRY	NOVEMBER - DECEMBER 15/12/2021 ENTRY
Hot spring 1	Iron	mg Fe/L	0.02	0.05	0.02	0.08	0.03	0.09
	Magnesium	mg Mg/L	N.D	N.D	N.D	N.D	N.D	9.64
	Manganese	mg Mn/L	0.02	0.02	0.02	0.02	0.02	0.02
	Mercury	mg Hg/L	N.Q	N.Q	N.Q	N.D	N.D	N.D
	Nickel	mg Ni/L	N.Q	N.Q	N.Q	N.Q	N.Q	N.D
Hot spring 2	Iron	mg Fe/L	6.63	7.95	7.14	8.76	14.28	9.26
	Magnesium	mg Mg/L	N.D	N.D	N.D	N.D	N.D	3.29
	Manganese	mg Mn/L	0.22	0.22	0.25	0.24	0.25	0.29
	Mercury	mg Hg/L	N.Q	N.Q	N.Q	N.Q	N.D	N.D
	Nickel	mg Ni/L	N.Q	N.Q	N.Q	N.Q	N.Q	N.D

N.Q = Not quantifiable, N.D = No Data.

Once the student's t-tests of the Fe, Mg, Mn, Hg, and Ni parameters of the input data were determined, the results shown in Appendix E were obtained.

Iron

The regulations are shown in Table 3.2, the values oscillated between 0.2 and ≤ 0.3 mg Fe/L for drinking water. In swimming pool water was not regulated. Only Japan has a specific value in regulation for hot springs, it is ≥10 mg Fe/L.

The student's t-test, the iron data analyzed did not present significant statistical differences between the samples with a confidence level of 95%. In hot spring 1, the average Fe was 0.05 mg Fe/L and in hot spring 2 was 9.0 mg Fe/L. In Figure 5.25, the iron results of each hot spring are presented.

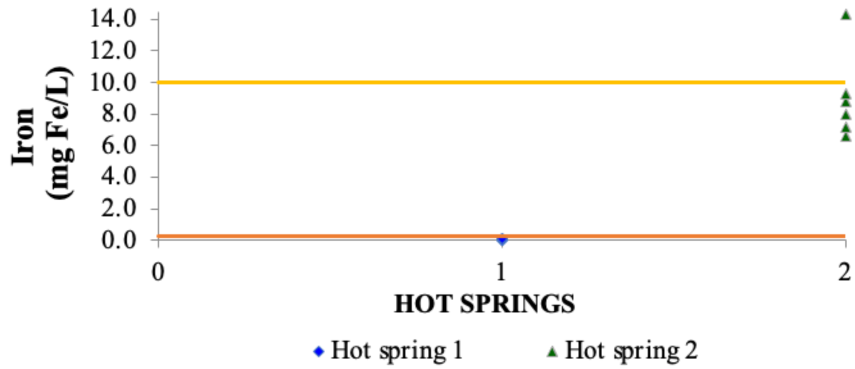


Figure 5.25. Results of the input data of iron, where it was observed that the data of hot spring 2, did not fulfill the regulation of drinking water and only one data point was outside the limit values of the regulations of Japan for hot springs.

Magnesium

The standards are shown in Table 3.2, only the Colombian standard has a limit value of 36 mg Mg^{2+}/L for drinking water. Only one data point of the hot springs was measured. Hot spring 1 with a data of 9.64 mg Mg/L and hot spring 2 of 3.29 mg Mg/L. In Figure 5.26, the magnesium results of each hot spring are presented.

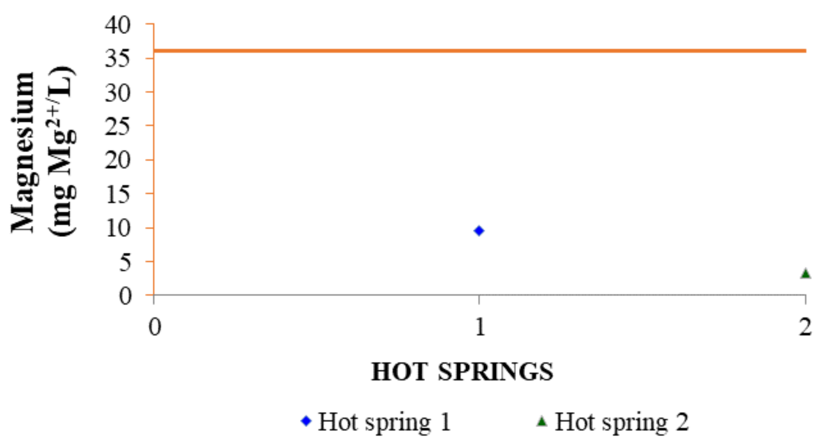


Figure 5.26. Results of the input data of magnesium, where it was observed that the data from the hot springs fulfilled the regulation of Colombian drinking water.

Manganese

The regulations are shown in Table 3.2, the maximum values oscillate between 0.05, 0.12, and 0.4 mg Mn/L for drinking water, in swimming pool water was not regulated. Only Japan has a specific value in regulation for hot springs, it is ≥10 mg Mn/L.

The student's t-test, the manganese results of each of the hot springs showed that there was no statistical difference in the samples, for which the null hypothesis was rejected. The results obtained from hot spring 1 presented an average value of 0.02 mg Mn/L and hot spring 2 had 0.25 mg Mn/ L. In Figure 5.27, the manganese results of each hot spring are presented.

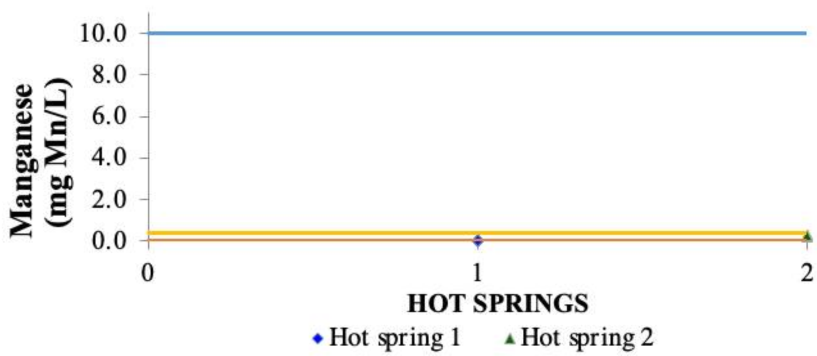


Figure 5.27. Results of the input data of manganese, where it was observed that the data from the hot springs fulfilled the regulations.

Mercury

The regulations are shown in Table 3.2, the maximum values oscillated between 0.001 and 0.006 mg Hg/L for drinking water. In swimming pool water was not regulated. The results obtained from each of the hot springs were not quantifiable, which complied with the provisions of the limit of the standards.

Nickel

The regulations are shown in Table 3.2, the maximum values oscillated between 0.02 and 0.07 mg Ni/L for drinking water. In swimming pool water was not regulated. The results obtained from each of the hot springs were not quantifiable, which complied with the limit standards.

- **Lead (Pb), Selenium (Se), Zinc (Zn), and Strontium (Sr)**

Table 5.15 presents the results of the parameters Pb, Se, Zn, and Sr.

Table 5.15. Pb, Se, Zn, and Sr parameter results in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
			ENTRY	ENTRY	ENTRY	ENTRY	ENTRY	ENTRY
Hot spring 1	Lead	mg Pb/L	N.Q	N.Q	N.Q	N.Q	N.Q	N.Q
	Selenium	mg Se/L	N.Q	N.Q	N.Q	N.Q	N.Q	N.Q
	Zinc	mg Zn/L	0.01	N.Q	N.Q	N.Q	N.Q	N.Q
	Strontium	mg Sr/L	0.66	0.64	0.66	0.65	0.93	0.8
Hot spring 2	Lead	mg Pb/L	N.Q	N.Q	N.Q	N.Q	N.Q	N.Q
	Selenium	mg Se/L	N.Q	N.Q	N.Q	N.Q	N.Q	N.D
	Zinc	mg Zn/L	0.03	N.Q	0.02	N.Q	0.01	0.01
	Strontium	mg Sr/L	N.Q	N.Q	N.Q	N.Q	0.04	N.Q

N.Q = Not quantifiable, N.D = No Data.

Once student's t-tests of Lead (Pb), Selenium (Se), Zinc (Zn), and Strontium (Sr) parameters of the input data were determined, the results shown in Appendix E were obtained.

Lead

The regulations are shown in Table 3.2, the maximum values oscillated between 0.005 and 0.01 mg Pb/L for drinking water. In swimming pool water was not regulated. The results obtained from each of the hot springs were not quantifiable, which complied with the provisions of the limit standards.

Selenium

The regulations are shown in Table 3.2, the maximum values oscillated between 0.01 and 0.05 mg Se/L for drinking water. In swimming pool water was not regulated. The results obtained from each of the hot springs were not quantifiable, which complied with the limit standards.

Zinc

The student's t-test, the zinc results of each of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was not rejected. The results obtained from hot spring 1 presented an average value of 0.01 mg Zn/L and hot spring 2 had 0.02 mg Zn/ L.

The regulations are shown in Table 3.2, the maximum values oscillated between ≤ 5 mg Zn/L and 3.0 mg Zn/L for drinking water. In swimming pool water was not regulated. In Figure 5.28, the zinc results of each hot spring are presented.

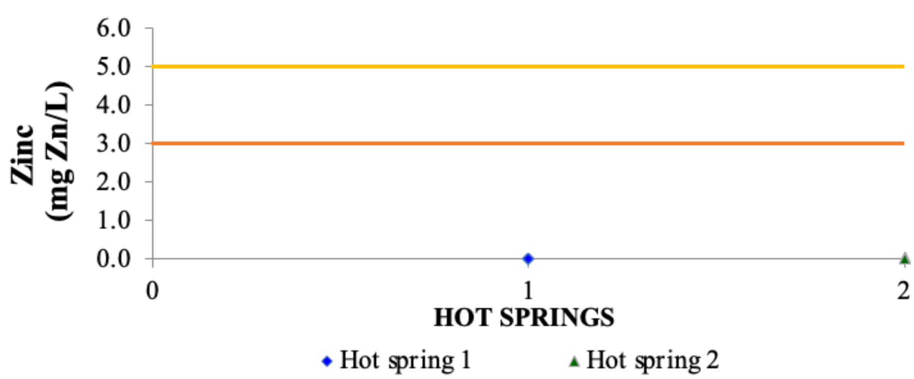


Figure 5.28. Results of the input data of zinc, where it was observed that the data from the hot springs fulfilled the regulations.

Strontium

The student's t-test, the strontium results of each of the hot springs showed that there was a statistical difference in the samples, therefore the null hypothesis was rejected. The results obtained from hot spring 1 presented an average value of 0.72 mg Sr/L and hot spring 2 had 0.04 mg Sr/ L.

The regulations are shown in Table 3.2, the maximum values established by the Canadian Guidelines for drinking water is 7 mg Sr/L. In swimming pool water are not regulated. Only Japan has a specific value in regulation for hot springs is ≥10 mg Sr/L. In Figure 5.29, the strontium results of each hot spring are presented.

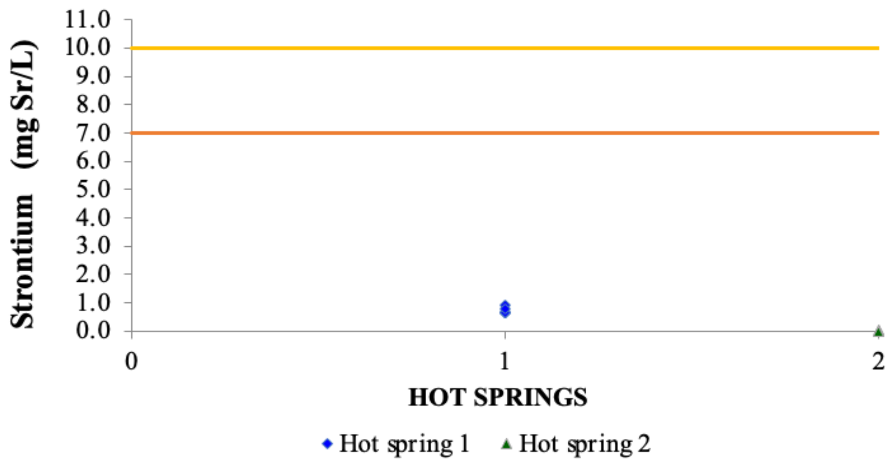


Figure 5.29. Results of the input data of strontium, where it was observed that the data from the hot springs fulfilled the regulations.

To give depth to this topic you can review the following publication:

Conference, article and poster

- Y. Sánchez, M. Mehrvar, L. McCarthy, E. Quiñones, L.R. Cheu, A. Reuß, J. Romero. **Presence of metals in ferruginous hot spring in the Cundinamarca region, Colombia**, *Quinto Encuentro Nacional de Estudiantes de Doctorados en Ingeniería (ENEDI 2023)*, ACOFI 2023, Cartagena, Colombia, September 20-22, 2023. In process.

- **Apparent color, Turbidity, Oils and Fats, Alkalinity, and Calcium (Ca)**

Table 5.16 presents the results of the parameters apparent colour, turbidity, oils and fats, alkalinity, and calcium (Ca).

Table 5.16. Apparent colour, turbidity, oils and fats, alkalinity, and calcium (Ca) parameters results in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
			ENTRY	ENTRY	ENTRY	ENTRY	ENTRY	ENTRY
Hot spring 1	Apparent colour	TCU	1	5	1	1	N.D	2
	Turbidity	NTU	0.3	0.75	1.6	1	0.25	0.2
	Oils and fats	mg/L	N.D	N.Q	N.Q	N.Q	N.Q	N.Q
	Alkalinity	mg $CaCO_3$/L	231	240	228	223	226	246
	Calcium	mg Ca/L	42.18	38.71	45.31	39.74	46.22	63.72
Hot spring 2	Apparent Colour	UPC	5	22	34	15	21	56
	Turbidity	NTU	8.7	50	N.D	38	65	50
	Oils and fats	mg/L	N.D	N.Q	N.Q	N.Q	N.Q	N.Q
	Alkalinity	mg $CaCO_3$/L	22	29	22	21	22	22
	Calcium	mg Ca/L	2.61	2.63	2.98	2.68	2.61	3.23

N.Q = Not quantifiable, N.D = No Data.

Once student's t-tests of apparent colour, turbidity, oils and fats, alkalinity, and calcium (Ca^{2+}) parameters of the input data were determined, the results shown in Appendix E were obtained.

Apparent colour

The student's t-test, the apparent colour results of each of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was not rejected. The results obtained from hot spring 1 presented an average value of 2.0 true colour units (TCU) and hot spring 2 had 25.5 TCU.

The regulations are shown in Table 3.2, the maximum values oscillated between 5 TCU and ≤ 15 TCU for drinking water. In swimming pool water was not regulated. In Figure 5.30, the apparent colour results of each hot spring are presented.

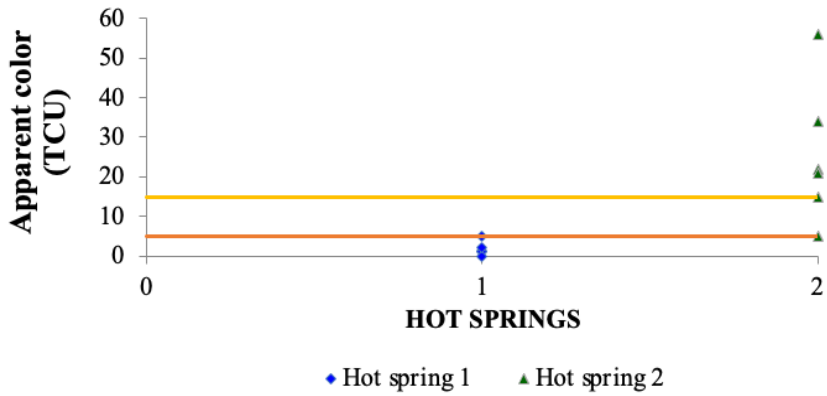


Figure 5.30. Results of the apparent colour input data, where it was observed that the data from hot spring 2 did not comply with the regulations because it was a ferruginous water.

Turbidity

The regulations are shown in Table 3.2, the maximum values oscillated between ≤ 0.3 and 5.0 nephelometric turbidity unit (NTU) for drinking water. In swimming pool water was regulated with values 0.5 and 2.0 NTU.

The student's t-test, the turbidity results of each of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was not rejected. The results obtained from hot spring 1 presented an average value of 0.68 NTU and for hot spring 2 was 42.34 NTU. In Figure 5.31, the turbidity results of each hot spring are presented.

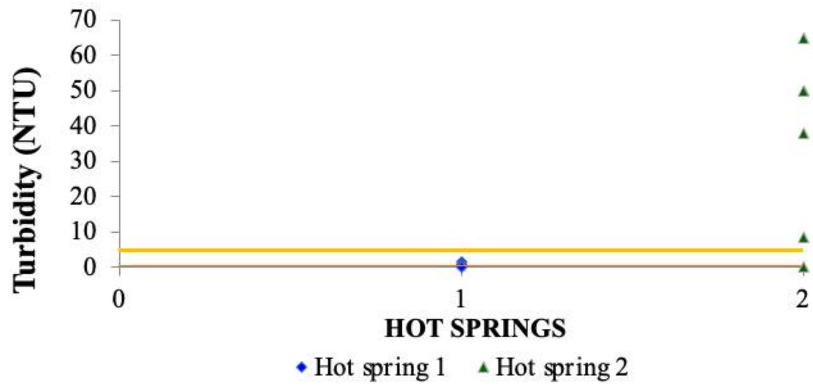


Figure 5.31. Results of the turbidity input data, where it was observed that the data from hot spring 2 did not comply with the regulations because it was a ferruginous water.

Oils and fats

The regulations are shown in Table 3.2, drinking water and swimming pool water are not regulated. The results obtained from each of the hot springs were not quantifiable.

Alkalinity

The student's t-test, the alkalinity results of each one of the hot springs showed that there was a strong statistical difference in the samples, therefore the null hypothesis was rejected.

The regulations are shown in Table 3.2, the maximum values oscillated between 30 and 500 mg $CaCO_3$/L for drinking water; in swimming pool water 60 to 180 mg $CaCO_3$/L. The results obtained from hot spring 1 presented an average value of 232.33 mg $CaCO_3$/L and for hot spring 2 was 23.0 mg $CaCO_3$/L. In Figure 5.32, the alkalinity results of each hot spring are presented.

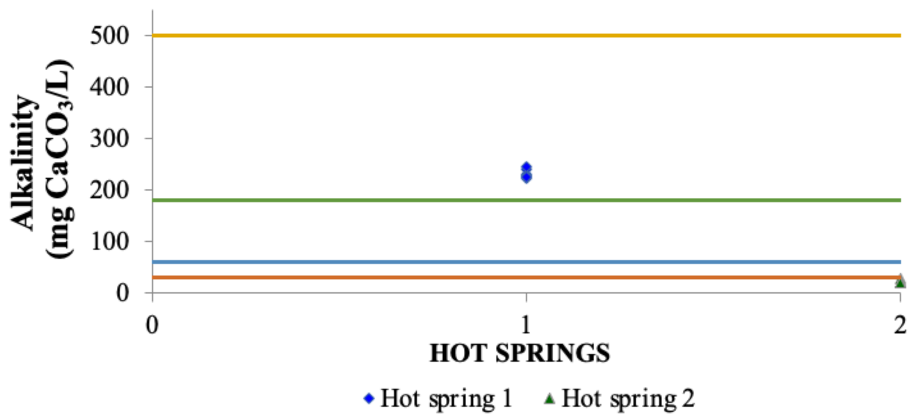


Figure 5.32. Results of the input data of alkalinity, where it was observed that the data of hot spring 1 was outside the limit values of the regulations of swimming pools, and hot spring 2 did not comply with the regulations.

Calcium

The student's t-test, the calcium results of each one of the hot springs, it was observed that there was a strong statistical difference in the samples, therefore the null hypothesis was rejected.

The regulations are shown in Table 3.2, Colombian drinking water regulation established that there is a limit value of 60 mg Ca^{2+}/L. In swimming pool water was not regulated. The results obtained from hot spring 1 presented an average value of 45.98 mg Ca^{2+}/L and for hot spring 2 was 2.79 mg Ca^{2+}/L. In Figure 5.33, the calcium results of each hot spring are presented.

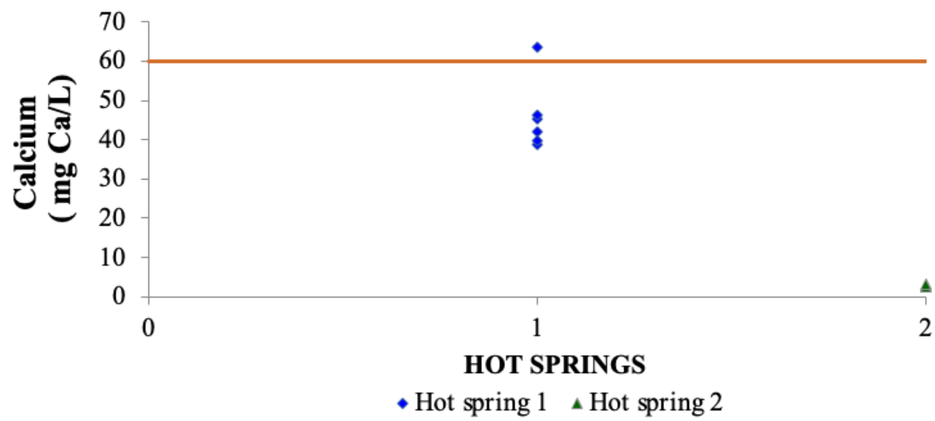


Figure 5.33. Results of the calcium input data, where it was observed that only one data point from hot spring 1 was outside the limit values of the Colombian drinking water regulations.

- **Total Inorganic Carbon (TIC), Total Organic Carbon (TOC), Biochemical Oxygen Demand (BOD), and Chemical Oxygen Demand (COD)**

Table 5.17 presents the results of the parameters TIC, TOC, BDO, and COD.

Table 5.17. Results of parameters TIC, TOC, BDO and COD in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021 ENTRY	28/07/2021 ENTRY	2/09/2021 ENTRY	3/10/2021 ENTRY	17/11/2021 ENTRY	15/12/2021 ENTRY
Hot spring 1	Total Inorganic Carbon (TIC)	mg/L	57.71	56.1	55	57.3	60	55.3
	Total Organic Carbon (TOC)	mg/L	4.9	3.8	3.6	N.Q	4.2	4.4
	Biochemical Oxygen Demand (BOD)	mg O²/L	100	N.Q	N.Q	N.Q	167	7
	Chemical Oxygen Demand (COD)	mg O²/L	164	132	360	56	339	72
Hot spring 2	Total Inorganic Carbon (TIC)	mg/L	12.2	26.7	6.6	9.5	11.9	11
	Total Organic Carbon (TOC)	mg/L	N.Q	N.Q	N.Q	N.Q	4	N.Q
	Biochemical Oxygen Demand	mg O²/L	7	N.Q	N.Q	N.Q	2	6

PARAMETER		UNIT	JUNE - JULY 30/06/2021 ENTRY	JULY - AUGUST 28/07/2021 ENTRY	AUGUST - SEPTEMBER 2/09/2021 ENTRY	SEPTEMBER - OCTOBER 3/10/2021 ENTRY	OCTOBER - NOVEMBER 17/11/2021 ENTRY	NOVEMBER - DECEMBER 15/12/2021 ENTRY
	(BOD)							
	Chemical Oxygen Demand (COD)	mg O^2/L	132	N.Q	15	N.Q	N.Q	14

N.Q = Not quantifiable, N.D = No Data.

Once the student's t-tests of the TIC, TOC, BDO, and COD parameters of the input data were determined, the results shown in Appendix E were obtained.

Total Inorganic Carbon (TIC)

The student's t-tests, the TIC results of each one of the hot springs showed that there was a strong statistical difference in the samples, therefore the null hypothesis was rejected.

The regulations are shown in Table 3.2, drinking water and swimming pool water are not regulated. The results obtained from hot spring 1 presented an average value of 56.90 mg /L and for hot spring 2 was 12.98 mg /L. In Figure 5.34, the TIC results of each hot spring are presented.

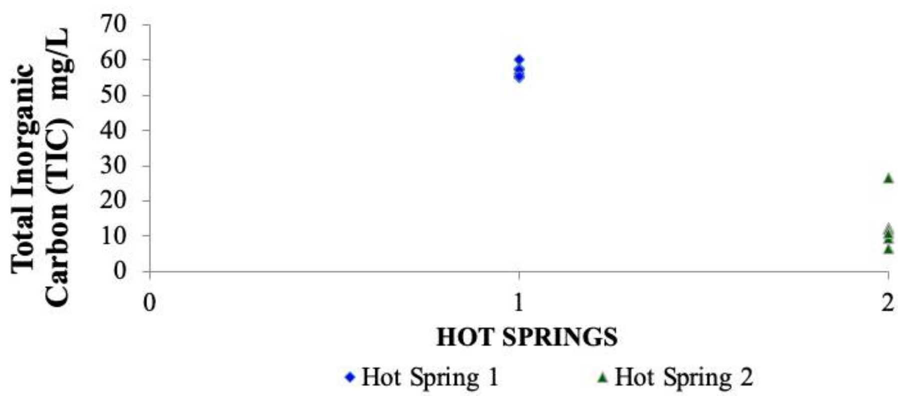


Figure 5.34. Results of the TIC input data.

Total Organic Carbon (TOC)

The regulations are shown in Table 3.2, the limit of values of TOC is 5.0 mg/L for drinking water. In swimming pool water was not regulated.

The student's t-tests, the apparent color results of each of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was not rejected. The results obtained from hot spring 1 presented an average value of 4.18 mg/L and for hot spring 2 was 4.0 mg/L. In Figure 5.35, the TOC results of each hot spring are presented.

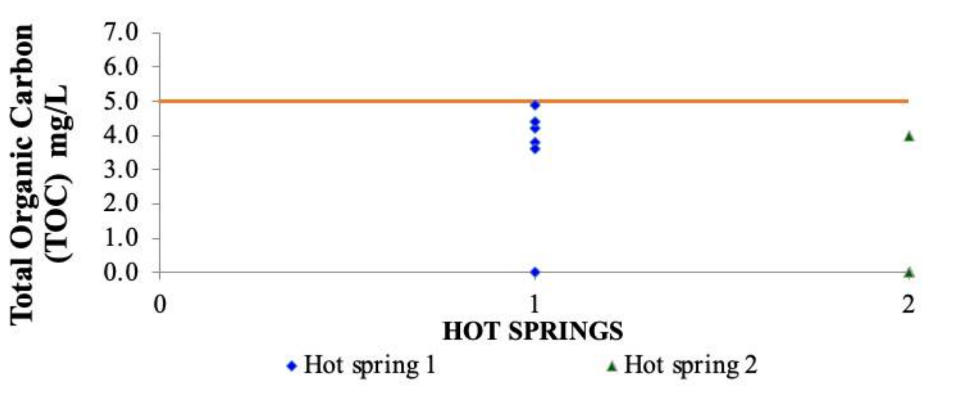


Figure 5.35. Results of the TOC input data, where it was observed that the data from the hot springs fulfilled the regulations.

Biochemical Oxygen Demand (BOD)

The student's t-test, the BOD results of each one of the hot springs showed that there was a strong statistical difference in the samples, therefore the null hypothesis was rejected.

The regulations are shown in Table 3.2, drinking water and swimming pool water are not regulated. The results obtained from hot spring 1 presented an average value of 91.33 mg /L and for hot spring 2 was 5.0 mg /L. In Figure 5.36, the BOD results of each hot spring are presented.

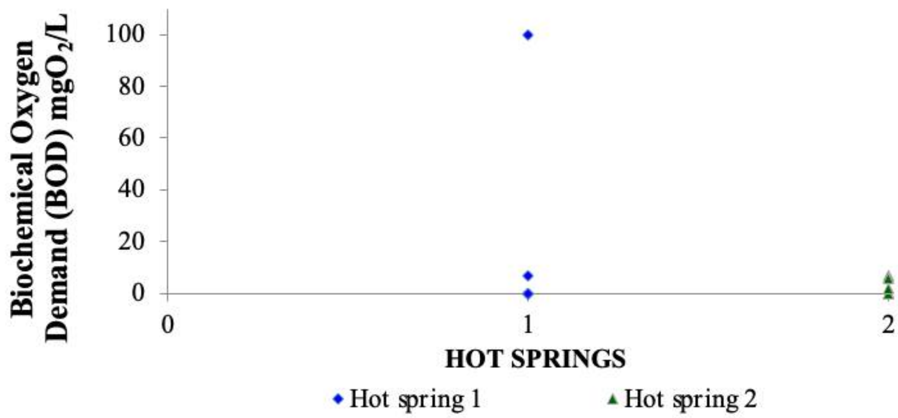


Figure 5.36. Results of the BOD input data.

Chemical Oxygen Demand (COD)

The student's t-tests, the COD results of each one of the hot springs showed that there was a strong statistical difference in the samples, therefore the null hypothesis was rejected.

The regulations are shown in Table 3.2, drinking water and swimming pool water are not regulated. The results obtained from hot spring 1 presented an average value of 187.17 mg /L and for hot spring 2 was 53.67 mg /L. In Figure 5.37, the COD results of each hot spring are presented.

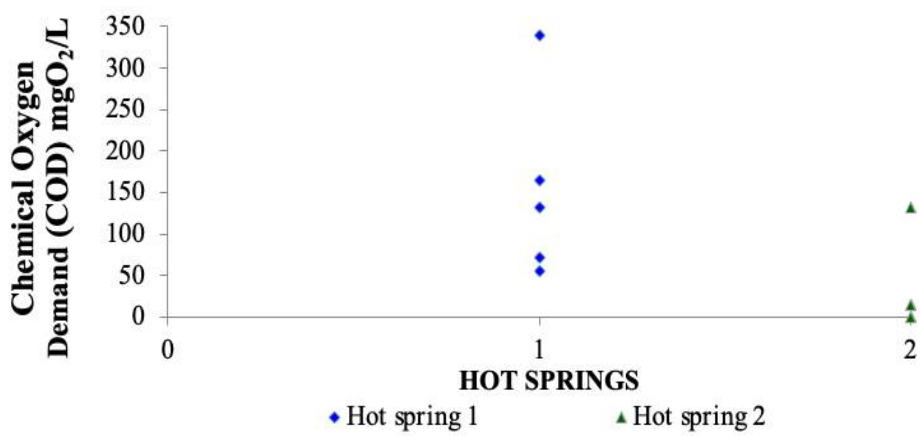


Figure 5.37. Results of the COD input data.

- **Calcium Hardness, Total Hardness, Soluble Phosphorus and Total Phosphorus**

Table 5.18 presents the results of the parameters calcium hardness, total hardness, soluble phosphorus, and total phosphorus.

Table 5.18. Results of parameters calcium hardness, total hardness, soluble phosphorus, and total phosphorus in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
			ENTRY	ENTRY	ENTRY	ENTRY	ENTRY	ENTRY
Hot spring 2	Calcium Hardness	mg $CaCO_3$/L	105	97	113	99	115	159
	Total Hardness	mg $CaCO_3$/L	137	127	148	130	147	199
	Soluble Phosphorus	mg P/L	N.D	N.D	N.D	N.D	N.Q	0.03
	Total Phosphorus	mg P/L	0.07	N.Q	0.04	N.Q	N.Q	0.18
Hot spring 2	Total Inorganic Carbon (TIC)	mg/L	12.2	26.7	6.6	9.5	11.9	11
	Total Organic Carbon (TOC)	mg/L	N.Q	N.Q	N.Q	N.C	4	N.Q
	Biological Oxygen Demand (BOD)	mg O^2/L	7	N.Q	N.Q	N.Q	2	6
	Chemical Oxygen Demand (COD)	mg O^2/L	132	N.Q	15	N.Q	N.Q	14

N.Q = Not quantifiable, N.D = No Data.

Once the student's t-tests of the calcium hardness, total hardness, soluble phosphorus, and total phosphorus parameters of the input data were determined, the results shown in Appendix E were obtained.

Calcium Hardness

The student's t-test, the calcium hardness results of each one of the hot springs showed that there was a strong statistical difference in the samples, therefore the null hypothesis was rejected.

The regulations are shown in Table 3.2, drinking water and swimming pool water are not regulated. The results obtained from hot spring 1 presented an average value of 114.67 mg

$CaCO_3$/L and for hot spring 2 was 7.0 mg $CaCO_3$/L. In Figure 5.38, the calcium hardness results of each hot spring are presented.

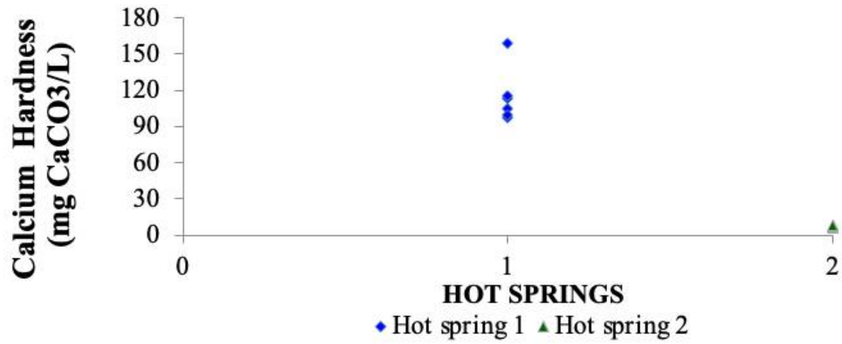


Figure 5.38. Results of the Calcium Hardness input data.

Total Hardness

The regulations are shown in Table 3.2, the maximum values oscillated between 80 to 100 mg $CaCO_3$/L (Canadian regulation) and 300 mg $CaCO_3$/L (Colombian regulation) for drinking water. In swimming pool water, Colombia regulated with the values < 400 mg $CaCO_3$/L.

The student's t-test, the total hardness results of each of the hot springs showed that there was a strong statistical difference in the samples, therefore the null hypothesis was rejected. The results obtained from hot spring 1 presented an average value of 148.0 mg $CaCO_3$/L and for hot spring 2 was 18.17 mg $CaCO_3$/L. In Figure 5.39, the total hardness results of each hot spring are presented.

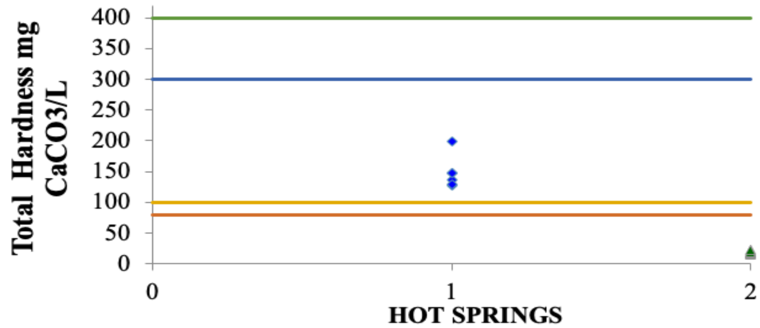


Figure 5.39. Total hardness input data results, where it can be seen that hot springs 1 and 2 did not comply with Canadian drinking water regulation, but those of Colombia do.

Soluble Phosphorus

In the regulations are shown in Table 3.2, drinking water and swimming pool water are not regulated. Only one result was obtained from each of the hot springs, for hot spring 1 it was 0.03 mg P/L and for hot spring 2 was 0.04 mg P/L.

Total Phosphorus

The student's t-test, the total phosphorus results of each of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was not rejected.

The regulations are shown in Table 3.2, drinking water and swimming pool water are not regulated. The results obtained from hot spring 1 presented an average value of 0.11 mg P/L and for hot spring 2 was 0.91 mg P/L. In Figure 5.40, the total phosphorus results of each hot spring are presented.

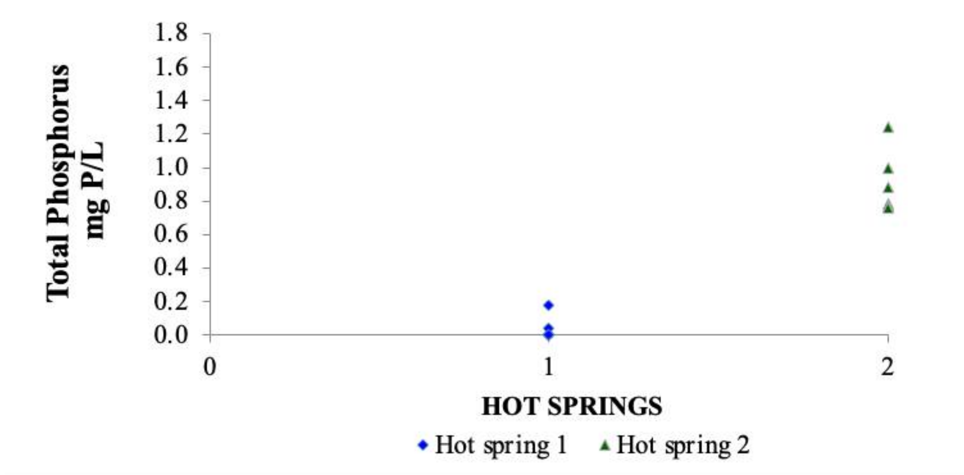


Figure 5.40. Results of the total phosphorus input data.

- **Ammoniacal Nitrogen, Total Kjeldahl Nitrogen, Active Substance to Methylene Blue and Sodium**

Table 5.19 presents the results of the parameters ammoniacal nitrogen, total Kjeldahl nitrogen, active substance to methylene blue, and sodium.

Table 5.19. Results of parameters ammoniacal nitrogen, total Kjeldahl nitrogen, active substance to methylene blue, and sodium in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021 ENTRY	28/07/2021 ENTRY	2/09/2021 ENTRY	3/10/2021 ENTRY	17/11/2021 ENTRY	15/12/2021 ENTRY
Hot spring 2	Ammoniacal Nitrogen	mg NH_3-N/L	N.Q	N.Q	1	N.Q	N.Q	N.Q
	Total Kjeldahl Nitrogen	mg N/L	N.Q	N.Q	1	N.Q	N.Q	N.Q
	Active substance to methylene blue	mg detergents/L calculate LAS 288,37 g/mol	N.Q	0.06	N.D	N.D	N.D	N.Q
	Sodium	mg Na/L	1619.3	N.D	N.D	N.D	N.D	N.D
Hot sprin	Ammoniacal Nitrogen	mg NH3-N/L	N.Q	N.Q	N.Q	N.Q	N.Q	N.Q
	Total Kjeldahl	mg N/L	N.Q	N.Q	N.Q	N.Q	N.Q	N.Q

PARAMETER	UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
		30/06/2021 ENTRY	28/07/2021 ENTRY	2/09/2021 ENTRY	3/10/2021 ENTRY	17/11/2021 ENTRY	15/12/2021 ENTRY
Nitrogen							
Active substance to methylene blue	mg SAAM/L como LAS 288,37 g/mol	N.Q	N.Q	N.Q	N.D	N.D	N.D
Sodium	mg Na/L	3.28	N.D	N.D	N.D	N.D	N.Q

N.Q = Not quantifiable, N.D = No Data.

Once the student's t-tests of the ammoniacal nitrogen, total Kjeldahl nitrogen, active substance to methylene blue, and sodium parameters of the input data were determined, the results shown in Appendix E were obtained.

Ammoniacal Nitrogen

The regulations are shown in Table 3.2, drinking water and swimming pool water are not regulated. The results obtained from each of the hot springs were not quantifiable.

Total Kjeldahl Nitrogen

The regulations are shown in Table 3.2, drinking water and swimming pool water are not regulated. Only one result was obtained from hot spring 1, with value of 1 mg N/L, the other data were not quantifiable for hot springs 1 and 2.

Active Substance to Methylene Blue

The regulations are shown in Table 3.2, drinking water and swimming pool water are not regulated. Only one result was obtained from hot spring 1, with a value of 0.1 mg N/L, the other data were not quantifiable or data were not taken for hot springs 1 and 2.

Sodium

The regulations are shown in Table 3.2, Canada and Germany establish a limit value of ≤ 200 mg Na/L for drinking water regulation. In swimming pool water was not regulated. Only one result was obtained from hot spring 1, with value of 1619.27 mg Na/L and hot spring 2 had 3.28 mg Na/L; the other data were not quantifiable for hot springs 1 and 2. In Figure 5.41, the sodium results of each hot spring are presented.

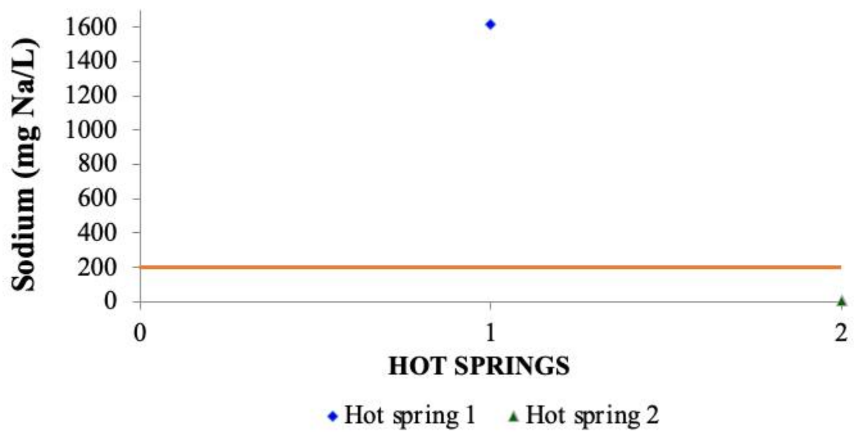


Figure 5.41. Sodium input data results, where it can be seen that hot spring 1 did not comply with Canadian and German drinking water regulations.

- **Settleable Solids, Total Suspended Solids, Total Solids, and Sulphides**

Table 5.20 presents the results of the parameters of settleable solids, total suspended solids, total solids, and sulphides.

Table 5.20. Results of parameters of settleable solids, total suspended solids, total solids, and sulphides in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021 ENTRY	28/07/2021 ENTRY	2/09/2021 ENTRY	3/10/2021 ENTRY	17/11/2021 ENTRY	15/12/2021 ENTRY
Hot spring 2	Settleable Solids	mg SS/L	N.D	N.Q	N.Q	N.Q	N.Q	N.Q
	Total Suspended Solids	mg SST/L	N.D	N.Q	4	2	3	4
	Total Solids	mg /L	81	4976	6588	6366	6436	5729
	Sulphides	mg S^2/L	N.Q	2	N.Q	N.Q	N.Q	N.Q
Hot spring 2	Settleable solids	mg SS/L	N.D	N.Q	N.Q	N.Q	N.Q	N.Q
	Total Suspended Solids	mg TSS/L	N.D	15	20	34	44	7
	Total Solids	mg /L	64	83	70	104	85	56

PARAMETER	UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
		30/06/2021 ENTRY	28/07/2021 ENTRY	2/09/2021 ENTRY	3/10/2021 ENTRY	17/11/2021 ENTRY	15/12/2021 ENTRY
Sulphides	mg S^{2}/L	N.Q	N.Q	N.Q	N.Q	N.Q	N.Q

N.Q = Not quantifiable, N.D = No Data.

Once the student's t-tests of the settleable solids, total suspended solids, total solids, and sulphides parameters of the input data were determined, the results shown in Appendix E were obtained.

Settleable Solids and Total Suspended Solids

The regulations are shown in Table 3.2, drinking water and swimming pool water are not regulated. The results obtained from each of the hot springs were not quantifiable in settleable solids.

The student's t-test, the total suspended solids result of each of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was not rejected. The results obtained from hot spring 1 presented an average value of 3.25 mg SST/L and for hot spring 2 had 24.0 mg SST/L. In Figure 5.42, the total suspended solids result of each hot spring are presented.

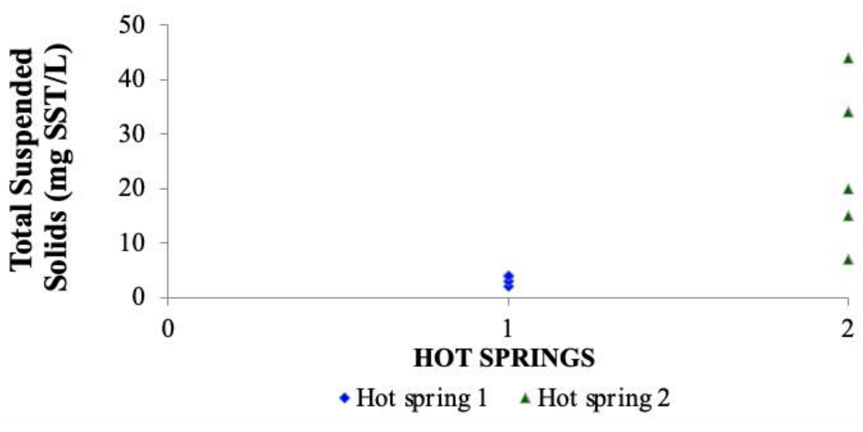


Figure 5.42. Total suspended solids input data results.

Total Solids

The regulations are shown in Table 3.2, drinking water and swimming pool water are not regulated.

The student's t-test, the total solids result of each of the hot springs showed that there was strong statistical difference in the samples, therefore the null hypothesis was rejected. The results obtained from hot spring 1 presented an average value of 5029.33 mg/L and for hot spring 2 had 77.0 mg/L. In Figure 5.43, the total solids result of each hot spring are presented.

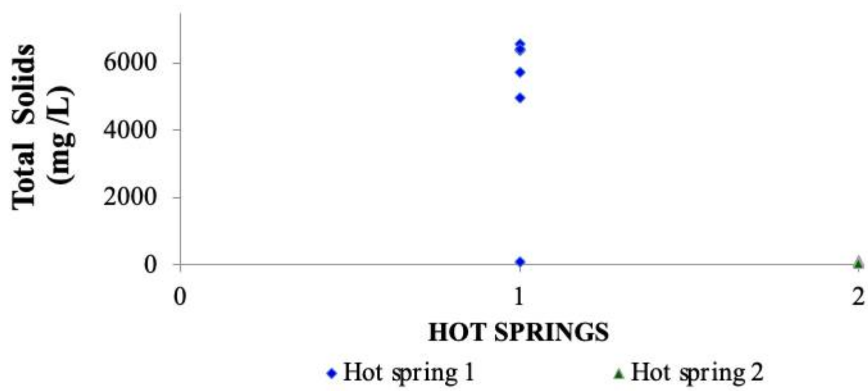


Figure 5.43. Total solids input data results.

Sulphides

The regulations are shown in Table 3.2, Canada establishes a limit value of ≤ 0.05 mg S^2/L for drinking water, and Colombia establishes a value of 250 mg S^2/L. In swimming pool water is not regulated.

Only one result was from hot spring 1, with a value of 2.0 mg S^2/L and the other data were not quantifiable for hot springs 1 and 2.

- **Acidity, Chlorides, Fluorides, and Reactive Phosphorus**

Table 5.21 presents the results of the parameters acidity, chlorides, fluorides, and reactive phosphorus.

Table 5.21. Results of parameters acidity, chlorides, fluorides, and reactive phosphorus in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY 30/06/2021 ENTRY	JULY - AUGUST 28/07/2021 ENTRY	AUGUST - SEPTEMBER 2/09/2021 ENTRY	SEPTEMBER - OCTOBER 3/10/2021 ENTRY	OCTOBER - NOVEMBER 17/11/2021 ENTRY	NOVEMBER - DECEMBER 15/12/2021 ENTRY
Hot spring 2	Acidity	mg $CaCO_3$/L	N.Q	17.19	2	7	N.Q	N.Q
	Chlorides	mg Cl-/L	3460	N.Q	N.D	N.D	N.D	0.37
	Fluorides	mg F-/L	2.78	N.Q	N.D	N.D	0.41	N.D
	Reactive phosphorus	mg PO_4/L	N.Q	N.Q	N.Q	N.D	N.D	N.D
Hot spring 2	Acidity	mg $CaCO_3$/L	12.45	N.Q	5	17	N.Q	N.Q
	Chlorides	mg Cl-/L	41.3	104.8	N.D	0.24	N.D	N.D
	Fluorides	mg F-/L	1.37	0.25	N.D	N.D	0.32	0.37
	Reactive phosphorus	mg PO_4/L	0.24	0.59	0.17	N.D	N.D	N.D

N.Q = Not quantifiable, N.D = No Data.

Once the student's t-tests of the acidity, chlorides, fluorides, and reactive phosphorus parameters of the input data were determined, the results shown in Appendix E were obtained.

Acidity

The regulations are shown in Table 3.2, drinking water and swimming pool water are not regulated.

The student's t-test, the total solids result of each of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was not rejected. The results obtained from hot spring 1 presented an average value of 8.73 mg $CaCO_3$/L and hot spring 2 had 11.48 mg $CaCO_3$/L. In Figure 5.44, the acidity results of each hot spring are presented.

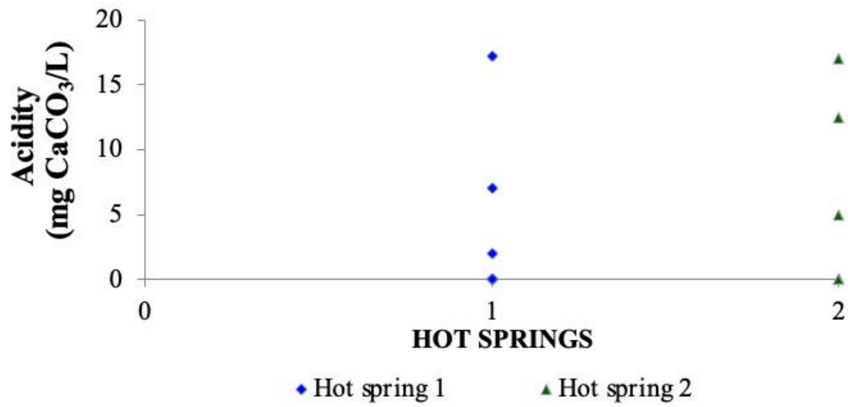


Figure 5.44. Acidity input data results.

Chlorides

The regulations are shown in Table 3.2, Canada and Germany establish a limit value of ≤ 250 mg/L for drinking water regulations. In swimming pool water is not regulated.

The student's t-test, the chlorides result of each of the hot springs showed that there was statistical difference in the samples, therefore the null hypothesis was rejected. The results obtained from hot spring 1 presented an average value of 1730.19 mg/L and hot spring 2 had 48.78 mg/L. In Figure 5.45, the chlorides result of each hot spring are presented.

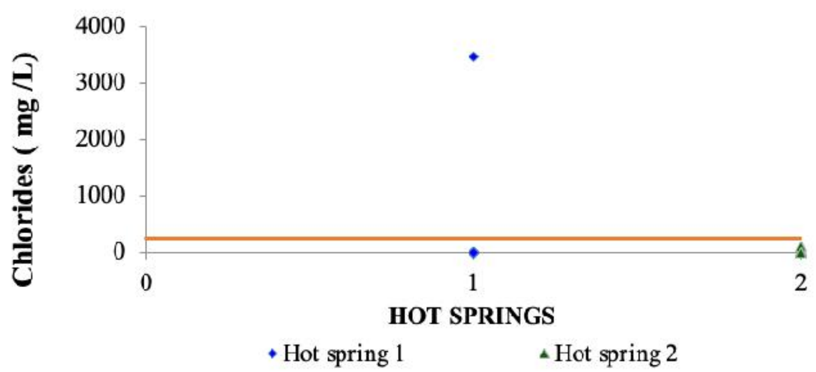


Figure 5.45. Chlorides input data results, where it can be seen that one data from hot spring 1 did not comply with Canadian and German drinking water regulations.

Fluorides

The regulations are shown in Table 3.2, the maximum limit value for drinking water is 1.5 mg F^-/L (Canadian regulation) and 1.0 mg F^-/L (Colombian regulation). In swimming pool water, it is not regulated.

The student's t-test, the fluorides result of each of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was not rejected. The results obtained from hot spring 1 presented an average value of 1.60 mg/L and hot spring 2 had 0.58 mg/L. In Figure 5.46, the fluorides result of each hot spring are presented.

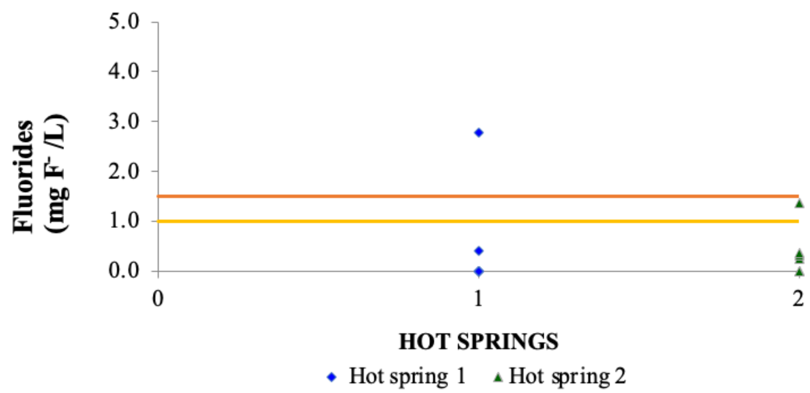


Figure 5.46. Fluorides input data results, where it can be seen that one data from hot spring 1 did not comply with Canadian and Colombian drinking water regulations.

Reactive Phosphorus

The student's t-test, the reactive phosphorus results of each of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was not rejected.

The results obtained from hot spring 1 were not quantifiable and hot spring 2 had 0.58 mg PO_4/L. The regulations are shown in Table 3.2, drinking water and swimming pool water are not regulated.

- **Nitrates, Nitrites, Sulphate, and Total Dissolved Solids**

Table 5.22 presents the results of the parameters nitrates, nitrites, sulphate, and total dissolved solids.

Table 5.22. Results of parameters nitrates, nitrites, sulphate, and total dissolved solids in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	**28/07/2021**	**2/09/2021**	**3/10/2021**	**17/11/2021**	**15/12/2021**
			ENTRY	**ENTRY**	**ENTRY**	**ENTRY**	**ENTRY**	**ENTRY**
Hot spring 1	Nitrates	mg NO_3-N/L	0.1	0.2	0.4	3.7	1.2	2.6
	Nitrites	mg NO_3-N/L	0.02	N.Q	N.Q	N.Q	0.79	0.77
	Sulphate	mg SO_4/L	4	N.Q	12	11	9	N.Q
	Total dissolved solids	mg/L	N.D	N.D	N.D	N.D	N.D	N.D
Hot spring 2	Nitrates	mg NO_3-N/L	N.Q	N.Q	N.Q	N.Q	0.1	1.9
	Nitrites	mg NO_3-N/L	N.Q	N.Q	0.04	0.04	0.43	0.39
	Sulphates	mg SO_4/L	N.Q	N.Q	11	5	6	N.Q
	Total Dissolved Solids	mg/L	N.D	N.D	N.D	N.D	N.D	N.D

N.Q = Not quantifiable, N.D = No Data.

Once the student's t-tests of the nitrates, nitrites, sulphates, and total dissolved solids parameters of the input data were determined, the results shown in Appendix E were obtained.

Nitrates

The regulations are shown in Table 3.2, the maximum limit value for drinking water is 10 mg NO_3-N/L (Canadian and Colombian regulations) and 50 mg NO_3-N/L (WHO). In swimming pool water Germany regulated a limit value of 20 mg NO_3-N/L.

The student's t-test, the fluorides result of each of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was not rejected. The results obtained from hot spring 1 presented an average value of 1.37 mg NO_3-N/L and hot spring 2 had 1.0 mg NO_3-N/L. In Figure 5.47, the nitrates result of each hot spring are presented.

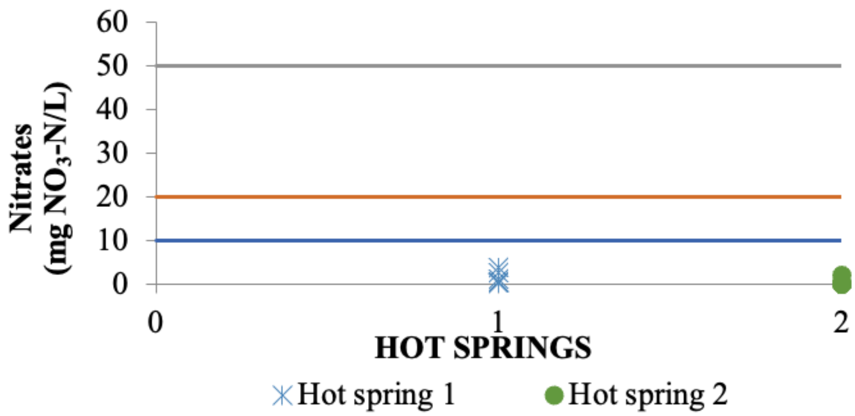


Figure 5.47. Results of the nitrates input data, where it was observed that the data from the hot springs fulfilled the regulations.

Nitrites

The regulations are shown in Table 3.2, the maximum limit value for drinking water is 1.0 mg NO_3-N/L (Canadian regulation), 0.5 mg NO_3-N/L (German regulation), and 0.1 mg NO_3-N/L (WHO). In swimming pool water is not regulated.

The student's t-test, the fluorides result of each of the hot springs show that there was statistical difference in the samples, therefore the null hypothesis was rejected. The results obtained from hot spring 1 presented an average value of 0.53 mg NO_3-N/L and hot spring 2 had 0.23 mg NO_3-N/L. In Figure 5.48, the nitrites result of each hot spring are presented.

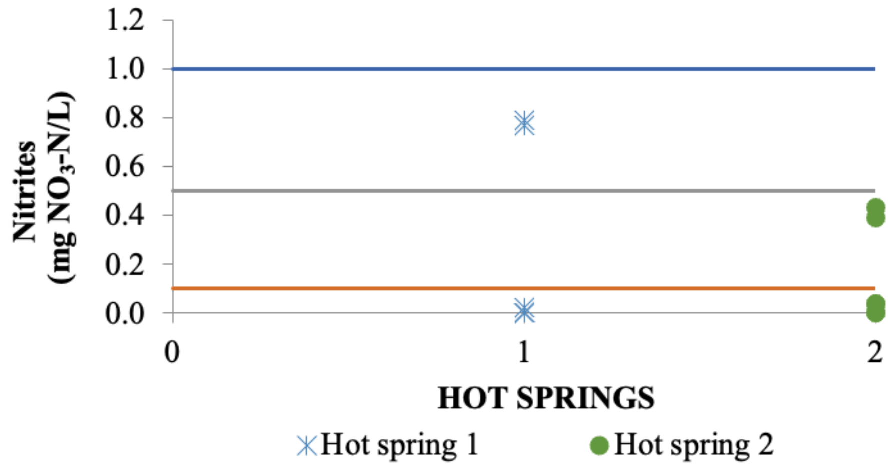


Figure 5.48. Nitrites input data results, where it can be seen that all data from hot springs complied with Canadian drinking water regulation but not the other regulations.

Sulphate

The regulations are shown in Table 3.2, the maximum limit value for drinking water is ≤ 500 mg SO_4/L (Canadian regulation) and 250 mg SO_4/L (German and Colombian regulation). In swimming pool water is not regulated.

The student's t-tests, the sulphate results of each of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was not rejected. The results obtained from hot spring 1 presented an average value of 9.0 mg SO_4/L and hot spring 2 had 7.33 mg SO_4/L. In Figure 5.49, the sulphate results of each hot spring are presented.

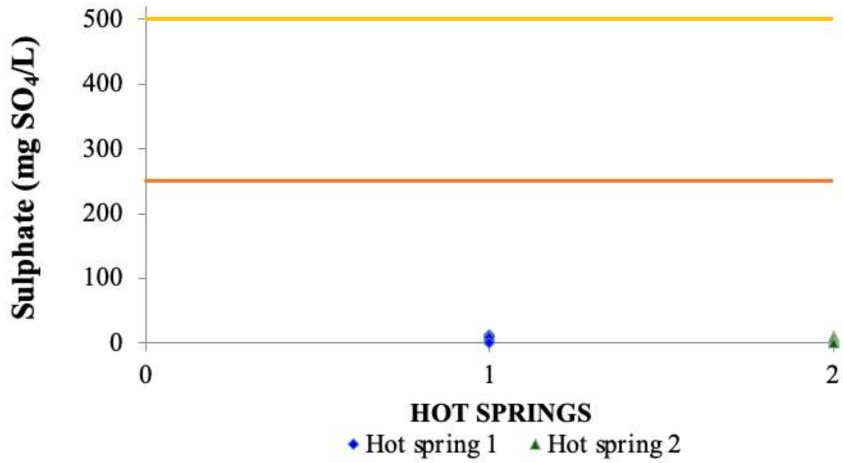


Figure 5.49. Sulphate input data results, where it was observed that the data from the hot springs fulfilled the regulations.

Total Dissolved Solids

The regulations are shown in Table 3.2, the maximum limit value for drinking water is ≤ 500 mg SO_4/L (Canadian regulation). In swimming pool water is not regulated. The data were not measured for hot springs 1 and 2.

5.4.3 Microbiological analysis

Table 5.23 presents the results of the parameters total coliforms, fecal coliforms (*E. coli*), Enterococci, *Legionella*, *Pseudomonas aeruginosa*, molds and yeasts.

Table 5.23. Total Coliforms, Fecal coliforms (*Escherichia coli*), Enterococci, *Legionella*, *Pseudomonas aeruginosa*, molds and yeasts parameters result in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
			ENTRY	ENTRY	ENTRY	ENTRY	ENTRY	ENTRY
Hot spring 1	Total Coliforms	MPN/ 100 mL	691	24196	12590	23820	980	959
	Fecal Coliforms (*E. coli*)	MPN/ 100 mL	<10	<10	< 100	< 100	<100	<10
	Enterococci	MPN/ 100 mL	31	10.8	< 1	< 1	<1	<1
	Legionella	MPN/ mL	< 1	< 1	< 1	< 1	< 1	< 1
	Pseudomonas aeruginosa	MPN/ 100 mL	118.7	160	< 10	< 10	< 1	44.8
	Molds	MPN/ mL	0	0	0	0	0	0
	Yeasts	MPN/ mL	9	2	28	0	88	0
Hot spring 2	Total Coliforms	MPN/ 100 mL	959	31	299	402	226	31
	Fecal Coliforms (*E. coli*)	MPN/ 100 mL	*228*	< 10	233	< 10	<10	< 10
	Enterococci	MPN/ 100 mL	< 1	*1*	< 1	< 1	3.1	< 1
	Legionella	MPN/ mL	< 1	< 1	< 1	< 1	< 1	< 1
	Pseudomonas aeruginosa	MPN/ 100 mL	< 1	< 10	< 1	< 1	< 1	< 1
	Molds	MPN/ mL	0	0	0	60	0	50
	Yeasts	MPN/ mL	*40*	*0*	614	910	109	480

N.Q = Not quantifiable, N.D = No Data.

Once the student's t-tests of total coliforms, fecal coliforms (*E. coli*), Enterococci, *Legionella*, *Pseudomonas aeruginosa*, molds and yeasts parameters of the input data were determined, the results shown in Appendix E were obtained

Total Coliforms

The regulations are shown in Table 3.2, the maximum limit value for total coliform was not detectable for drinking water and swimming pool water. Only Chile in swimming pool regulation is < 20 CFU/ 100 cm^3 or MPN/ 100 mL.

The student's t-test, the total coliform results of each of the hot springs showed that there was statistical difference in the samples, therefore the null hypothesis was rejected. The results obtained from hot spring 1 presented an average value of 10539.3 MPN/100 mL and hot spring 2 had 324.67 MPN/100 mL. In Figure 5.50, the total coliform results of each hot spring are presented.

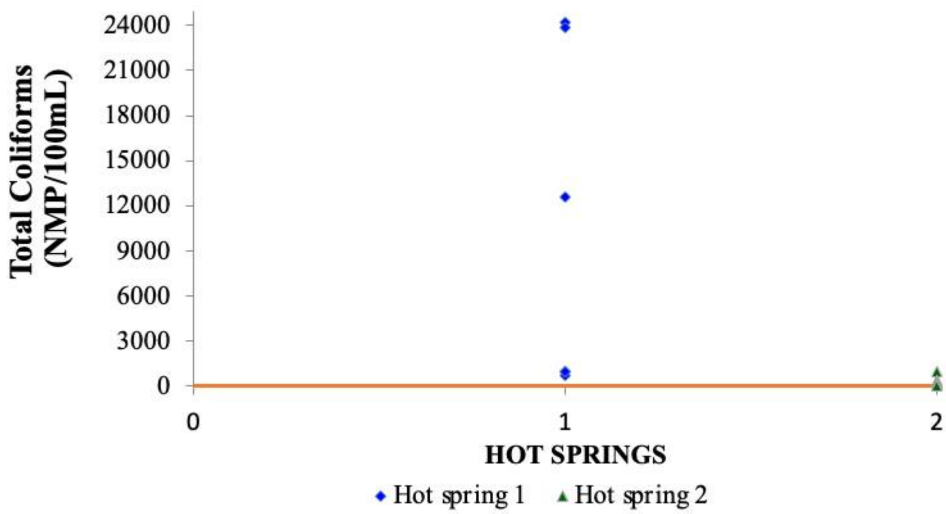


Figure 5.50. Total coliforms input data results, where it was observed that the data from the hot springs did not fulfill the regulations.

Fecal Coliforms *(E. coli)*

The regulations are shown in Table 3.2, the maximum limit value for *E. coli* is not detectable for drinking water and swimming pool water.

The student's t-test, the *E. coli* results of each of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was not rejected. The results obtained from hot spring 1 presented an average value of 53.50 MPN/100 mL and hot spring 2 had 83.50 MPN/100 mL. In Figure 5.51, the *E. coli* results of each hot spring are presented.

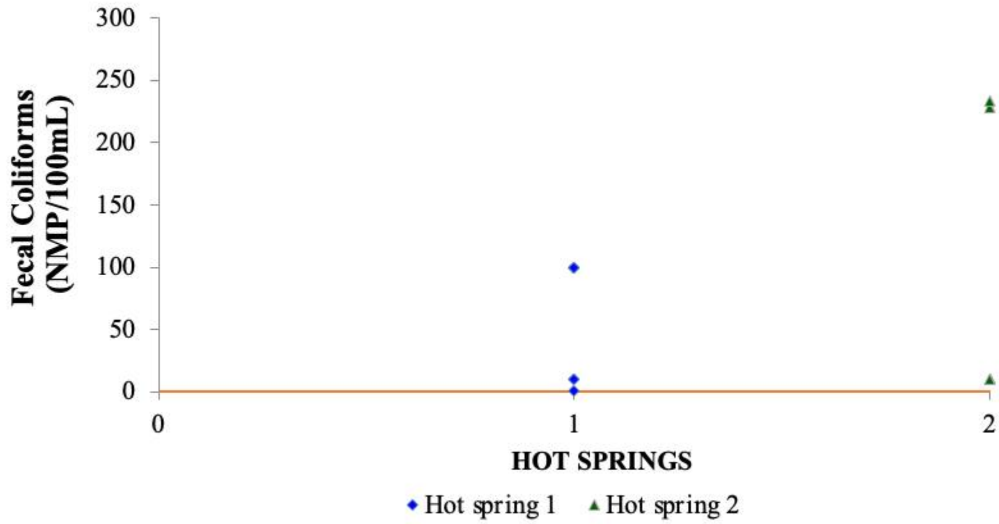


Figure 5.51. *E. coli* input data results, where it was observed that the data from the hot springs did not fulfill the regulations.

Enterococci

The regulations are shown in Table 3.2, the maximum limit value for Enterococci is 0 MPN/100 mL for drinking water. In swimming pool water is not regulated.

The student's t-test, the Enterococci results of each of the hot springs, it was observed that there was statistical difference in the samples, therefore the null hypothesis was rejected. The results obtained from hot spring 1 presented an average value of 7.63 MPN/100 mL and hot spring 2 had 1.33 MPN/100 mL. In Figure 5.52, the Enterococci results of each hot spring are presented.

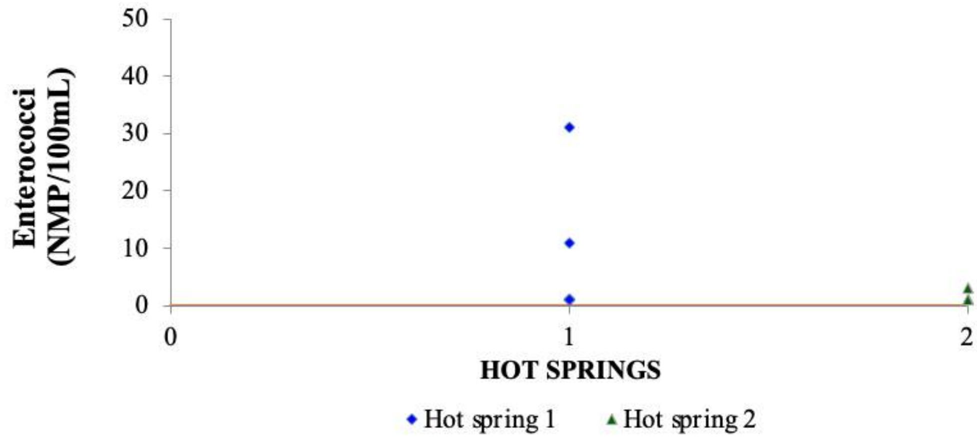


Figure 5.52. Enterococci input data results, where it was observed that the data from the hot springs did not fulfill the regulations.

Legionella pneumophila

The regulations are shown in Table 3.2, the maximum limit value for *L. pneumophila* is < 1 MPN /100 mL for drinking water (WHO guidelines). In swimming pool water is not regulated.

The result obtained from hot springs 1 and 2 were <1 MPN/100 mL which complied with the WHO guidelines.

Pseudomonas aeruginosa

The regulations are shown in Table 3.2, the maximum limit value for *P. aeruginosa* is 0 CFU/ 100 mL or 0 MPN/100 mL for swimming pool. In drinking water is not regulated.

The student's t-test, the *P. aeruginosa* results of each of the hot springs showed that there was statistical difference in the samples, therefore the null hypothesis was rejected. The results obtained from hot spring 1 presented an average value of 57.42 MPN/100 mL and hot spring 2 had 2.50 MPN/100 mL. In Figure 5.53, the *P. aeruginosa* results of each hot spring are presented.

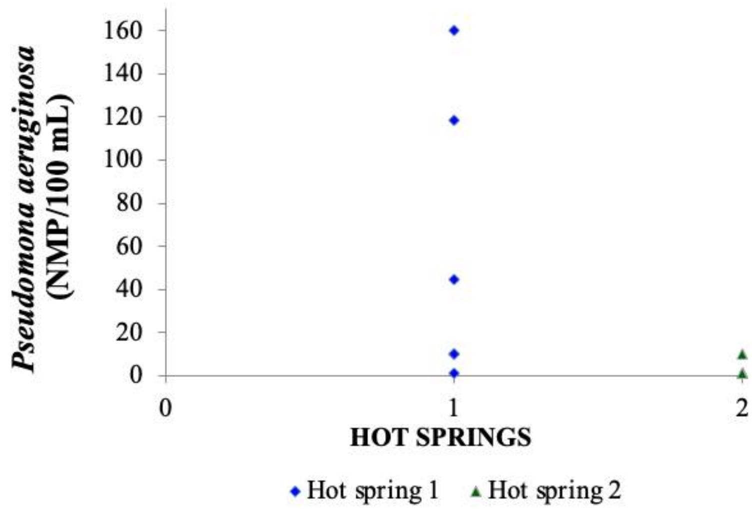


Figure 5.53. *P. aeruginosa* input data results, where it was observed that the data from the hot springs did not fulfill the regulations.

Molds and yeasts

The regulations are shown in Table 3.2, drinking water and swimming pool water are not regulated.

The student's t-test, the molds and yeasts result of each of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was not rejected. The results obtained from hot spring 1 presented an average value of 0 UFC/mL of molds and 21.17 UFC/mL of yeast, and hot spring 2 had 18.33 UFC/mL of molds and 358.83 UFC/mL of yeasts. In Figures 5.54 and 5.55, the molds and yeasts result of each hot spring are presented.

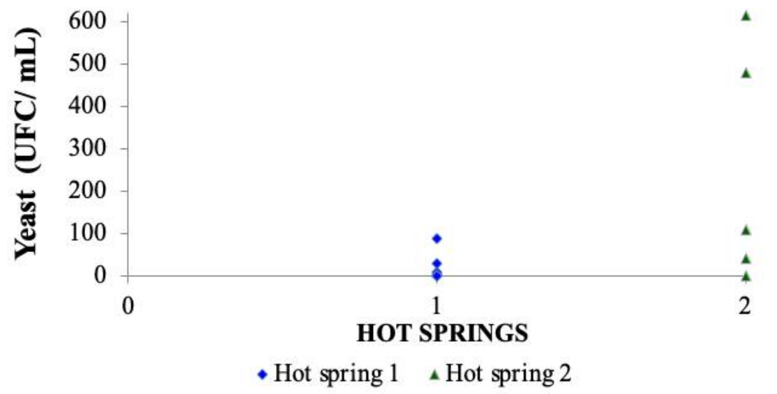


Figure 5.54. Yeasts input data results.

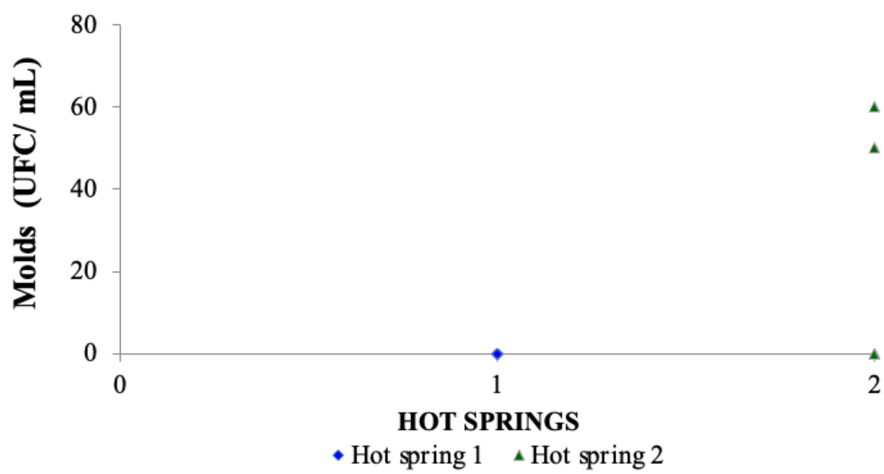


Figure 5.55. Molds input data results.

Next, some correlations between pH and Temperature with microbiological parameters and Fecal Coliforms with Totals will be made and determine if there is any correlation.

Correlation between pH and Temperature with microbiological parameters for input data

- **Hot spring 1**

The correlation for the input data of pH and Temperature with microbiological parameters (total coliforms (TC), fecal coliforms (FC) (*E.coli*), Enterococci, *L. pneumophila*, *P.*

aeruginosa, molds and yeasts) of hot springs 1 are show in Table 5.24 and Figure 5.56 and hot spring 2 in Table 5.25 and Figure 5.57.

Table 5.24. Correlation of pH and Temperature with TC, FC (*E. coli*), Enterococci, *L. pneumophila*, *P. aeruginosa*, molds and yeasts for hot spring 1.

PARAMETER	UNIT	JUNE - JULY 30/06/2021 ENTRY	JULY - AUGUST 28/07/2021 ENTRY	AUGUST - SEPTEMBER 2/09/2021 ENTRY	SEPTEMBER - OCTOBER 3/10/2021 ENTRY	OCTOBER - NOVEMBER 17/11/2021 ENTRY	NOVEMBER - DECEMBER 15/12/2021 ENTRY
Hour	a.m/p.m	8:00 a.m	8:30 a.m	1:45 p.m	8:30 a.m	8:15 a.m	8:00 a.m
pH	pH units	8.1	7.8	7.3	7.5	7.2	7.3
Temperature	°C	31.1	24.3	30.2	34.9	25.2	20.5
Total Coliforms	MPN/ 100 mL	691	24196	12590	23820	980	959
Fecal Coliforms (*E. coli*)	MPN/ 100 mL	<10	<10	<100	<100	<100	<10
Enterococci	MPN/ 100 mL	31	10.8	<1	<1	<1	<1
Legionella	MPN/ mL	<1	<1	<1	<1	<1	<1
Pseudomona aeruginosa	MPN/ 100 mL	118.7	160	10	10	1	44.8
Mold	UFC/ mL	0	0	0	0	0	0
Yeasts	UFC/ mL	9	2	28	0	88	0

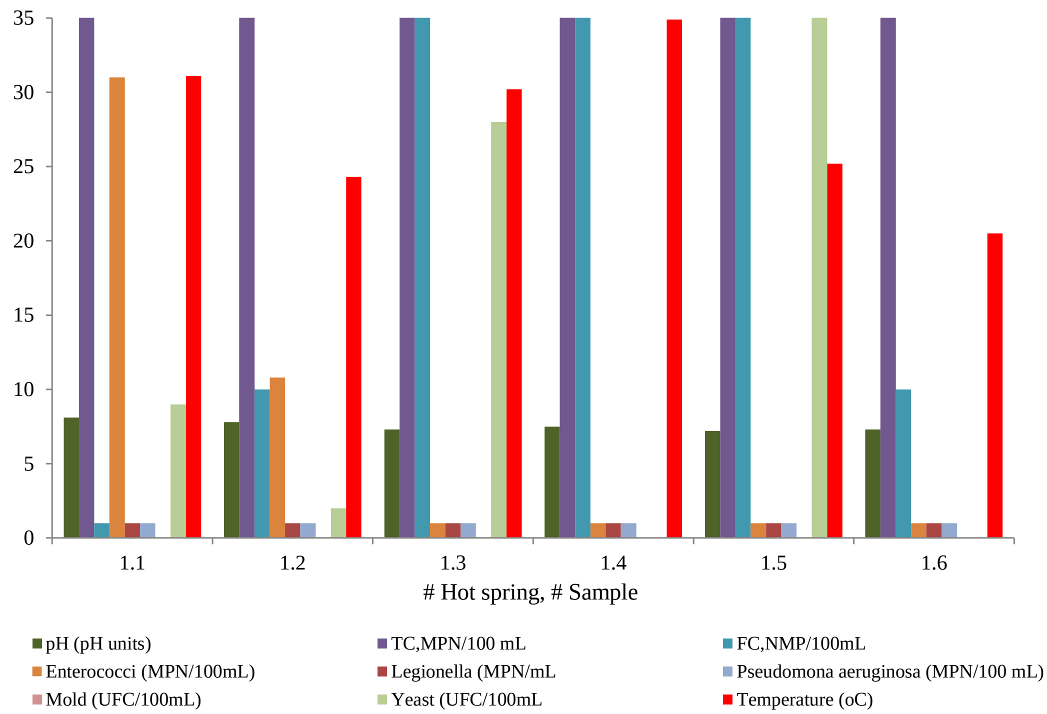


Figure 5.56. Correlations of pH and Temperature with TC, FC (*E. coli*), Enterococci, *L. pneumophila*, *P. aeruginosa*, molds and yeasts for hot spring 1.

- **Hot spring 2**

The correlation for the input data of pH and Temperature with microbiological parameters (total coliforms (TC), fecal coliforms (FC) (*E. coli*), Enterococci, *L. pneumophila*, *P. aeruginosa*, molds and yeasts) of hot springs 2 are show in Table 5.25 and Figure 5.57.

Table 5.25. Correlation of pH and Temperature with TC, FC (*E. coli*), Enterococci, *L. pneumophila*, *P. aeruginosa*, molds and yeasts for hot spring 2.

PARAMETER	UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
		30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
		ENTRY	ENTRY	ENTRY	ENTRY	ENTRY	ENTRY
Hour	a.m/p.m	11:10 a.m	11:30 a.m	10:30 a.m	11:30 a.m	10:20 a.m	10:30 a.m
pH	pH units	7.7	6.8	6.4	6.2	6.7	6.8

PARAMETER	UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
		30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
		ENTRY	**ENTRY**	**ENTRY**	**ENTRY**	**ENTRY**	**ENTRY**
Total Coliforms	MPN/ 100 ML	959	31	299	402	226	31
Fecal Coliforms (*E. coli*)	MPN/ 100 ML	*228*	10	233	10	10	10
Enterococci	MPN/ 100 ML	1	1	1	1	3.1	1
Legionella	MPN/ ML	1	1	1	1	1	1
Pseudomona aeruginosa	MPN/ 100 ML	1	10	1	1	1	1
Fungi	UFC/ ML	0	0	0	60	0	50
Yeasts	UFC/ ML	*40*	*0*	614	910	109	480

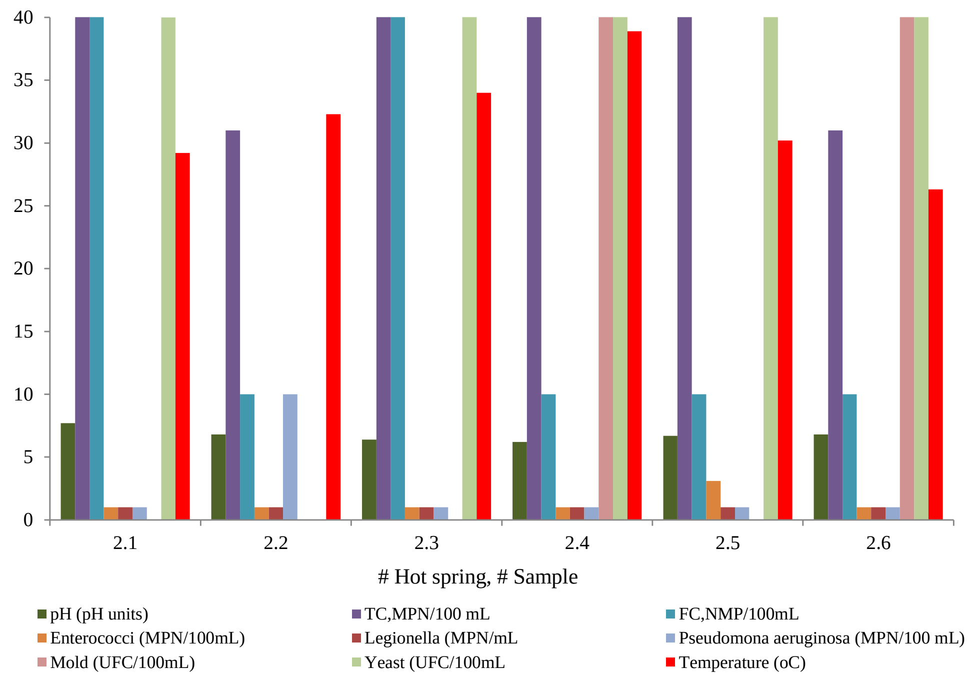


Figure 5.57. Correlations of pH and Temperature with TC, FC (*E. coli*), Enterococci, *L. pneumophila*, *P. aeruginosa*, molds and yeasts for hot spring 2.

Analyzing the results of the correlations of pH and temperature with the microbiological parameters, it was observed that there was a presence of bacteria at temperatures between

20 and 35 °C; suitable environment for mesophilic bacteria that can be found in this type of habitat.

5.4.4 Output Parameter Result

The results of the output parameters of each one of the hot springs are presented in Appendix E, which were analyzed by the laboratory of the Bogota Water and Sewerage Company (in Spanish EAAB).

Result Parameters In situ

Table 5.26 presents the results of the parameters measured in the field of hot springs 1 and 2.

Table 5.26. Results of parameters measured in situ hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
			EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
Hot spring 1	Flow	L/s	N.D	1.82	1.42	1.65	1.04	N.D
	Temperature	°X	N.D	25.8	26.9	31.4	27.4	N.D
	Conductivity	µS/cm	N.D	5887	7882	7990	7987	N.D
	pH	pH units	N.D	7.6	7.8	7.8	7.5	N.D
	Dissolved Oxygen	mg/L – O_2	N.D	3.9	4	4	4.1	N.D
Hot spring 2	Flow	L/s	1.63	3.66	N.D	1.38	3.13	3.54
	Temperature	°X	26.5	29.8	36.3	36.1	32.4	27.4
	Conductivity	µS/cm	91	82	76	108	102	73
	pH	pH units	7.1	6.1	7	6.5	7.1	6.2
	Dissolved Oxygen	mg/L – O_2	3.7	3.8	3.2	3.9	3.3	4.1

N.D = No Data.

Once the student's t-tests of the in-situ parameters of the output data were determined, the results shown in Appendix E were obtained.

Flow

In Figures 5.58 and 5.59, the distribution of the values of each flow of the hot spring is shown, which conform to a normal distribution in probability paper, with an average value of 1.48 L/s for hot spring 1 and an average value of 2.67 L/s for hot spring 2. According to the student's t-test, there was no statistically significant differences between the samples with a confidence level and a probability of 95%, for which the null hypothesis was not rejected (See Appendix E).

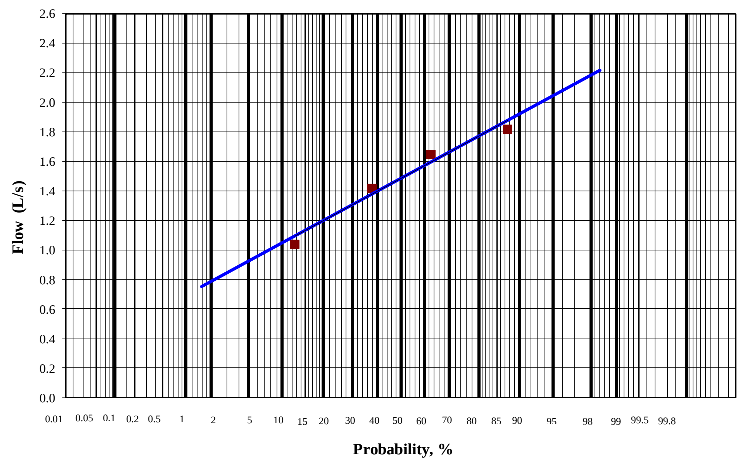


Figure 5.58. Probability of occurrence of flow - hot spring 1.

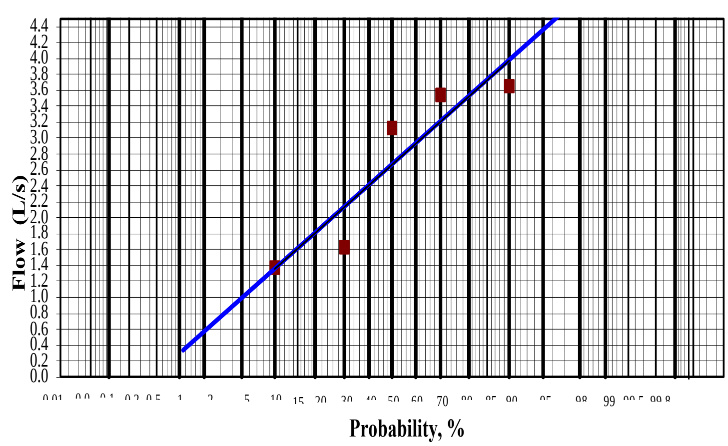


Figure 5.59. Probability of occurrence of flow - hot spring 2.

Temperature

In Figure 5.60, the temperature results of each of the hot springs are shown. It is observed that hot spring 1 corresponds to a type of hypothermal water, with temperatures between 20 and 35 °C and with an average value of 27.88 °C. In the case of hot spring 2, most of the data corresponds to a hypothermal water with a mean value of 31.42 °C.

The statistical analysis of student's t-test was performed between hot springs 1 and 2. The results revealed that no statistically significant differences between the samples with a confidence level of 95%, for which the null hypothesis was not rejected. Comparing the values with the wastewater discharge regulation in Table 3.4, it can be seen that Germany establishes a value of 35 ^{o}C.

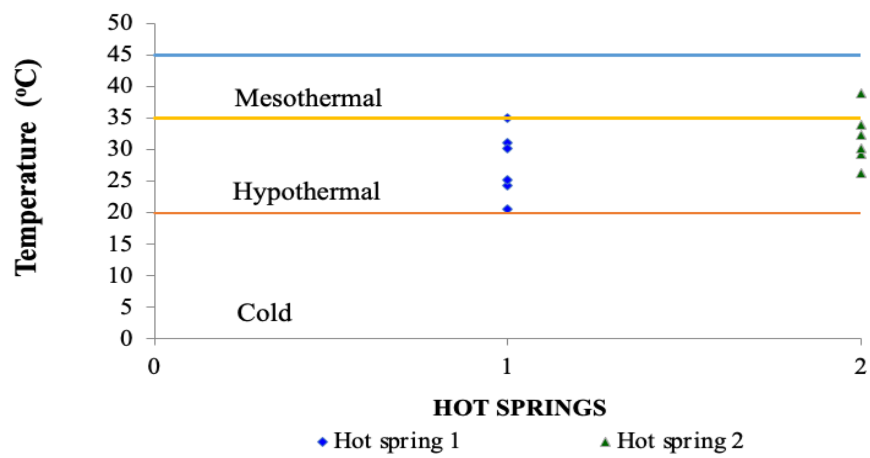


Figure 5.60. Temperature output data results, where it was observed that only one value of the hot spring 2 presented values higher than the regulated temperature of 35 °C.

Conductivity

The student's t-test of the conductivity results of each of the hot springs showed that there was a strong statistical difference in the samples, for which the null hypothesis was rejected. This is due to the properties of each of the hot springs, hot spring 1 is bicarbonate water and hot spring 2 is ferruginous water. In hot spring 1, the average conductivity was 7436.5 µS/cm and in hot spring 2 was 88.67 µS/cm. The revision of wastewater regulations in Table 3.4, a limit value is not established for this parameter. Figure 5.61 shows the results of each hot spring.

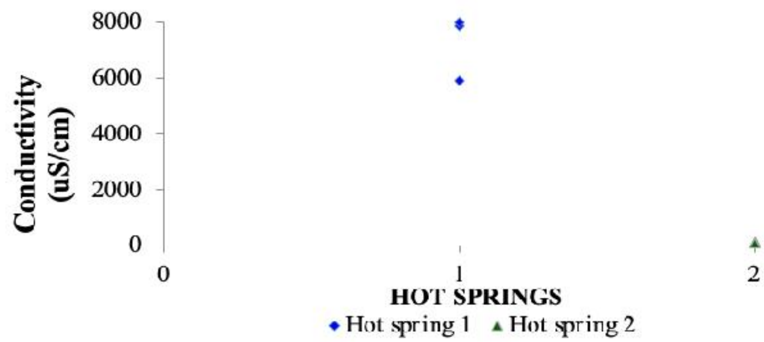


Figure 5.61. Conductivity output data results, where the difference in conductivity in each of the hot spring was observed.

pH

The pH values of the different standards of wastewater discharges are compared in Table 8. It was observed that the regulations show that minimum value of 4.5 and maximum value of 10 are allowed. In the case of the hot springs of the present study, hot spring 1 belongs to class I of discharge on the Bogota River, where the pH must be between 6.5 and 8.5 and hot spring 2 to class II with pH from 5.0 to 9.0. In Figure 5.62, it can be seen that each of the hot springs complies with the standard.

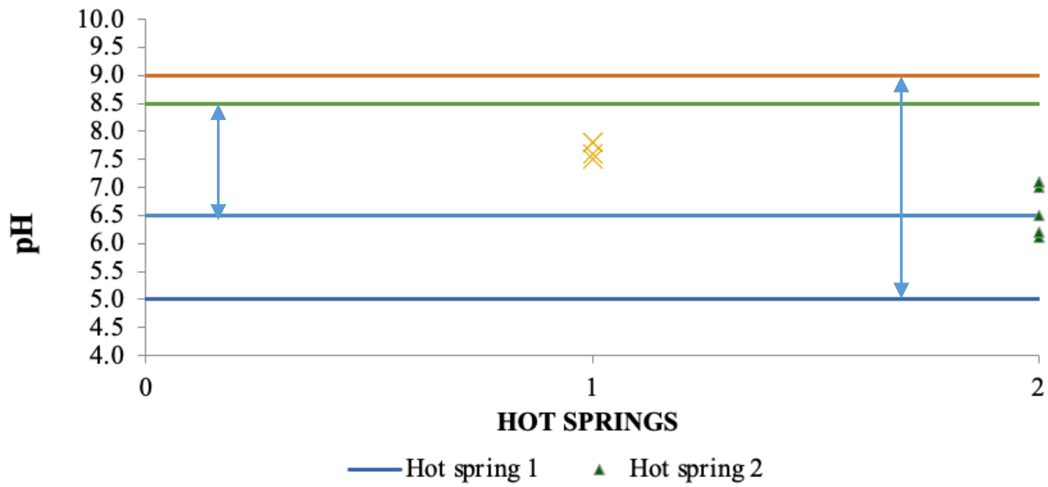


Figure 5.62. pH output data results, where it was observed that the data from hot springs complied with the regulations.

The student's t-test of the pH results of each of the hot springs showed that there was a strong statistical difference in the samples, for which the null hypothesis was rejected. In hot spring 1, the average pH was 7.68 and hot spring 2 was 6.67.

Dissolved Oxygen

The DO data was analyzed according to the student's t-test, there was no statistically significant differences between the samples with a confidence level of 95%, therefore the null hypothesis was not rejected.

The regulations are shown in Table 3.4, only for the case of the Bogota River, they establish a specific DO value of 4.0 mg/L – O_2 (class I) or >4 mg/L – O_2 (class II). In the case of the hot springs of the present study, hot spring 1 belongs to class I and hot spring 2 to class II. In hot spring 1, the average DO was 4.0 mg/L – O_2 and hot spring 2 was 3.67 mg/L – O_2. Figure 5.63 shows the results of each hot spring.

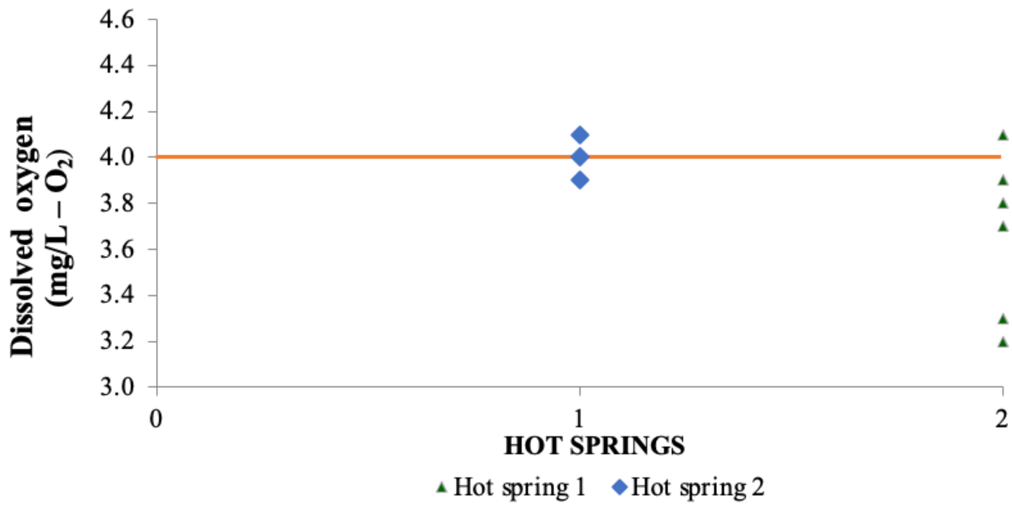


Figure 5.63. Results of the DO output data, where it was observed that the hot springs did not comply with the standard. In the case of hot spring 2, most of its data was below 4 mg/L – O_2.

5.4.5 Results of physical – chemical parameters output

- **Aluminum (Al), Arsenic (As), Boron (B), Copper (Cu), and Chromium (Cr)**

Table 5.27 presents the results of the parameters Aluminum (Al), Arsenic (As), Boron (B), Copper (Cu), and Chromium (Cr).

Table 5.27. Results of parameters Al, As, B, Cu, and Cr in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021 EXIT	28/07/2021 EXIT	2/09/2021 EXIT	3/10/2021 EXIT	17/11/2021 EXIT	15/12/2021 EXIT
Hot spring 2	Aluminum	mg Al/L	N.D	N.Q	0.03	N.Q	0.12	N.D
	Arsenic	mg As/L	N.D	N.D	N.Q	N.D	N.Q	N.D
	Boron	mg B/L	N.D	0.07	0.08	0.06	0.09	N.D
	Copper	mg Cu/L	N.D	N.D	N.D	N.D	N.D	N.D
	Chromium	mg Cr/L	N.D	N.D	N.D	N.D	N.Q	N.D

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
			EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
Hot spring 1	Aluminum	mg Al/L	0.04	0.08	0.04	0.11	N.Q	0.04
	Arsenic	mg As/L	N.Q	N.Q	N.Q	N.D	N.Q	N.Q
	Boron	mg B/L	N.Q	N.Q	N.Q	N.Q	N.Q	0.02
	Copper	mg Cu/L	N.Q	N.D	N.D	N.D	N.Q	N.Q
	Chromium	mg Cr/L	N.D	N.D	N.D	N.D	N.D	N.D

N.Q = Not quantifiable, N.D = No Data.

Once the student's t-tests of the Al, As, B, Cu, and Cr parameters of the output data were determined, the results shown in Appendix E were obtained.

Aluminum

The student's t-test, the aluminum data analyzed did not present significant statistical differences between the samples with a confidence level of 95%, therefore the null hypothesis was not rejected. The wastewater regulations in Table 8, it is a parameter that is regulated with values of 5 mg Al/L for the Bogota River and 50 mg Al/L in Toronto – Canada. In hot spring 1, the average of Al was 0.08 mg Al/L and hot spring 2 was 0.06 mg Al/L. In Figure 5.64, the Aluminum results of each hot spring are presented, which are below values of 5 mg Al/L.

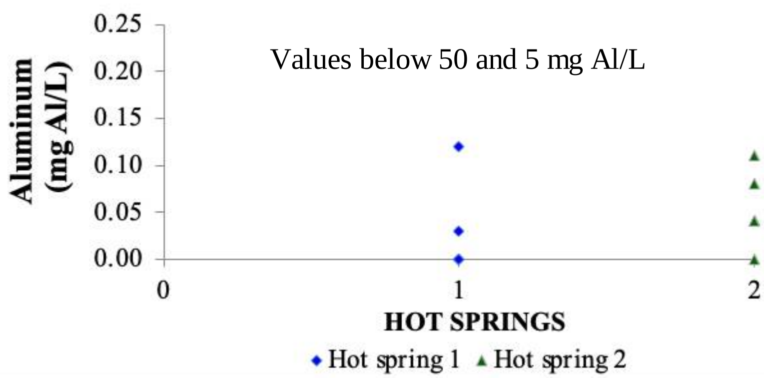


Figure 5.64. Results of the Al output data, where it was observed that the data from the hot springs complied with the limit values of the regulations.

Arsenic

The regulations are shown in Table 8 for wastewater discharge, establish as limit values of 0.05 and 0.1 mg As/L for the Bogota River and 1.0 mg As/L in Canada and Germany. The results obtained from each of the hot springs were not quantifiable, which complied with the limits established by the regulations.

Boron

The student's t-test, the boron data analyzed present significant statistical differences between the samples with a confidence level of 95%, therefore the null hypothesis was rejected. The regulations are shown in Table 8 for wastewater discharge, establish as limit values of 0.3 and 0.4 mg B/L for the Bogota River and 10 mg As/L in Japan. The measured data of hot spring 1 had an average value of 0.08 mg B/L and in hot spring 2, it was only possible to quantify a value of 0.02 mg B/L, and the other measurements were not quantifiable. In Figure 5.65, the Boron results of each hot spring are presented.

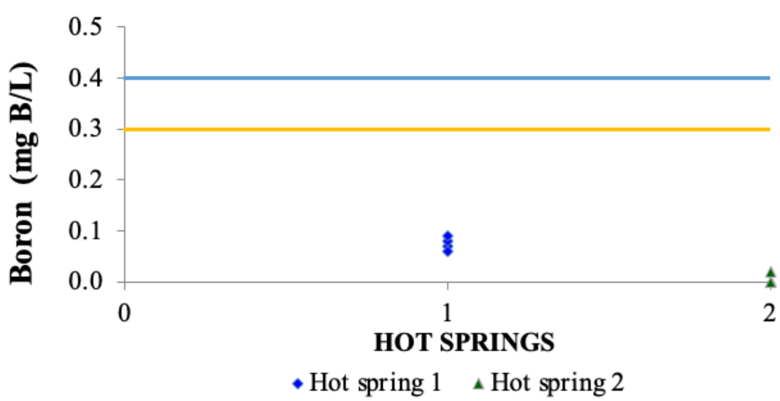


Figure 5.65. Results of the output data Boron, where it was observed that the data from the hot springs complied with the limit values of the regulations.

Copper

The regulations are shown in Table 3.4+ for wastewater discharge establish as limit values 0.1 mg Cu/L (Class I) and 0.2 mg Cu/L (Class II, III, IV and V) for the Bogota River and 1.0, 2.0, and 3.0 mg Cu/L, at the other regulations. In hot spring 1 no data was presented and hot spring 2 those that were determined were not quantifiable, which complied with the established limits of the standards.

Chromium

The regulations are shown in Table 3.4 for wastewater discharge, establish as limit values of 0.05 mg Cr/L (Class I, II and III) and 0.1 mg Cr/L (Class IV and V) for the Bogota River and 0.5, 1.0, and 2.0 mg Cr/L, at the other regulations. In hot spring 1 the data that was determined were not quantifiable, which complied with the established limits of the standards. In hot spring 2 no data was presented.

- **Iron (Fe), Magnesium (As), Manganese(B), Mercury (Cu), and Nickel (Cr)**

Table 5.28 presents the results of the parameters Fe, Mg, Mn, Hg, and Ni.

Table 5.28. Fe, Mg, Mn, Hg, and Ni parameter results in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
			EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
Hot spring 1	Iron	mg Fe/L	N.D	0.03	0.06	N.Q	0.05	N.D
	Magnesium	mg Mg/L	N.D	N.D	N.D	N.D	N.D	N.D
	Manganese	mg Mn/L	N.D	0.02	0.02	0.01	0.02	N.D
	Mercury	mg Hg/L	N.D	N.Q	N.Q	N.D	N.D	N.D
	Nickel	mg Ni/L	N.D	N.Q	N.Q	N.Q	N.Q	N.D
Hot spring 2	Iron	mg Fe/L	3.77	7.85	0.06	9.4	0.03	9.42
	Magnesium	mg Mg/L	N.D	N.D	N.D	N.D	N.D	3.5
	Manganese	mg Mn/L	0.23	0.25	7.14	0.21	N.Q	0.03
	Mercury	mg Hg/L	N.Q	N.Q	0.26	N.D	N.D	N.D

PARAMETER	UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
		30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
		EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
Nickel	mg Ni/L	N.Q	N.Q	N.Q	N.Q	N.Q	N.D

N.Q = Not quantifiable, N.D = No Data.

Once the t-student's test of the Fe, Mg, Mn, Hg, and Ni parameters of the output data were determined, the results shown in Appendix E were obtained.

Iron

The regulations are shown in Table 8 for wastewater discharge, establish as limit values 0.1 mg Fe/L (Class I) and 5.0 mg Fe/L (Class IV and V) for the Bogota River and 10 mg Cu/L, Japanese regulations. In this case, hot spring 1 corresponds to class I and hot spring 2 corresponds to class II. The student's t-test, the iron data analyzed did not present significant statistical differences between the samples with a confidence level of 95%, therefore the null hypothesis was not rejected. In hot spring 1, the average Fe was 0.05 mg Fe/L and in hot spring 2 was 5.09 mg Fe/L. Figure 5.66 presents the iron results for each hot spring.

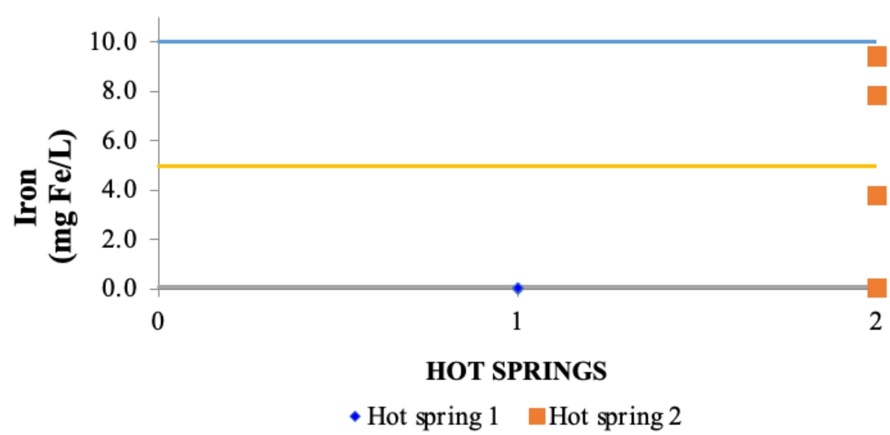


Figure 5.66. Results of the output data iron, where it was observed that the data of hot spring 1, fulfilled the Bogota River regulation and hot spring 2 fulfilled the Japan regulations.

Magnesium

The standards are shown in Table 3.4 for wastewater discharge is not regulated. Only one data of the hot spring 2 were measured. Hot spring 2 with a data of 3.5 mg Mg/L.

Manganese

The regulations are shown in Table 3.4 for wastewater discharge establish as limit values 0.1 mg Mn/L (Class I) and 0.2 mg Mn/L (Class IV and V) for the Bogota River, 5.0 mg Mn/L (Canadian regulation) and 10 mg Mn/L (Japanese regulation). In this case, hot spring 1 corresponds to class I and hot spring 2 corresponds to class II.

The student's t-test, the manganese results of each of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was not rejected. The results obtained from hot spring 1 presented an average value of 0.02 mg Mn/L and hot spring 2 had 1.57 mg Mn/ L. In Figure 5.67, the manganese results of each hot spring are presented.

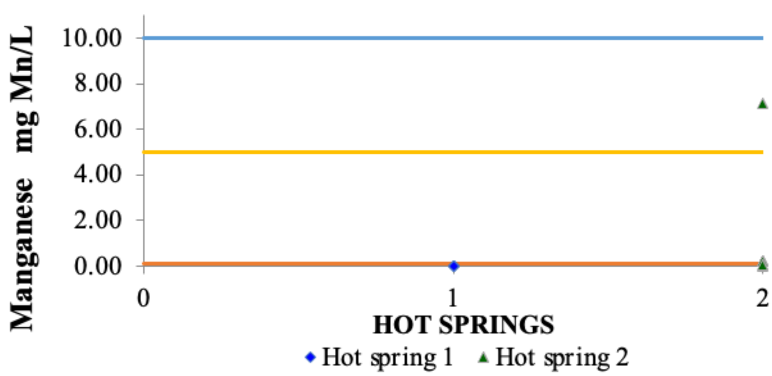


Figure 5.67. Results of the output data of manganese, where it was observed that the data from the hot spring 1 fulfilled with Bogota River regulation. Hot spring 2 fulfilled the regulation of Japan but only one value exceeds Canadian standard and Bogota River regulations.

Mercury

The regulations are shown in Table 3.4 for wastewater discharge establish as limit values of 0.002 mg Hg/L (Class I and III) and 0.01 mg Hg/L (Class IV and V) for the Bogota River, the other regulations vary in a value of 0.005 to 0.02 mg Hg/L. The results obtained from hot spring 1 were not quantifiable. Hot spring 2 only had one data with value of 0.26 mg Hg/L, which complied with the provisions of the limit of the standards.

Nickel

The regulations are shown in Table 3.4 for wastewater discharge establish as limit values of 0.01 mg Ni/L (Class I) and 0.2 mg Ni/L (Class IV and V) for the Bogota River, the other regulations vary in a value of 0.5 mg Ni/L (Colombian and German regulations) and 2 mg Ni/L (Canadian regulation). The results obtained from hot springs were not quantifiable, which complied with the provisions of the limit of the standards.

- **Lead (Pb), Selenium (Se), Zinc (Zn), and Strontium (Sr)**

Table 5.29 presents the results of the parameters Pb, Se, Zn, and Sr.

Table 5.29. Pb, Se, Zn, and Sr parameter results in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
			EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
Hot spring 1	Lead	mg Pb/L	N.D	N.Q	N.Q	N.Q	N.Q	N.D
	Selenium	mg Se/L	N.D	N.Q	N.Q	N.Q	N.Q	N.D
	Zinc	mg Zn/L	N.D	N.Q	N.Q	N.Q	N.Q	N.D
	Strontium	mg Sr/L	N.D	0.65	0.66	0.6	0.91	N.D
Hot spri	Lead	mg Pb/L	N.Q	N.Q	N.Q	N.Q	N.Q	N.Q
	Selenium	mg Se/L	N.Q	N.Q	N.Q	N.Q	N.Q	N.D

	Zinc	mg Zn/L	0.03	0.03	N.Q	0.01	N.Q	0.05
	Strontium	mg Sr/L	N.Q	N.Q	N.Q	N.Q	0.04	N.Q

N.Q = Not quantifiable, N.D = No Data.

Once the student's t-tests of Lead (Pb), Selenium (Se), Zinc (Zn), and Strontium (Sr) parameters of the output data were determined, the results shown in Appendix E were obtained.

Lead

The regulations are shown in Table 3.4 for wastewater discharge establish as limit values of 0.01 mg Pb/L (Class I), 0.05 mg Pb/L (Class II) and 0.1 mg Pb/L (Class IV and V) for the Bogota River, the other regulations vary in a value of 0.5 mg Pb/L (Colombian and German regulations) and 1.0 and 0.1 mg Pb/L (Canadian and Japanese regulation). The results obtained from hot springs were not quantifiable, complied with the provisions of the limit of the standards.

Selenium

The regulations are shown in Table 3.4 for wastewater discharge establish as limit values of 0.01 mg Se/L (Class I and III), 0.05 mg Se/L (Class II), and 0.02 mg Se/L (Class IV and V) for the Bogota River, the other regulations vary in a value of 1.0 mg Se/L (German and Canadian regulations) and 0.1 mg Se/L (Japanese regulation). The results obtained from hot springs were not quantifiable, complied with the provisions of the limit of the standards.

Zinc

The regulations are shown in Table 3.4 for wastewater discharge establish as limit values of 0.01 mg Zn/L (Class I) and 2.0 mg Zn/L (Class III, IV and V) for the Bogota River, the other regulations vary in a value of 2.0 mg Zn/L (Canadian regulation) and 3.0 mg Zn/L (German and Colombian regulations). The results obtained from hot spring 1 were not quantifiable, complied with the Bogota River standards. In hot spring 2, the average Zn was 0.03 mg Zn/L complied with the provisions of the limit of the standards.

Strontium

The student's t-test, the strontium results of each of the hot springs showed that there was a strong statistical difference in the samples, therefore the null hypothesis was rejected. The results obtained from hot spring 1 presented an average value of 0.71 mg Sr/L and hot spring 2 had 0.04 mg Sr/ L. The standards are shown in Table 3.4 for wastewater discharge are not regulated. In Figure 5.68, the strontium results of each hot spring are presented.

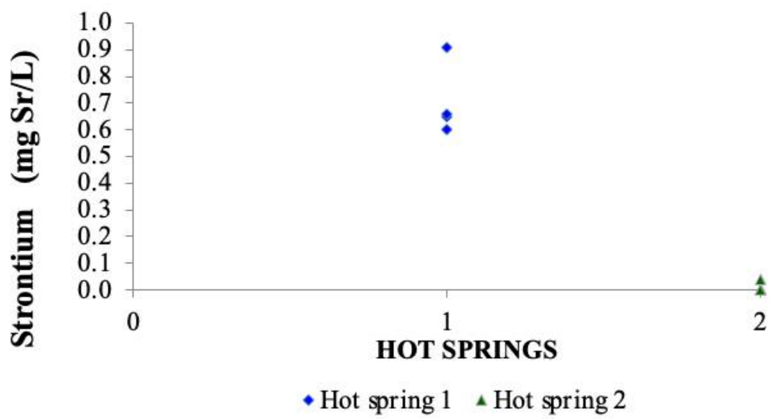


Figure 5.68. Results of the output data strontium.

- **Apparent color, Turbidity, Oils and Fats, Alkalinity, and Calcium (Ca)**

Table 5.30 presents the results of the parameters apparent color, turbidity, oils and fats, alkalinity, and calcium (Ca).

Table 5.30. Apparent color, Turbidity, Oils and fats, Alkalinity, and Calcium (Ca) parameters results in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
			EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
Hot spring 1	Apparent color	TCU	N.D	5	1	N.D	2	N.D
	Turbidity	NTU	N.D	1.6	N.D	0.4	0.95	N.D
	Oils and fats	mg/L	N.D	N.Q	N.Q	N.Q	N.Q	N.D

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
			EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
	Alkalinity	mg $CaCO_3$/L	N.D	257	227	24	225	N.D
	Calcium	mg Ca/L	N.D	39.64	47	37.29	46.87	N.D
Hot spring 2	Apparent Color	UPC	5	27	15	11	33	8
	Turbidity	NTU	3.1	50	40	65	55	37
	Oils and fats	mg/L	N.D	N.Q	N.Q	N.Q	N.Q	N.Q
	Alkalinity	mg $CaCO_3$/L	33	22	23	21	22	25
	Calcium	mg Ca/L	2.95	2.97	N.D	2.63	2.87	3.75

N.Q = Not quantifiable, N.D = No Data.

Once the student's t –tests of apparent color, turbidity, oils and fats, alkalinity, and calcium (Ca) parameters of the output data were determined, the results shown in Appendix E were obtained.

Apparent color

The t-student's test, the apparent color results of each of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was not rejected. The results obtained from hot spring 1 presented an average value of 2.67 TCU and hot spring 2 had 16.5 TCU. The regulations are shown in Table 3.4 for wastewater discharge only the Colombian regulation establish that it should be analysis and report. In Figure 5.69, the apparent color results of each hot spring are presented.

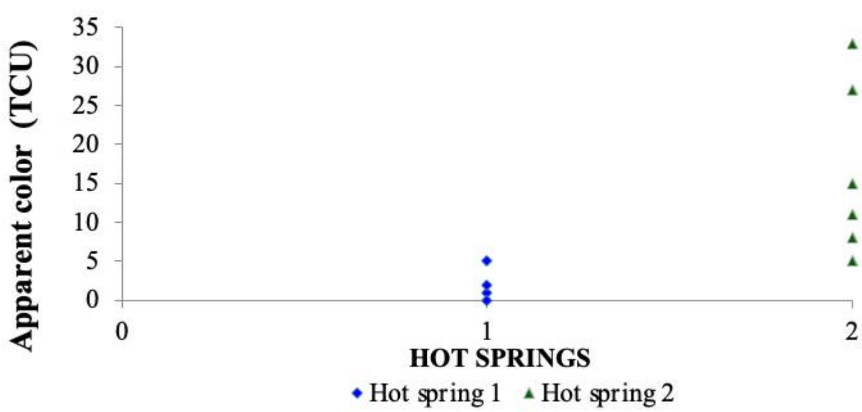


Figure 5.69. Results of the apparent color output data.

Turbidity

The standards are shown in Table 3.4 for wastewater discharge were not regulated. The t-student's t-test, the turbidity results of each of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was not rejected.

The results obtained from hot spring 1 presented an average value of 0.98 NTU and hot spring 2 had 41.68 NTU. In Figure 5.70, the turbidity results of each hot spring are presented.

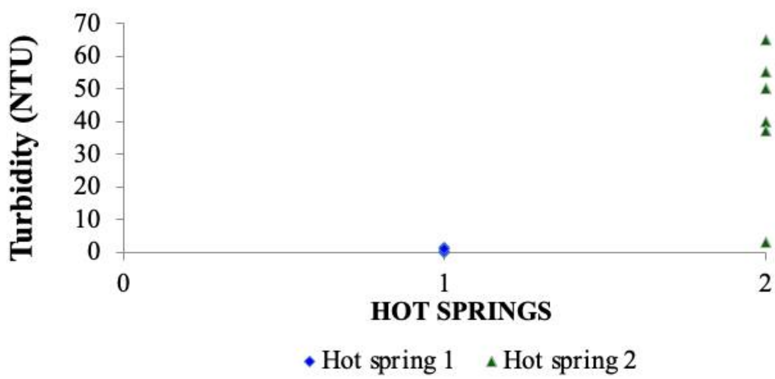


Figure 5.70. Results of the turbidity output data, where it can be seen that the data from hot spring 2 is higher than that of hot spring 1because it is a ferruginous water.

Oils and fats

The regulations are shown in Table 3.4 for wastewater discharge establish as limit values of 0.01 mg /L (Class I) and absent (Class V) for the Bogota River, while the other regulations vary in a value of 10 to 250 mg /L.

The results obtained from each of the hot springs were not quantifiable, which complied with the regulations.

Alkalinity

The t-student's t-test, the alkalinity results of each one of the hot springs showed that there was a strong statistical difference in the samples, therefore the null hypothesis was rejected.

The regulations are shown in Table 3.4 for wastewater discharge, only the Colombian regulation establish that it should be analysis and report. The results obtained from hot spring 1 presented an average value of 183.25 mg $CaCO_3$/L and hot spring 2 had 24.33 mg $CaCO_3$/L. In Figure 5.71, the alkalinity results of each hot spring are presented.

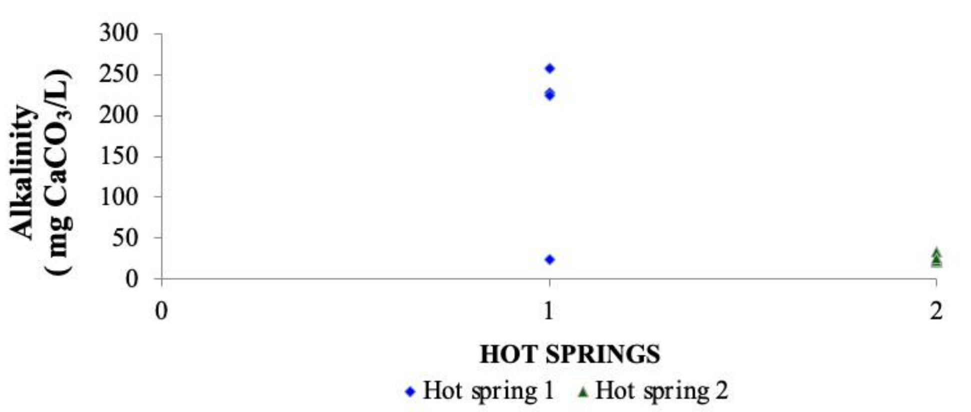


Figure 5.71. Results of the output data alkalinity

Calcium

The t-student's t-test, the calcium results of each one of the hot springs showed that there was a strong statistical difference in the samples, therefore the null hypothesis was rejected.

The standards are shown in Table 3.4 for wastewater discharge were not regulated. The results obtained from hot spring 1 presented an average value of 42.70 mg Ca^{2+}/L and hot spring 2 had 3.03 mg Ca $^{2+}$/L. In Figure 5.72, the calcium results of each hot spring are presented.

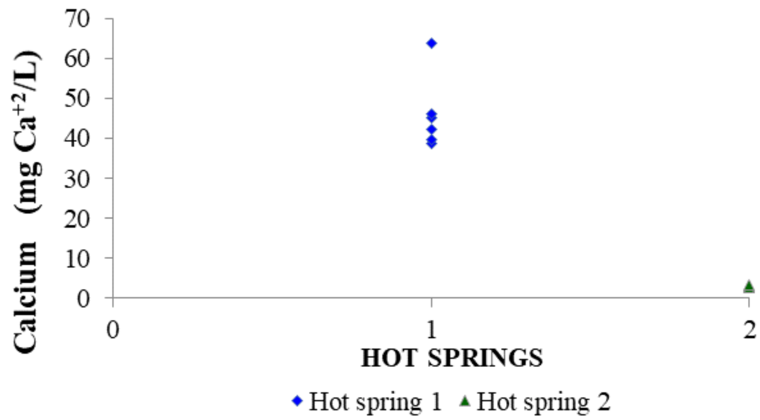


Figure 5.72. Results of the calcium output data.

- **Total Inorganic Carbon (TIC), Total Organic Carbon (TOC), Biological Oxygen Demand (BOD), and Chemical Oxygen Demand (COD)**

Table 5.31 presents the results of the parameters TIC, TOC, BDO, and COD.

Table 5.31. Results of parameters TIC, TOC, BDO, and COD in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
			EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
Hot spring 1	Total Inorganic Carbon (TIC)	mg/L	N.D	56.0	55	58.3	57.8	N.D
	Total Organic Carbon (TOC)	mg/L	N.D	N.Q	N.Q	5	6.2	N.D
	Biochemical Oxygen Demand (BOD)	mg O2/L	N.D	N.Q	N.Q	N.Q	3	N.D
	Chemical Oxygen Demand (COD)	mg O2/L	N.D	84	498	350	195	N.D
Hot spring 2	Total Inorganic Carbon (TIC)	mg/L	8.4	47.2	5.7	6	12	6.8
	Total Organic Carbon (TOC)	mg/L	N.Q	N.Q	5.6	2.2	4.8	N.Q
	Biochemical Oxygen Demand (BOD)	mg O2/L	9	N.Q	N.Q	2	N,C	11
	Chemical Oxygen Demand (COD)	mg O2/L	31	N.Q	N.Q	N.Q	19	N.D

N.Q = Not quantifiable, N.D = No Data.

Once the student's t-test of the TIC, TOC, and COD parameters of the output data were determined, the results shown in Appendix E were obtained.

Total Inorganic Carbon (TIC)

The student's t-test, the TIC results of each one of the hot springs showed that there was a strong statistical difference in the samples, therefore the null hypothesis was rejected.

The standards are shown in Table 3.4 for wastewater discharge are not regulated. The results obtained from hot spring 1 presented an average value of 56.78 mg /L and hot spring 2 had 14.35 mg /L. In Figure 5.73, the TIC results of each hot spring are presented.

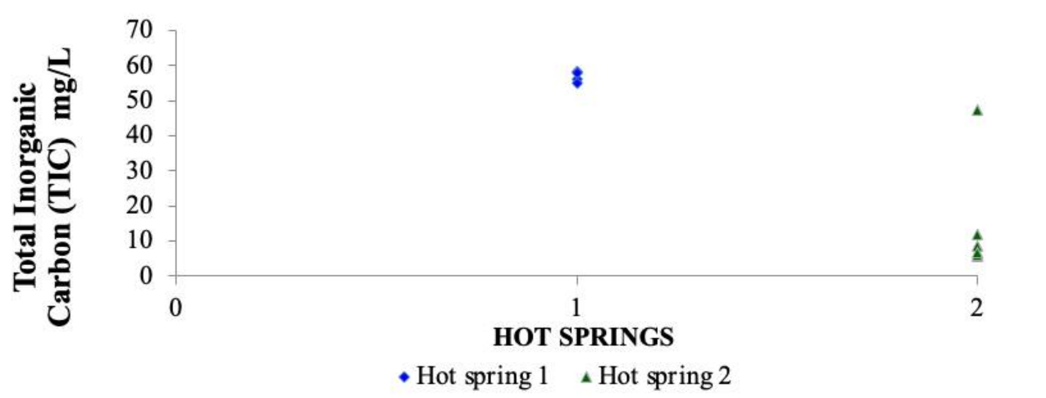


Figure 5.73. Results of the TIC output data.

Total Organic Carbon (TOC)

The student's t-test, the TOC results of each one of the hot springs showed that there was a strong statistical difference in the samples, therefore the null hypothesis was rejected.

The standards are shown in Table 3.4 for wastewater discharge were not regulated. The results obtained from hot spring 1 presented an average value of 5.60 mg/L and hot spring 2 had 4.20 mg/L. In Figure 5.74, the TOC results of each hot spring are presented.

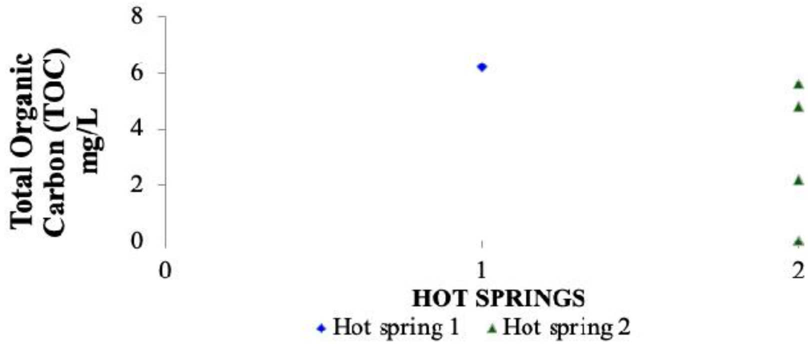


Figure 5.74. Results of the TOC output data.

Biochemical Oxygen Demand (BOD)

The t-student's t-test, the BOD results of each one of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was not rejected. The regulations are shown in Table 3.4 for wastewater discharge, establish as limit values of 7 mg O_2/L (Class I and II), 20 mg O_2/L (Class III), 50 mg O_2/L (Class IV) and 70 mg O_2/L (Class V) for the Bogota River, while the other regulations vary in a value of 70 (Colombian regulation) to 300 mg O_2/L (Canadian regulation). The results obtained from hot spring 1 was not quantifiable and hot spring 2 presented an average value of 5.5 mg /L. In Figure 5.75, the BOD results of each hot spring are presented.

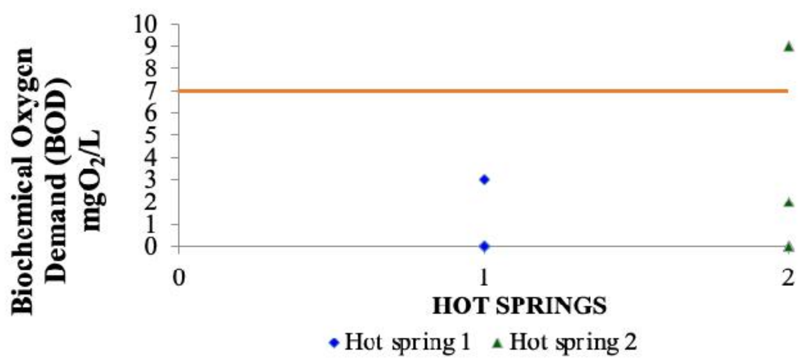


Figure 5.75. Results of the BOD output data, showed that hot spring 2 complied with the regulations and hot spring 2 sometimes exceeds the Bogota River regulation, which was the one with the highest restrictive value.

Chemical Oxygen Demand (COD)

The student's t-test, the COD results of each one of the hot springs showed that there was a strong statistical difference in the samples, therefore the null hypothesis was rejected.

The regulations are shown in Table 3.4 for wastewater discharge, 150 mg O_2/L (Colombian regulation) the other regulations vary in a value of 500 to 2000 mg O_2/L (German regulation) to 160 mg O_2/L (Japanese regulation). The results obtained from hot spring 1 presented an average value of 281.75 mg /L and hot spring 2 had 25.0 mg /L. In Figure 5.76, the COD results of each hot spring are presented.

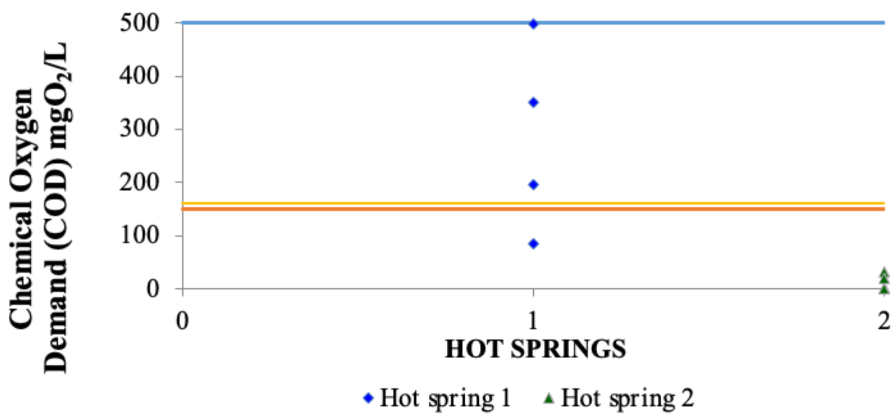


Figure 5.76. Results of the COD input data. It was observed that hot spring 2 was below the limit established by the regulations, but for hot spring 1, its values were above 150 mg /L. Only one value was found below 160 mg /L.

- **Calcium Hardness, Total Hardness, Soluble Phosphorus, and Total Phosphorus**

Table 5.32 presents the results of the parameters calcium hardness, total hardness, soluble phosphorus, and total phosphorus.

Table 5.32. Results of parameters calcium hardness, total hardness, soluble phosphorus, and total phosphorus in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
			EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
Hot spring 1	Calcium Hardness	mg $CaCO_3$/L	N.D	99	117	93	117	N.D
	Total Hardness	mg $CaCO_3$/L	N.D	129	152	122	148	N.D
	Soluble Phosphorus	mg P/L	N.D	N.D	N.D	N.D	N.Q	N.D
	Total Phosphorus	mg P/L	N.D	N.Q	N.Q	N.Q	N.Q	N.D
Hot spring 2	Calcium Hardness	mg $CaCO_3$/L	7	7	8	7	7	9
	Total Hardness	mg $CaCO_3$/L	18	18	103	16	19	24
	Soluble Phosphorus	mg P/L	N.D	N.D	N.D	N.D	0.15	0.06
	Total Phosphorus	mg P/L	3.06	0.84	0.51	1.14	3.24	N.D

N.Q = Not quantifiable, N.D = No Data.

Once the student's t-tests of the TIC, TOC, BDO, and COD parameters of the output data were determined, the results shown in Appendix E were obtained.

Calcium Hardness

The student's t-test, the calcium hardness results of each one of the hot springs showed that there was a strong statistical difference in the samples, therefore the null hypothesis was rejected.

The regulations are shown in Table 3.4 for wastewater discharge, only Colombian regulations were established, and should be analysis and report. The results obtained from hot spring 1 presented an average value of 106.50 mg $CaCO_3$/L and for hot spring 2 had 7.5 mg $CaCO_3$/L. In Figure 5.77, the calcium hardness results of each hot spring are presented.

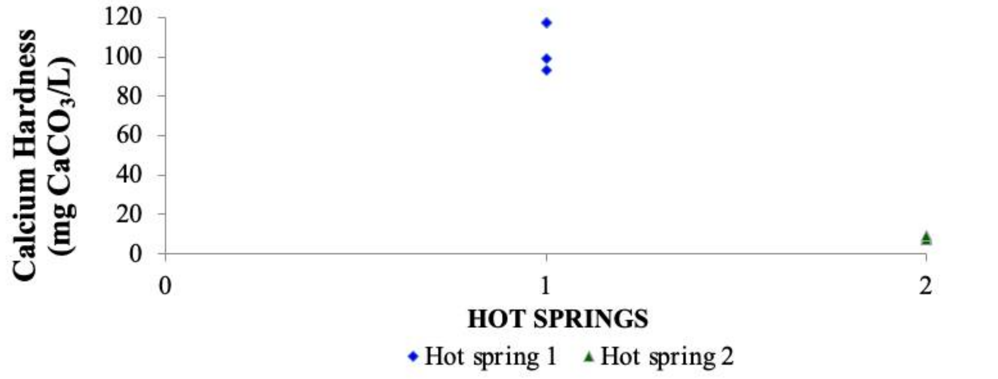


Figure 5.77. Results of the calcium hardness output data.

Total Hardness

The regulations are shown in Table 3.4 for wastewater discharge only Colombian regulations establish what should be analysis and report.

The student's t-test, the total hardness results of each of the hot springs showed that there was a strong statistical difference in the samples, therefore the null hypothesis was rejected. The results obtained from hot spring 1 presented an average value of 137.75 mg $CaCO_3$/L and hot spring 2 had 33.00 mg $CaCO_3$/L. In Figure 5.78, the total hardness results of each hot spring are presented.

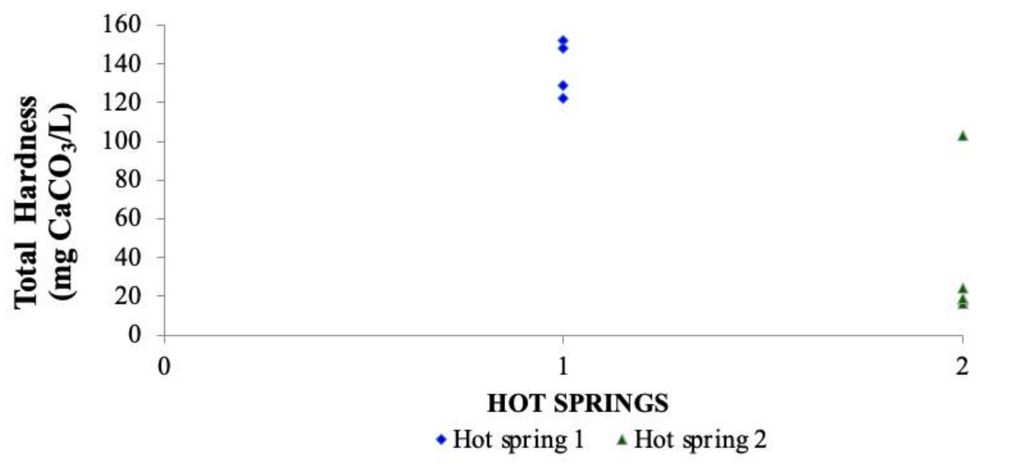


Figure 5.78. Total hardness output data results.

Soluble Phosphorus

The standards are shown in Table 3.4 for wastewater discharge are not regulated. Only two data of the hot spring 2 were measured with average of 0.11 mg P/L.

Total Phosphorus

The regulations are shown in Table 3.4 for wastewater discharge, establishes as limit values of 0.1 mg P/L (Class III) for the Bogota River, Colombian regulation establishes what should be analyzed and reported, Canada establishes a value of 10 mg P/L and Japan 8,0 to 16,0 mg P/L. The results obtained from hot spring 1 was not quantifiable and hot spring 2 presented an average value of 1.76 mg P/L. In Figure 5.79, the total phosphorus results of each hot spring are presented.

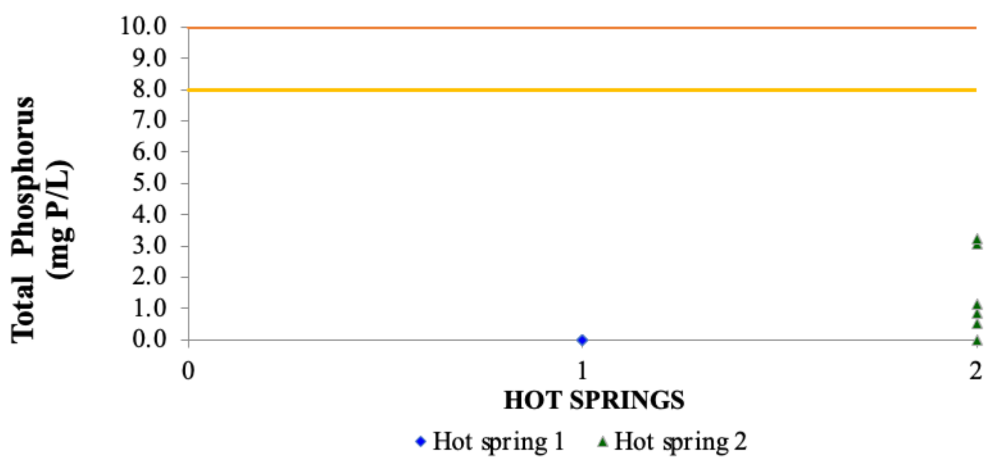


Figure 5.79. Results of the total phosphorus output data. It was observed that the values of the hot springs complied with the regulations.

- **Ammoniacal Nitrogen, Total Kjeldahl Nitrogen, Active Substance to Methylene Blue and Sodium**

Table 5.33 presents the results of the parameters ammoniacal nitrogen, total Kjeldahl nitrogen, active substance to methylene blue, and sodium.

Table 5.33. Results of parameters ammoniacal nitrogen, total Kjeldahl Nitrogen, active substance to methylene blue, and sodium in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
			EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
Hot spring 1	Ammoniacal Nitrogen	mg NH_3-N/L	N.D	N.Q	1	N.Q	N.Q	N.D
	Total Kjeldahl Nitrogen	mg N/L	N.D	N.Q	1	N.Q	N.Q	N.D
	Active substance to methylene blue	mg detergents/L calculate LAS 288,37 g/mol	N.D	0.07	N.D	N.D	N.D	N.D
	Sodium	mg Na/L	N.D	N.D	N.D	N.D	N.D	N.D
Hot spring 2	Ammoniacal Nitrogen	mg NH3-N/L	N.Q	N.Q	N.Q	N.Q	N.Q	N.Q
	Total Kjeldahl Nitrogen	mg N/L	N.Q	N.Q	N.Q	N.Q	N.Q	N.Q
	Active substance to methylene blue	mg SAAM/L como LAS 288,37 g/mol	N.Q	N.Q	N.Q	N.D	N.D	N.D
	Sodium	mg Na/L	3.28	N.D	N.D	N.D	N.D	N.Q

N.Q = Not quantifiable, N.D = No Data.

Once the student's t-test of the ammoniacal nitrogen, total Kjeldahl nitrogen, active substance to methylene blue, and sodium parameters of the input data were determined, the results shown in Appendix E were obtained.

Ammoniacal Nitrogen

The regulations are shown in Table 3.4 for wastewater discharge, establishes as limit values of 0.3 mg NH3-N/L (Class III) for the Bogota River, Colombian regulation establishes what should be analyzed and reported and, Japan establishes a value of 120 mg/L(Daily Average 60 mg/L). The results obtained from hot spring 1 presented only one data with a value of 1.0 mg NH3-N/L and hot spring 2 were not quantifiable.

Total Kjeldahl Nitrogen

The regulations are shown in Table 3.4 for wastewater discharge, establishes as limit values of 100 mg N/L for Canadian regulation (Toronto) and Colombian regulation establishes what should be analyzed and reported. The results obtained from hot spring 1 presented only one data with value of 1.0 mg N/L and hot spring 2 were not quantifiable.

Active Substance to Methylene Blue

The regulations are shown in Table 3.4 for wastewater discharge, only Colombian regulation establishes what should be analyzed and reported. The results obtained from hot spring 1 presented only one data with value of 0.07 mg detergents/L calculate LAS 288.37 g/mol and hot spring 2 were not quantifiable.

Sodium

The standards are shown in Table 3.4 for wastewater discharge are not regulated. Only one data was measured, which was not quantifiable from hot spring 2. In the other measurements there were no data.

- **Settleable Solids, Total Suspended Solids, Total Solids, and Sulphides**

Table 5.34 presents the results of the parameters settleable solids, total suspended solids, total solids, and sulphides.

Table 5.34. Results of parameters settleable solids, total suspended solids, total solids, and sulphides in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
			EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
Hot spring 1	Settleable solids	mg SS/L	N.D	N.Q	N.Q	N.Q	N.Q	N.D
	Total Suspended Solids	mg SST/L	N.D	N.Q	2	N.Q	4	N.D
	Total Solids	mg /L	N.D	6471	6330	6983	6481	N.D

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
			EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
	Sulphide	mg S^2/L	N.D	N.Q	N.Q	N.Q	N.Q	N.D
Hot spring 2	Settleable solids	mg SS/L	N.D	N.Q	N.Q	N,C	N.Q	N.Q
	Total Suspended Solids	mg TSS/L	N.D	15	20	34	44	7
	Total Solids	mg /L	64	83	70	104	85	56
	Sulfides	mg S^2/L	N.Q	N.Q	N.Q	N.Q	N.Q	N.Q

N.Q = Not quantifiable, N.D = No Data.

Once the student's t-test of the settleable solids, total suspended solids, total solids, and sulphides parameters of the input data were determined, the results shown in Appendix E were obtained.

Settleable Solids

The regulations are shown in Table 3.4 for wastewater discharge, establishes a value of 5 mg SS/L for Colombian regulations. The results obtained from hot springs were not quantifiable.

Total Suspended Solids

The regulations are shown in Table 3.4 for wastewater discharge, establishes as limit values of 10 mg SST/L (Class I and II), 20 mg SST/L (Class III), 40 mg SST/L (Class IV) and 50 mg SST/L (Class V) for the Bogota River, the other regulations vary in a value of 70 mg SST/L (Colombian regulation) to 350 mg SST/L (Canadian regulation) and Japanese 200 mg SST/L.

The student's t-test, the total suspended solids result of each of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was not rejected. The results obtained from hot spring 1 presented an average value of 3.0 mg SST/L and hot spring 2 had 34.20 mg SST/L. In Figure 5.80, the total suspended solids result of each hot spring are presented.

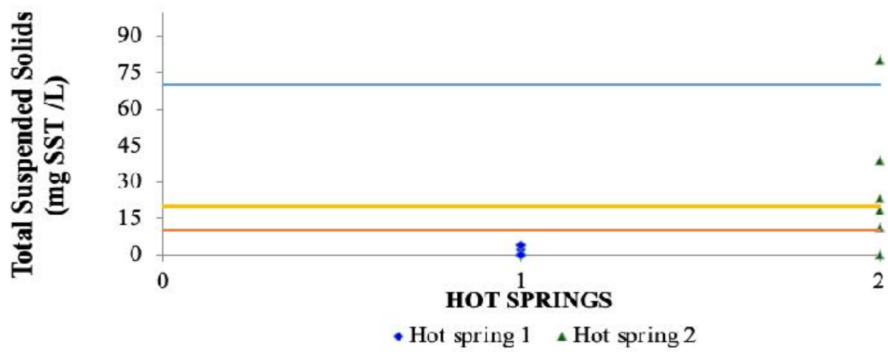


Figure 5.80. Total suspended solids output data results, where hot spring 1 complied with the regulations and hot spring 2 did not fulfill with regulation of Bogota River, only fulfilled the Canadian regulations.

Total Solids

The regulations are shown in Table 3.4 for wastewater discharge are not regulated. Analyzing the t-student's hypothesis test, the total solids result of each of the hot springs showed that there was a statistical difference in the samples, therefore the null hypothesis was rejected. The results obtained from hot spring 1 presented an average value of 6566.25 mg/L and hot spring 2 had 113.5 mg/L. In Figure 5.81, the total solids result of each hot spring are presented.

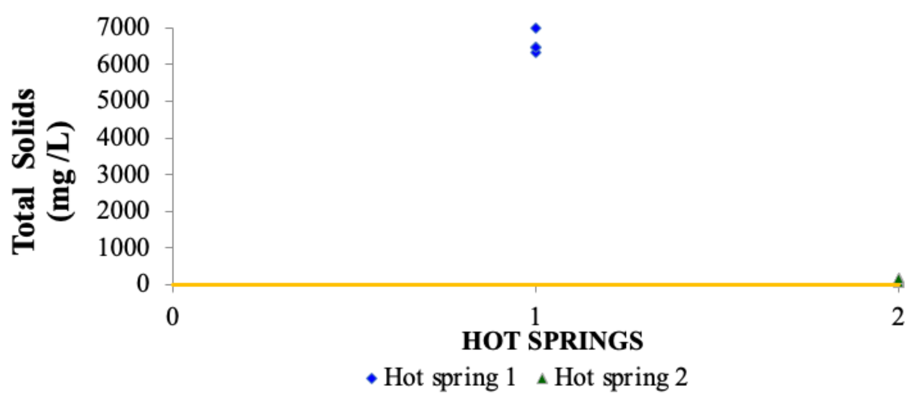


Figure 5.81. Total solids output data results.

Sulphides

The regulations are shown in Table 3.4 for wastewater discharge, only Colombian regulation establishes what should be analyzed and reported. The results obtained from hot springs were not quantifiable.

- **Acidity, Chlorides, Fluorides, and Reactive Phosphorus**

Table 5.35 presents the results of the parameters acidity, chlorides, fluorides, and reactive phosphorus.

Table 5.35. Results of parameters acidity, chlorides, fluorides, and reactive phosphorus in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
			EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
Hot spring 1	Acidity	mg $CaCO_3$/L	N.D	2	3	3	N.Q	N.D
	Chlorides	mg Cl-/L	N.D	N.Q	N.D	N.D	N.D	N.D
	Fluorides	mg F-/L	N.D	0.65	N.D	N.D	0.41	N.D
	Reactive phosphorus	mg PO_4/L	N.D	0.13	N.Q	N.D	N.D	N.D
Hot spring 2	Acidity	mg $CaCO_3$/L	12.45	N.Q	5	17	N.Q	N.Q
	Chlorides	mg Cl-/L	41.3	104.8	N.D	0.24	N.D	N.D
	Fluorides	mg F-/L	1.37	0.25	N.D	N.D	0.32	0.37
	Reactive phosphorus	mg PO_4/L	0.24	0.59	0.17	N.D	N.D	N.D

N.Q = Not quantifiable, N.D = No Data.

Once the student's t-tests of the acidity, chlorides, fluorides, and reactive phosphorus parameters of the output data were determined, the results shown in Appendix E were obtained.

Acidity

The regulations are shown in Table 3.4 for wastewater discharge, only Colombian regulation establishes what should be analyzed and reported.

The student's t-test, the total solids result of each of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was not rejected. The results obtained from hot spring 1 presented an average value of 2.67 mg $CaCO_3$/L and hot spring 2 had 5.50 mg $CaCO_3$/L. In Figure 5.82, the acidity results of each hot spring are presented.

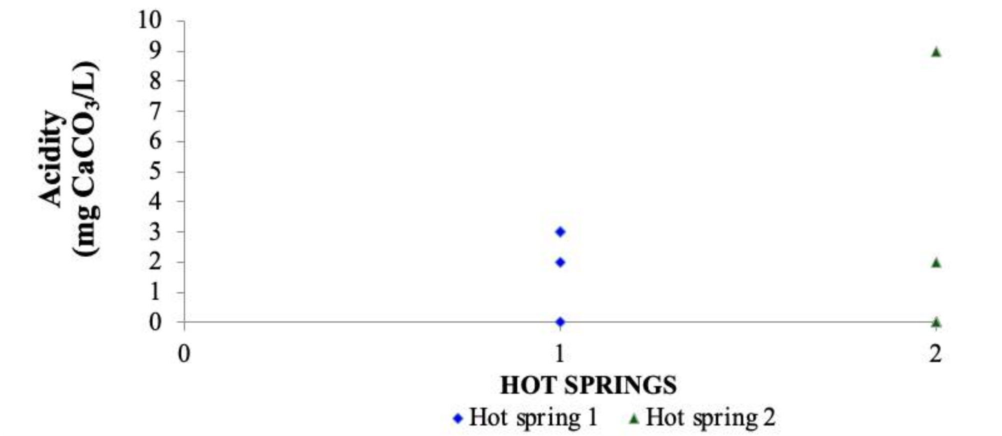


Figure 5.82. Acidity output data results.

Chlorides

The regulations are shown in Table 3.4 for wastewater discharge, establishes as limit values of 250 mg Cl^-/L (Class I and III) for the Bogota River and Colombian regulation establishes that they must be analyzed and reported.

The results obtained from hot spring 1 presented only one date that was not quantifiable and hot spring 2 was an average value of 29.93 mg Cl-/L. In Figure 5.83, the chlorides result of each hot spring are presented.

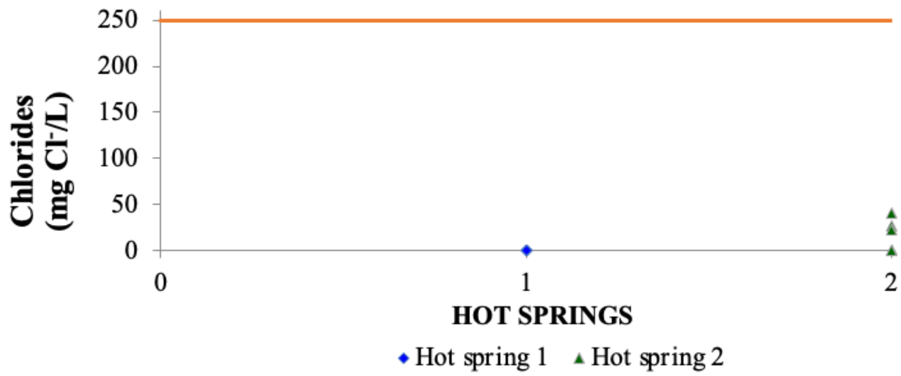


Figure 5.83. Results of the output data of chlorides, where it was observed that the data complied with the regulations.

Fluorides

The standards are shown in Table 3.4 for wastewater discharge, it is not regulated. The results obtained from hot spring 1 presented an average value of 0.53 mg F^-/L and hot spring 2 had 0.31 mg F^-/L. In Figure 5.84, the fluorides result of each hot spring are presented.

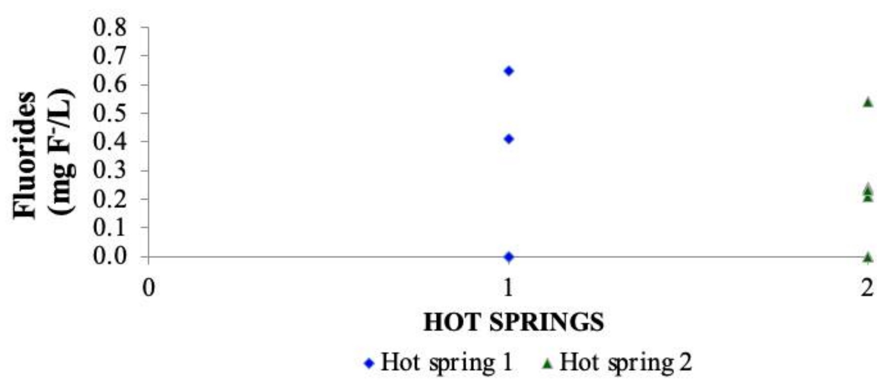


Figure 5.84. Fluorides output data results.

Reactive Phosphorus

The standards are shown in Table 3.4 for wastewater discharge, it is not regulated. The results obtained from hot spring 1 presented only two dates with 0.13 mg PO_4/L and not quantifiable, and hot spring 2 an average value of 0.29 mg PO_4/L. In Figure 5.85, the reactive phosphorus results of each hot spring are presented.

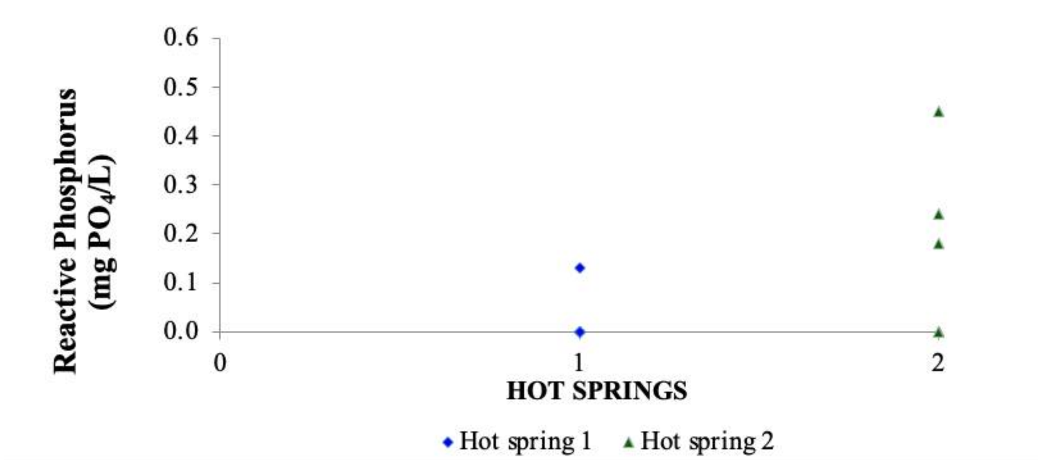


Figure 5.85. Reactive phosphorus output data results.

- **Nitrates, Nitrites, Sulphate, and Total Dissolved Solids**

Table 5.36 presents the results of the parameters nitrates, nitrites, sulphate, and total dissolved solids.

Table 5.36. Results of parameters nitrates, nitrites, sulphate, and total dissolved solids in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
			EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
Hot spring 1	Nitrates	mg NO_3-N/L	N.D	0.2	N.Q	N.Q	1.7	N.D
	Nitrites	mg NO_3-N/L	N.D	N.Q	N.Q	N.Q	0.64	N.D
	Sulphate	mg SO_4/L	N.D	14	11	11	11	N.D
	Total dissolved solids	mg/L	N.D	N.D	N.D	N.D	N.D	N.D
Hot spring 2	Nitrates	mg NO_3-N/L	N.Q	N.Q	N.Q	N.Q	0.1	1.9
	Nitrites	mg NO_3-N/L	N.Q	N.Q	0.04	0.04	0.43	0.39
	Sulphates	mg SO_4/L	N.Q	N.Q	11	5	6	N.Q
	Total Dissolved Solids	mg/L	N.D	N.D	N.D	N.D	N.D	N.D

N.Q = Not quantifiable, N.D = No Data.

Once the student's t-test of the nitrates, nitrites, sulphate, and total dissolved solids parameters of the input data were determined, the results shown in Appendix E were obtained.

Nitrates

The regulations are shown in Table 3.4 for wastewater discharge, establishes as limit values of 10 mg NO_3-N/L (Class I and II), and 1.0 mg NO_3-N/L (Class III), for the Bogota River, and Colombian regulation establishes what should be analyzed and reported.

The results obtained from hot spring 1 an average value of 1.70 mg NO_3-N/L and hot spring 2 presented only one date with 1.80 mg NO_3-N/L. In Figure 5.86, the reactive phosphorus results of each hot spring are presented.

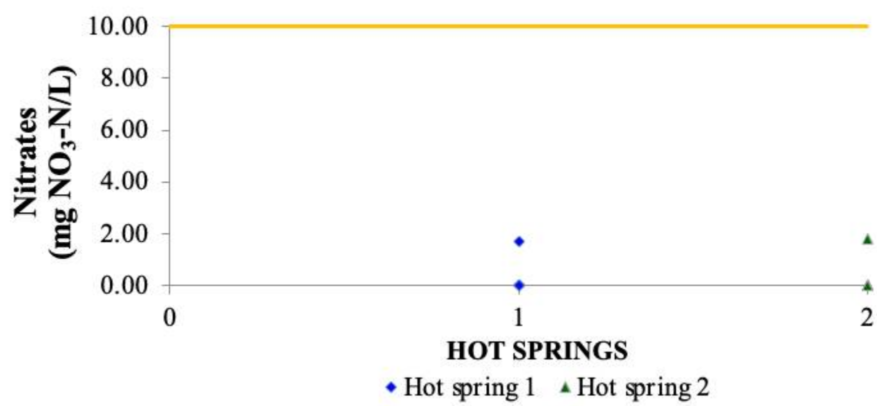


Figure 5.86. Results of the output data of nitrates, where it was observed that the data complied with the regulations.

Nitrites

The regulations are shown in Table 3.4 for wastewater discharge, establishes as limit values of 10 mg NO_3-N/L (Class I, II and IV), and 0.5 mg NO_3-N/L (Class III) for the Bogota River, and Colombian regulation establishes what should be analyzed and reported.

The student's t-test, the nitrites result of each of the hot springs showed that there was statistical difference in the samples, therefore the null hypothesis was rejected. The results obtained from hot spring 1 presented an average value of 0.64 mg NO_3-N/L and hot spring 2 had 0.10 mg NO_3-N/L. In Figure 5.87, the nitrites result of each hot spring are presented.

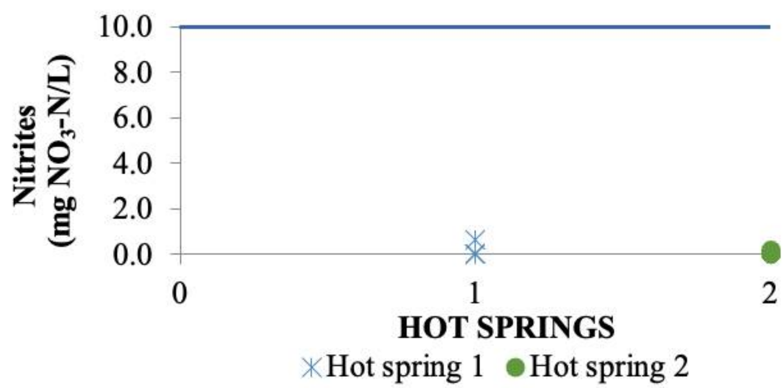


Figure 5.87. Results of the output data of nitrites, where it was observed that the data complied with the Bogota River regulations.

Sulphate

The regulations are shown in Table 3.4 for wastewater discharge, only Colombian regulation established what should be analyzed and reported.

The student's t-test, the sulphate results of each of the hot springs show that there was statistical difference in the samples, therefore the null hypothesis was not rejected. The results obtained from hot spring 1 presented an average value of 11.75 mg SO_4/L and hot spring 2 had 5.5 mg SO_4/L. In Figure 5.88, the sulphate results of each hot spring are presented.

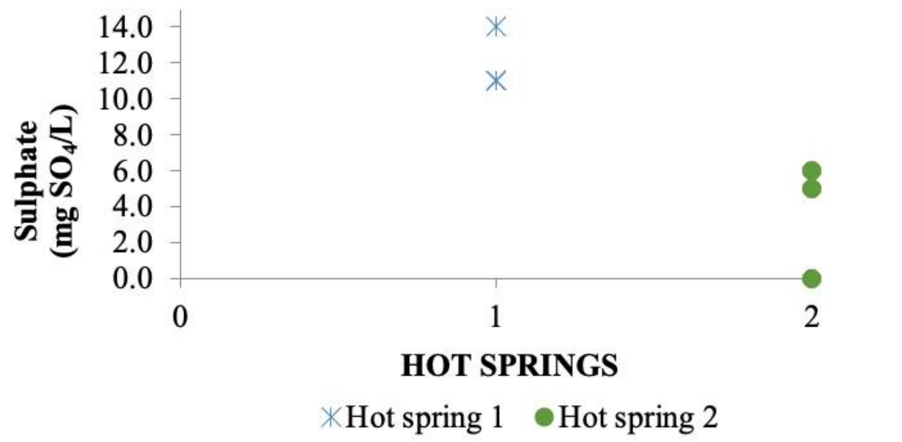


Figure 5.88. Sulphate input data results.

Total Dissolved Solids

The standards are shown in Table 3.4 for wastewater discharge is not regulated. The data were not measured for hot springs 1 and 2.

5.4.6 Microbiological analysis

Table 5.37 presents the results of the parameters total coliforms, fecal coliforms (*E. coli*), E*nterococci*, *L. pneumophila.*, *P. aeruginosa*, molds and yeasts.

Table 5.37. Total Coliforms, Fecal Coliforms (*E. coli*), Enterococci, *L. pheumophila*, *P. aeruginosa*, molds and yeasts parameters result in hot springs 1 and 2.

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
			ENTRY	ENTRY	ENTRY	ENTRY	ENTRY	ENTRY
Hot spring 1	Total coliforms	MPN/ 100 mL	N.D	>24196	>241960	310	61310	N.D
	Fecal coliforms (*E. coli*)	MPN/ 100 mL	N.D	<10	100	< 100	<100	N.D
	Enterococci	MPN/ 100 mL	N.D	9.4	< 1	< 1	1	N.D

PARAMETER		UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
			30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
			ENTRY	ENTRY	ENTRY	ENTRY	ENTRY	ENTRY
	L.pneumophila.	MPN/ mL	N.D	< 1	< 1	< 1	< 1	N.D
	P. aeruginosa	MPN/ 100 mL	N.D	51	< 10	< 10	< 1	N.D
	Molds	MPN/ mL	N.D	0	2	0	0	N.D
	Yeasts	MPN/ mL	N.D	0	320	1	0	N.D
Hot spring 2	Total coliforms	MPN/ 100 ML	809	52	402	530	3873	530
	Fecal coliforms (*E. coli*)	MPN/ 100 ML	*259*	*31*	269	98	197	52
	Enterococci	MPN/ 100 ML	*10*	*6.2*	< 1	< 1	12.1	5.2
	Legionella	MPN/ mL	< 1	< 1	< 1	< 1	12.4	< 1
	P. aeruginosa	MPN/ 100 ML	< 1	< 10	< 1	< 1	< 1	< 1
	Molds	MPN/ ML	4	0	0	0	0	0
	Yeasts	MPN/ ML	*6*	*0*	8	1580	27	790

N.Q = Not quantifiable, N.D = No Data.

Once the student's t-test of total coliforms, fecal coliforms (*E. coli*), Enterococci, *L. pneumophila*, *P. aeruginosa*, molds and yeasts parameters of the output data were determined, the results shown in Appendix E were obtained.

Total Coliforms

The regulations are shown in Table 3.4 for wastewater discharge, establish as limit values of 5000 MPN/100 mL (Class I and III) and 20000 MPN/100 mL (Class II and IV) were for the Bogota River, 200 microorganisms / 100 mL (Colombian regulation) and Japan establish daily average of 3000/cm^3.

The student's t-test, the total coliform results of each of the hot springs showed that there was a statistical difference in the samples, therefore the null hypothesis was rejected. The results obtained from hot spring 1 presented an average value of 81944.0 MPN/100 mL and hot spring 2 had 1032.67 MPN/100 mL. In Figure 5.89, the total coliform results of each hot spring are presented.

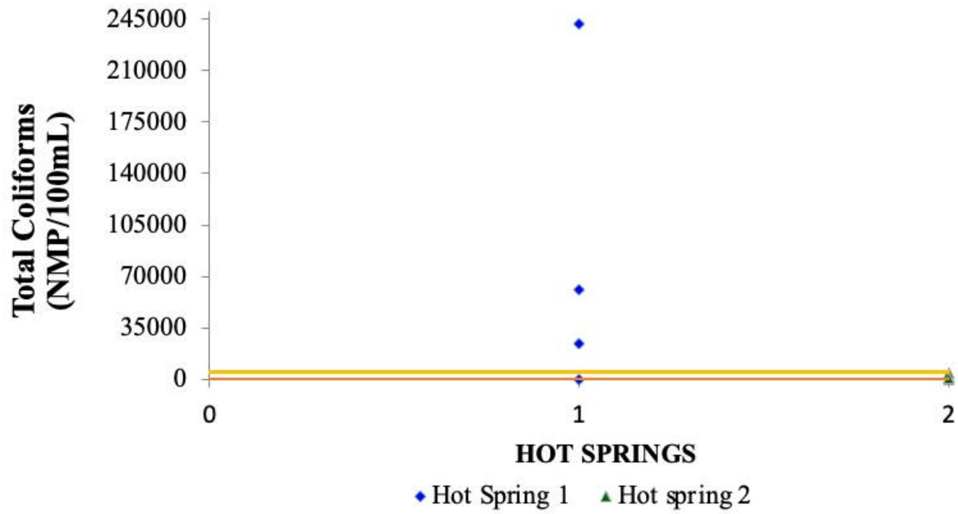


Figure 5.89. Total Coliforms input data results, where it is observed that hot spring 1, the data does not comply with Bogota River regulations.

Fecal Coliforms *(E. coli)*

The regulations analyzed in Table 3.4 for wastewater discharge, 150 to 200 organisms / 100 mL were established as limit values for the Canadian and Colombian regulation.

The student's t-test, the total coliform results of each of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was no rejected. The results obtained from hot spring 1 presented an average value of 77.5 MPN/100 mL and hot spring 2 had 151.0 MPN/100 mL. In Figure 5.90, the *E. coli* results of each hot spring are presented.

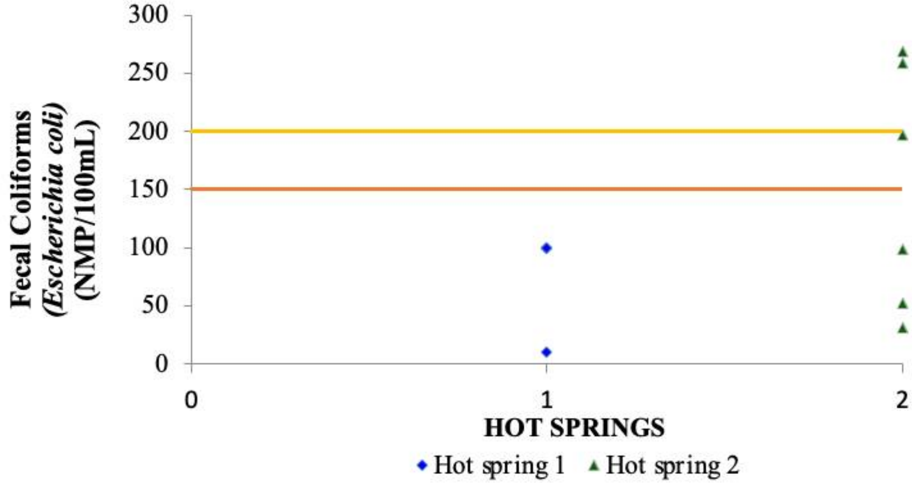


Figure 5.90. *E. coli* input data results, where it was observed that the data from hot spring 1 did not fulfill the regulations.

Enterococci

The standards analyzed in Table 3.4 for wastewater discharge is not regulated. The student's t-test, the Enterococci results of each of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was not rejected. The results obtained from hot spring 1 presented an average value of 3.10 MPN/100 mL and hot spring 2 had 5.92 MPN/100 mL. In Figure 5.91, the Enterococci results of each hot spring are presented.

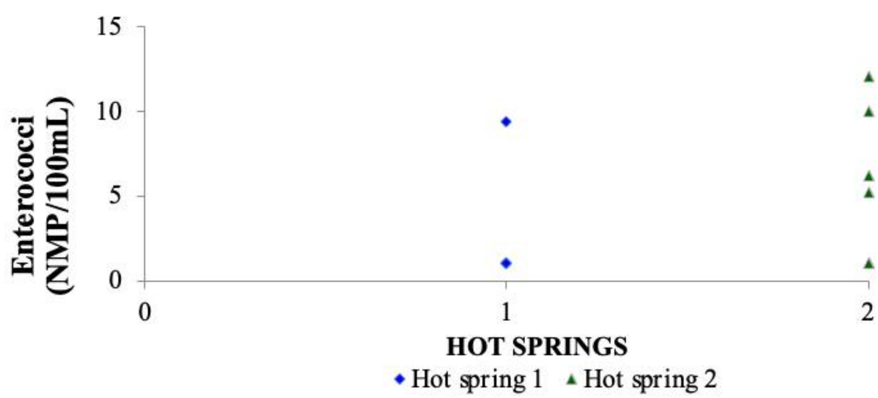


Figure 5.91. Results of Enterococci output data result, where it is observed that they are in a range of 0 to 15 MPN/100 mL.

Legionella pneumophila

In the regulations analyzed in Table 3.4 for wastewater discharge is not regulated. The result obtained from hot springs 1 and hot spring 2 were <1 MPN/100 mL. Only one value of hot spring 2 was 12.4 MPN/100 mL.

Pseudomonas aeruginosa

In the regulations analyzed in Table 3.4 for wastewater discharge is not regulated. The student's t-test, the *P. aeruginosa* results of each of the hot springs showed that there was a statistical difference in the samples, therefore the null hypothesis was rejected. The results obtained from hot spring 1 presented an average value of 18.0 MPN/100 mL and hot spring 2 had 2.50 MPN/100 mL. In Figure 5.92, the *P. aeruginosa* results of each hot spring are presented.

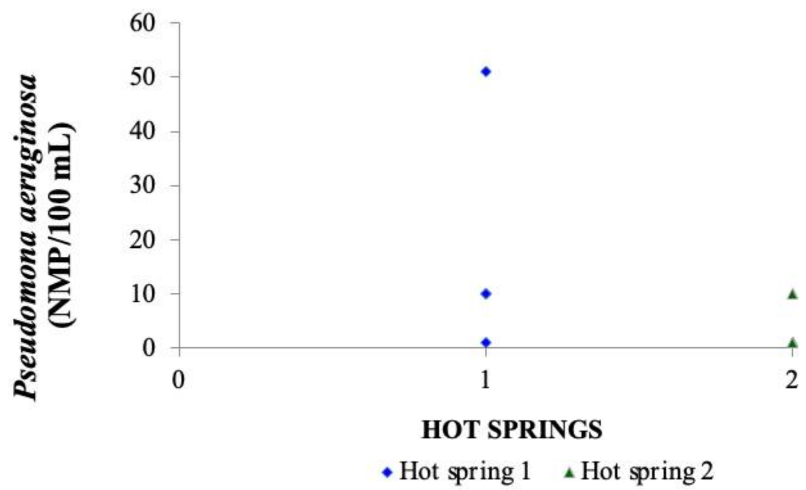


Figure 5.92. *P. aeruginosa* output data results, where it is observed that they are in a range of 0 to 60 MPN/100 mL.

Molds and yeasts

The regulations analyzed in Table 3.4 for wastewater discharge is not regulated. The student's t-test, the molds and yeasts result of each of the hot springs showed that there was no statistical difference in the samples, therefore the null hypothesis was not rejected. The results obtained from hot spring 1 presented an average value of 0.5 UFC/mL of molds and 80.25 UFC/mL of yeasts, and for hot spring 2 was 0.67 UFC/mL of molds and 401.83 UFC/mL of yeasts. In Figures 5.93 and 5.94, the molds and yeasts result of each hot spring are presented.

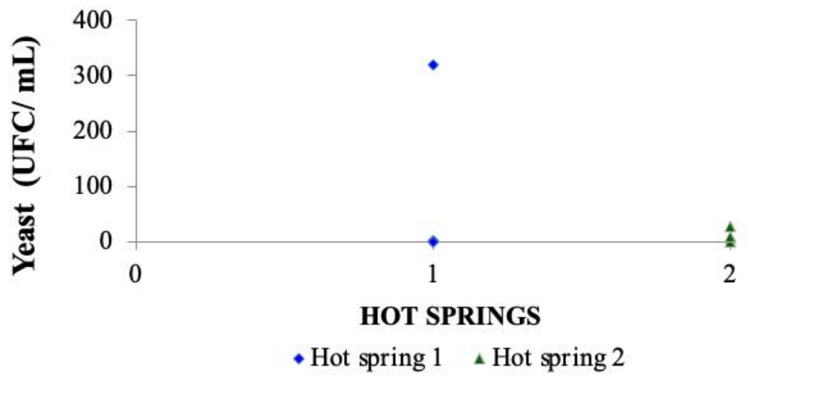


Figure 5.93. Yeasts input data results.

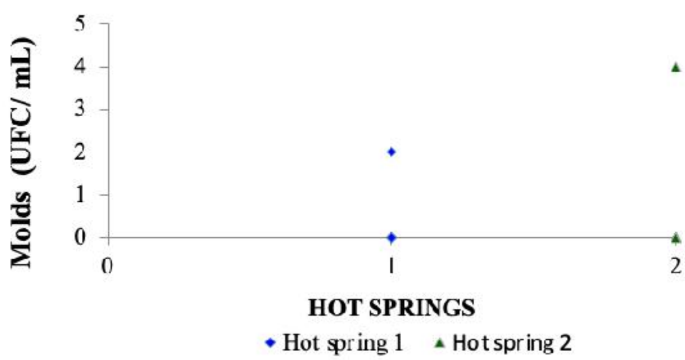


Figure 5.94. Molds input data results.

Correlation between pH and Temperature with microbiological parameters

- **Hot spring 1**

The correlation between pH and temperature with microbiological parameters (Total Coliforms, Fecal coliforms (*E. coli*), Enterococci, *L. pneumophila*, *P. aeruginosa*, molds and yeasts) are shown in Table 5.38 and Figure 5.95 for hot spring 1.

Table 5.38. Correlation between pH and Temperature with TC, FC (*E. coli*), Enterococci, *L. pneumophila*., *P. aeruginosa*, molds and yeasts for hot spring 1.

PARAMETER	UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
		30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
		EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
Hour	a.m/p.m	0.0	2:30 p.m	8:00 a.m	10:30 a.m	9:10 a.m	0.0
pH	pH units	0.0	7.6	7.8	7.8	7.5	0.0
Temperature	°C	0.0	25.8	26.9	31.4	27.4	0.0
Total Coliforms	MPN/ 100 mL	0.0	24196	241960	310	61310	0.0
Fecal Coliforms (*E. coli*)	MPN/ 100 mL	0.0	10	100	100	100	0.0
Enterococci	MPN/ 100 mL	0.0	9.4	1	1	1	0.0
Legionella	MPN/ mL	0.0	1	1	1	1	0.0
Pseudomonas aeruginosa	MPN/ 100 mL	0.0	51	10	10	1	0.0
Molds	MPN/ mL	0.0	0	2	0	0	0.0
Yeasts	MPN/ mL	0.0	0	320	1	0	0.0

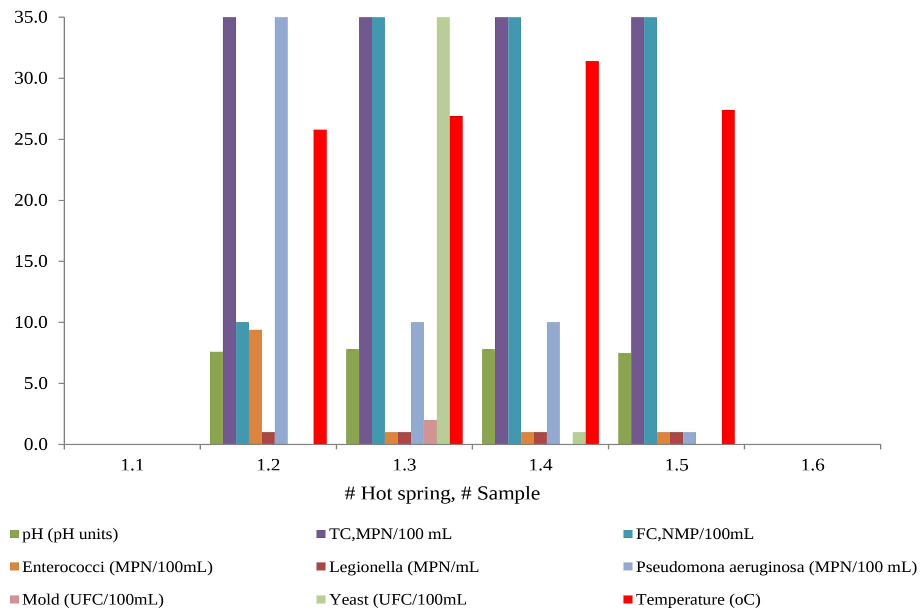


Figure 5.95. Correlations between pH and Temperature with TC, FC (*E. coli*), Enterococci, *Legionella pneumophila*., *Pseudomonas aeruginosa*, molds and yeasts for hot spring 1.

- **Hot spring 2**

The correlation between pH and temperature with microbiological parameters (Total Coliforms, Fecal coliforms (*E. coli*), Enterococci, *L. pneumophila*, *P. aeruginosa*, molds and yeasts) are shown in Table 5.39 and Figure 5.96 for hot spring 2.

Table 5.39. Correlation between pH and Temperature with TC, FC (*E. coli*), Enterococci, *L. pneumophila*, *P. aeruginosa*, molds and yeasts for hot spring 2.

PARAMETER	UNIT	JUNE - JULY	JULY - AUGUST	AUGUST - SEPTEMBER	SEPTEMBER - OCTOBER	OCTOBER - NOVEMBER	NOVEMBER - DECEMBER
		30/06/2021	28/07/2021	2/09/2021	3/10/2021	17/11/2021	15/12/2021
		EXIT	**EXIT**	**EXIT**	**EXIT**	**EXIT**	**EXIT**
Hour	a.m/ p.m	12:30 p.m	12:00 p.m	12:00 p.m	12:45 p.m	11:05 a.m	11:00 a.m
pH	pH units	7.1	6.1	7.0	6.5	7.1	6.2
Total Coliforms	MPN/ 100 ML	809	52	402	530	3873	530
Fecal coliforms (*E. coli*)	MPN/ 100 ML	*259*	*31*	269	98	197	52
Enterococci	MPN/ 100 ML	*10*	*6.2*	1	1	12.1	5.2
L.pneumophila	MPN/ ML	1	1	1	1	12.4	1
P. aeruginosa	MPN/ 100 ML	1	10	1	1	1	1
Fungi	MPN/ ML	4	0	0	0	0	0
Yeasts	MPN/ ML	*6*	*0*	8	1580	27	790

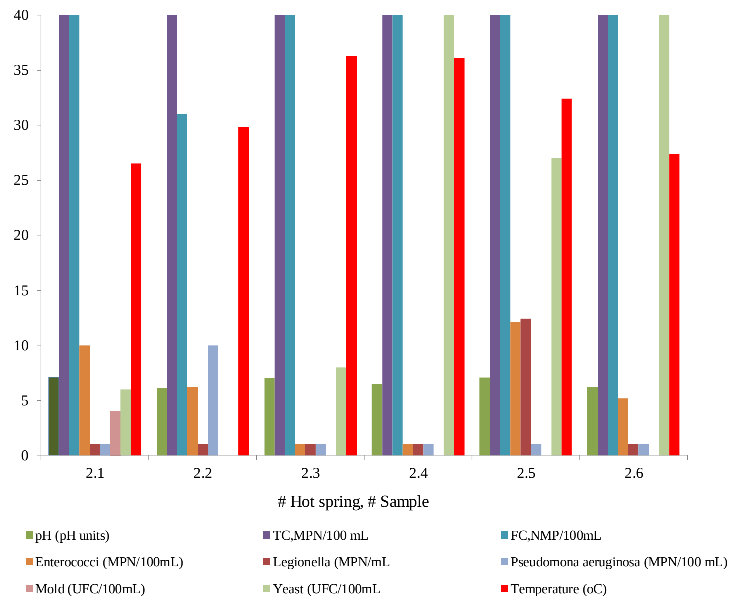


Figure 5.96. Correlations of pH and Temperature with TC, FC (*E. coli*), Enterococci, *L. pneumophila*, *P. aeruginosa*, molds and yeasts for hot spring 2.

Analyzing the results of the correlations of pH and temperature with the microbiological parameters, it is observed that the temperature of the hot springs of 20 to 35 °C allows the proliferation of mesophilic bacteria.

Most bacteria can grow at a pH between 5.5 and 8.0, so there are optimal pH conditions for their growth (Andueza, 2020).

5.5 CONCLUSIONS

Analyzing the results of each of the parameters, it is important to highlight that each hot spring has its own water characteristics. In this case, hot spring 1 is bicarbonate and hot spring 2 is ferruginous.

This work allowed to characterize physical, chemical, and microbiological parameters of two types of hot springs. The results of the parameters were analyzed and the compliance of the inlet water parameters to the hot springs with drinking water, swimming pool, and hot spring regulations was evaluated. This was compared with drinking water, considering that the bather could accidentally swallow water in swimming pools. Some countries regulate their hot springs with the same regulations of swimming pool water. In the case of Japan, it regulates only certain parameters in its hot springs.

In the case of wastewater discharge from hot springs, the parameter results were compared with regulations of different countries for wastewater discharge to water bodies. Hot springs 1 and 2 were classified as hypothermal because they had temperatures between 20°C and 35 °C, a perfect temperature and environment for the habitat of mesophilic bacteria that appear in hot springs.

Hot spring 1 presented conductivities greater than 5000 μS/cm, indicating that this hot spring presented high SDT, a parameter that did not have data in the measurements. Hot spring 2 had conductivities between 70 and 110 μS/cm. The analysis of the result compared to the drinking water regulation did not comply with hot spring 1. Considering that it is a specific property of its water and, to comply with this regulation, the water should be deionized.

Hot spring 1 presented pH values above 7.0. In the case of hot spring 2, it presented pH values between 6.0 and 7.7. The dissolved oxygen of the hot springs was maintained between 3.0 and 4.5 mg/L O_2.

The values from the heavy metals analyzed in the samples from hot springs 1 and 2 were compared with regulations for drinking water and swimming pools, whose values were within the limits established by the regulation analyzed in Table 3.2, with the exception of the hot spring 2 featuring high iron values, which becomes more of a water aesthetic problem.

Hot spring 2 presented values above 15 TCU and 5 UNT due to the properties of its waters, which correspond to ferruginous water. The results of hot springs 1 and 2 did not present quantifiable data on oil and fats. Hot spring 1 presented values above the limits of the regulations between 30 and 500 mg $CaCO_3$/L for drinking water; in swimming pool water, 60 to 180 mg $CaCO_3$/L.

The TIC in drinking water, swimming pool water and wastewater are not regulated. The results obtained from hot spring 1 presented an average value of 56.90 mg /L and for hot spring 2 was 12.98 mg /L in input data. For output data, hot spring 1 presented an average value of 56.78 mg /L and hot spring 2 had 14.35 mg /L.

The TOC results obtained from hot spring 1 presented an average value of 4.18 mg/L and for hot spring 2 was 4.0 mg/L in input data, which fulfilled the regulation with the limit of values of 5.0 mg/L for drinking water. In wastewater, TOC are not regulated. The results obtained from hot spring 1 presented an average value of 5.60 mg/L and hot spring 2 had 4.20 mg/L in output data.

The soluble phosphorus, total phosphorus, ammoniacal nitrogen, total Kjeldahl nitrogen, active substance to methylene blue, and settleable solids were not quantifiable in input and output data for hot springs 1 and 2.

Hot spring 1 only had a one data of sodium with a value of 1619.27 mg Na/L and hot spring 2 had a value of 3.28 mg Na/L for input data.

All samples presented the fecal coliforms (*E. coli*) in concentrations greater than 10 NMP/100 mL. The samples not only presented *E. coli*, but also total coliforms, enterococci, some presence of *L. pneumophila* and *P. aeruginosa*, molds and yeasts.

Chapter 6

OPERATIONAL CONDITIONS NECESSARY FOR THE DISINFECTION IN HOT SPRINGS

This chapter shows the fulfillment of the second objective of the doctoral *"To study the operational conditions of disinfection for its applications in hot springs".*

The control of pathogens in recreational waters is achieved with adequate treatment and influenced by disinfection with chlorine or other disinfectants (WHO, 2006). However, protozoa and parasites may require further treatment, such as UV radiation, to be completely deactivated (Government of Ontario, 2019). Disinfection is mainly achieved using chlorine, ozone, or Ultraviolet (UV) radiation (with ozone and UV being used in combination with chlorine or bromine) (Barrera et al., 2012; WHO, 2006; Bolton, 2022).

In countries such as Spain and Colombia, it is important to maintain the physical-chemical quality of the water rather than the microbiological one, which is why they do not add chemicals to water in hot spring. In other countries such as Germany, Canada, and Japan, the microbiological quality of water is a priority that is why they use chemical products to treat their hot springs. Therefore, disinfection of *E. coli* using Ultraviolet light without any addition of chemicals will be analyzed. Additionally, in this chapter, is also determined the demand chlorine of the hot springs of the study.

For the development of this chapter, a prototype made by Barrera, 2011, was used.

6.1 METHODOLOGY

The experiments were carried out in the Laboratory of Microbiology and Laboratory of Wastewater Treatment Technologies of Toronto Metropolitan University, using the schematic diagram shown in Figure 6.1.

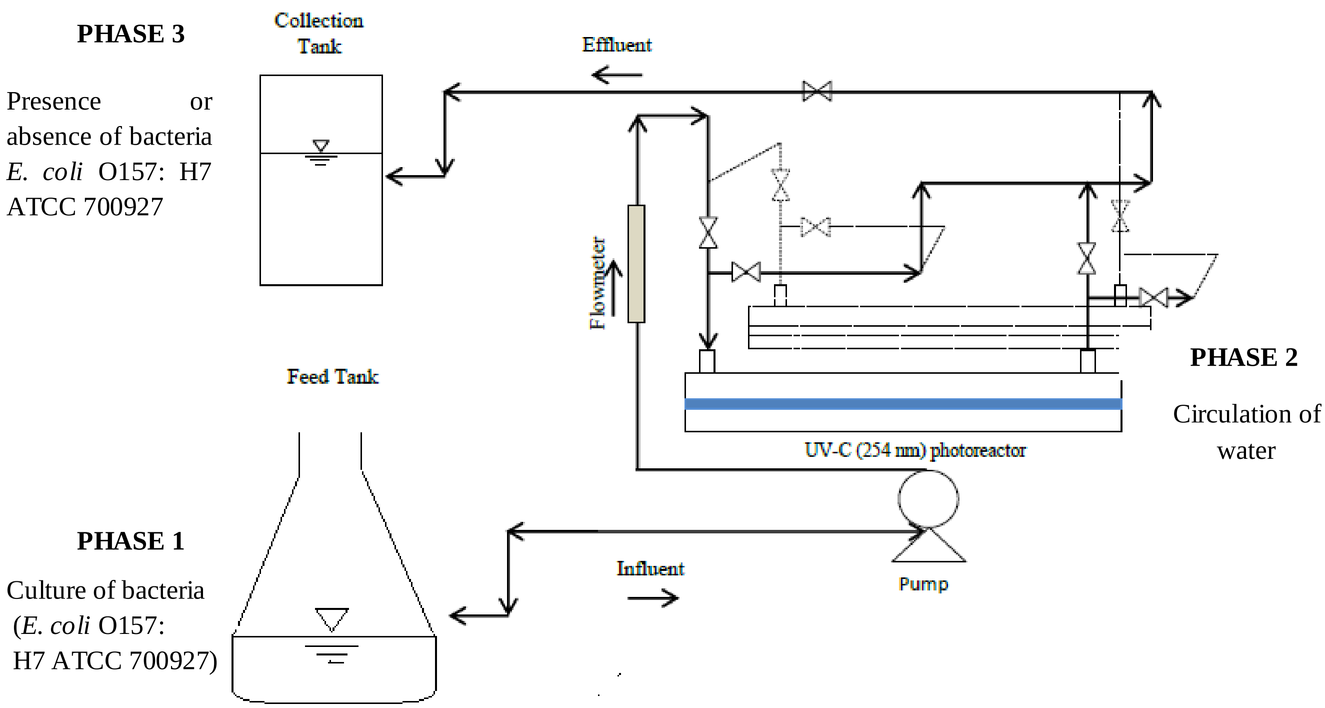


Figure 6.1. Schematic diagram of experimental setup with UV light at the Laboratory of Wastewater Treatment Technologies at TMU, Canada (Barrera, 2011).

One stainless steel photoreactor model SL-LAB 2 (Siemens Inc.) was used for the treatment of the sterilized water. The photoreactor had a capacity of 7.57 L/min, a length of 305 mm, and a diameter of 51.1 mm. According to the manufacturer, the capacity of 7.57 L/min is dependent on a 40 mJ cm^{-2} UV dosage at the end of lamp life and a UV transmittance of 98% (254 nm; 1 cm cell). The effective volume of the photoreactor was 0.46 L (Barrera, 2011).

The disinfection with UV light was developed in three phases, as shown in Figure 6.1. Phase 1 (culture of bacteria), Phase 2 (circulation of water through the reactor), and Phase 3 (presence or absence of the bacteria *E. coli*), as discussed below:

6.1.1 Phase 1: Culture of Bacteria

Materials

For this phase, the following materials were used:

- Vortex machine (VWR Mini Vortexer VM3000)
- Phosphate Buffered Saline (PBS) solution, pH (1 Tablet in 100 mL).
- 2 Pipettes Controler of 100 mL
- Pipette tips (0.1 to 10 µL)
- L-Shaped Cell Spreader, Sterile (are ideal for spreading cell or bacterial cultures evenly)
- Strain *E. coli* O157: H7 ATCC 700927
- C25KC classic incubator, New Brunswick Scientific Co. Edison, NJ, USA at 37 oC
- 5 L autoclaved tap water
- 10 agar plates

PROCEDURE

1. An inoculating loopful of bacteria from a previously inoculated solid bacterial growth medium (i.e., Tryptic Soy Agar) was aseptically transferred (this can be used to maintain a pure culture of bacteria for several weeks) to a sterile liquid bacteria growth medium (i.e., Tryptic Soy Broth (TSB); approx. 10 mL in a sterile 15 mL centrifuge tube) (refer to Figures 6.2 and 6.3).

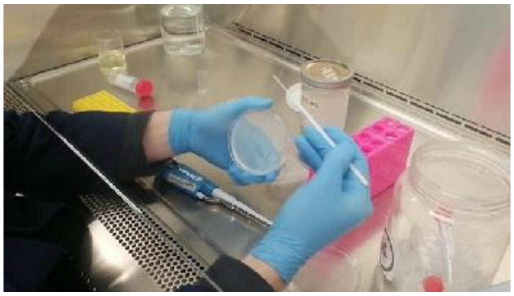


Figure 6.2. Agar plate with bacteria *E. coli*

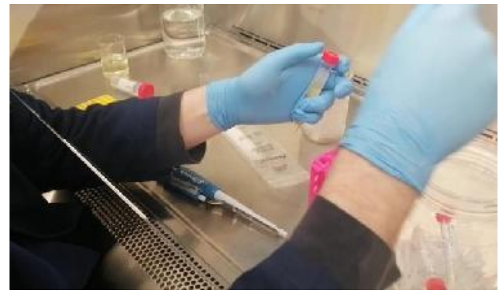


Figure 6.3. Sterile 15 mL centrifuge tube

2. The broth culture was vortexed. It was placed in a shaking incubator set to 37°C for 16-24 hours.

Cell Wash

3. After 16-24 hours, 2 mL of bacterial culture was transferred to 4 tubes of 5 mL.
4. The culture was centrifuged at 3.0 RPM and 4°C for 5 minutes. The 4 tubes of 5 mL were placed crosswise.
5. Without disturbing the pellet, the liquid in the centrifuge tube was aseptically drawn out using a pipette for all 4 tubes. The liquid was dispensed into a beaker with a small amount of bleach (refer to Figures 6.4 and 6.5).

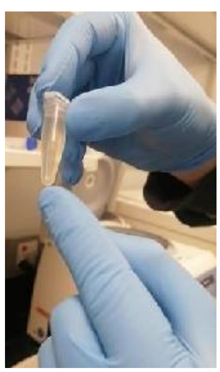


Figure 6.4. Bacteria pellet

Figure 6.5. Liquid extraction

6. The pellet was resuspended in sterile Phosphate Buffered Saline (PBS) for all 4 tubes. The tube was vortexed, ensuring that the pellet was completely resuspended (refer to Figures 6.6 and 6.7).

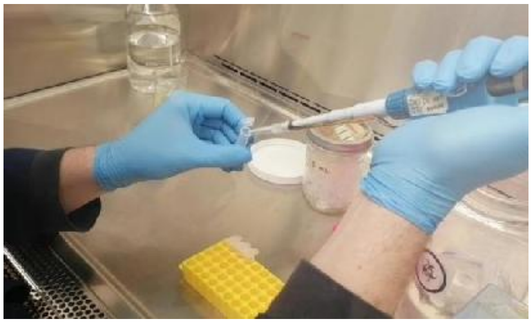


Figure 6.6. The pellet was resuspended in PBS

Figure 6.7. The tube was vortexed

7. The culture was centrifuged again at 3.0 RPM and 4°C for 5 minutes. The 4 tubes of 5 mL were placed crosswise (Same as step 4).

8. Step 5 was repeated (refer to Figures 6.8 and 6.9).

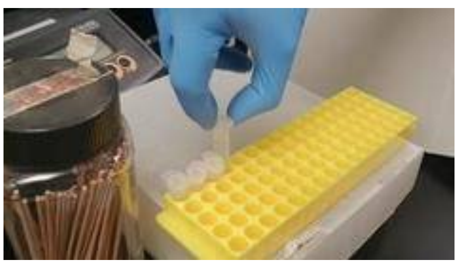


Figure 6.8. 4 Tubes of 3.0 mL

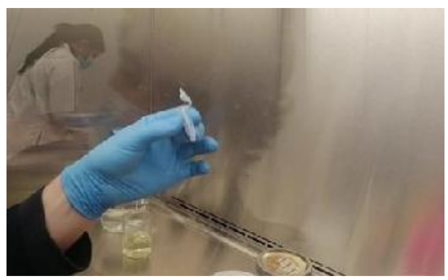


Figure 6.9. Tube with bacteria without liquid

9. The pellet was resuspended in sterile phosphate buffered saline. The tube was vortexed, ensuring that the pellet was completely resuspended. The culture was now 'washed' of growth medium and soluble metabolic byproducts. The content of the 4 tubes was combined in a single 15 mL tube.

Calibration Spectrophotometer

10. 1 mL of phosphate buffered saline (or medium of your choice) was aliquoted into a 10 mm cuvette. The cuvette was inserted into a spectrophotometer set to measure absorbance/optical density at 600 nm (i.e., OD_{600}). The machine was blanked/zeroed to the chosen medium. Spectrophotometer calibration is presented in Appendix D.

11. 1 mL of the culture was aliquoted into a 10 mm cuvette and the OD_{600} was measured (refer to Figures 6.10 and 6.11).

Figure 6.10. Cuvetted into a Spectrophotometer

Figure 6.11. OD 600 = 0.4899

12. Using the equation $c_1v_1=c_2v_2$, the volumes of Phosphate Buffered Saline (or medium of your choice) and culture were calculated to combine in a new centrifuge tube to obtain an OD_{600} of 0.1-0.15 (e.g., volume of culture to add = [desired Od_{600} x desired volume]/current culture's OD_{600}; volume of medium to add = desired volume – volume of culture to add). This OD_{600} range corresponded to approx. $1x10^8$ colony forming units/mL (CFU/mL; the term 'colony forming units' relates to the fact that a colony on an agar plate may have started from several cells, hence making the term 'cells/mL' unacceptable for most applications).

For example:

$$c_1v_1=c_2v_2,$$

$$0.1x\ 5\ mL\ /0.4899 = 0.5\ mL/0.4899 = 1.020\ mL \text{ washed cells}$$

$$V = 5\ mL – 1.020\ mL = 3.98\ mL\ PBS$$

13. In a new 15 mL tube, a portion of the culture was diluted in sterile Phosphate Buffered Saline to OD_{600}=0.1. The culture was vortexed and then 1 mL was aliquoted into a 10 mm cuvette and the OD_{600} was measured (refer to Figures 6.12 and 6.13).

Figure 6.12. OD 600 = 0.1

Figure 6.13. Vortex

14. The culture was diluted using the equation $c_1v_1=c_2v_2$ to desired CFU/mL. In this case using concentration of bacteria:

25000 CFU/mL x 2500 mL/ 100000000 CFU/mL = 0.625 mL of OD600 = 0.1

15. For the UV procedure, the plates 10 % TSB (Tryptone Soya Broth) were labeled and tap water was sterilized in an autoclave (refer to Figures 6.14 and 6.15).

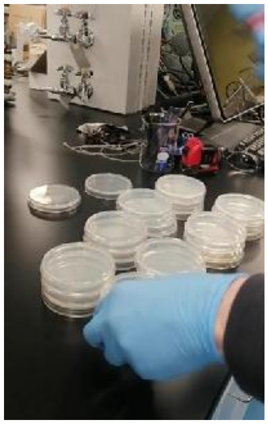


Figure 6.14. Agar plates

Figure 6.15. Autoclave

16. The standardized was expose culture to UV for a known period.

6.1.2 Phase 2: Circulation of water

Materials

The following materials were required to perform the procedures:

– Bunsen Gas Burner to decontaminate the environment
– Vortex machine (VWR Mini Vortexer VM3000)
– Beaker 2500 mL
– Beaker 4000 mL
– Phosphate Buffered Saline (PBS) solution, pH (1 Tablet in 100 mL).
– Test tube 250 mL
– 24 Agar Plates
– 2 Pipettes Controler of 100 mL
– Pipette tips (0.1 to 10 μL)

- L-Shaped Cell Spreader, Sterile (are ideal for spreading cell or bacterial cultures evenly)
- Culture of bacteria (*E. coli*)
- C25KC classic incubator, New Brunswick Scientific Co. Edison, NJ, USA at 37 ºC
- Reactor with UV light
- A pump and bail
- Tap water sterilized in an autoclave

In Figure 6.16, the laboratory assemble is shown.

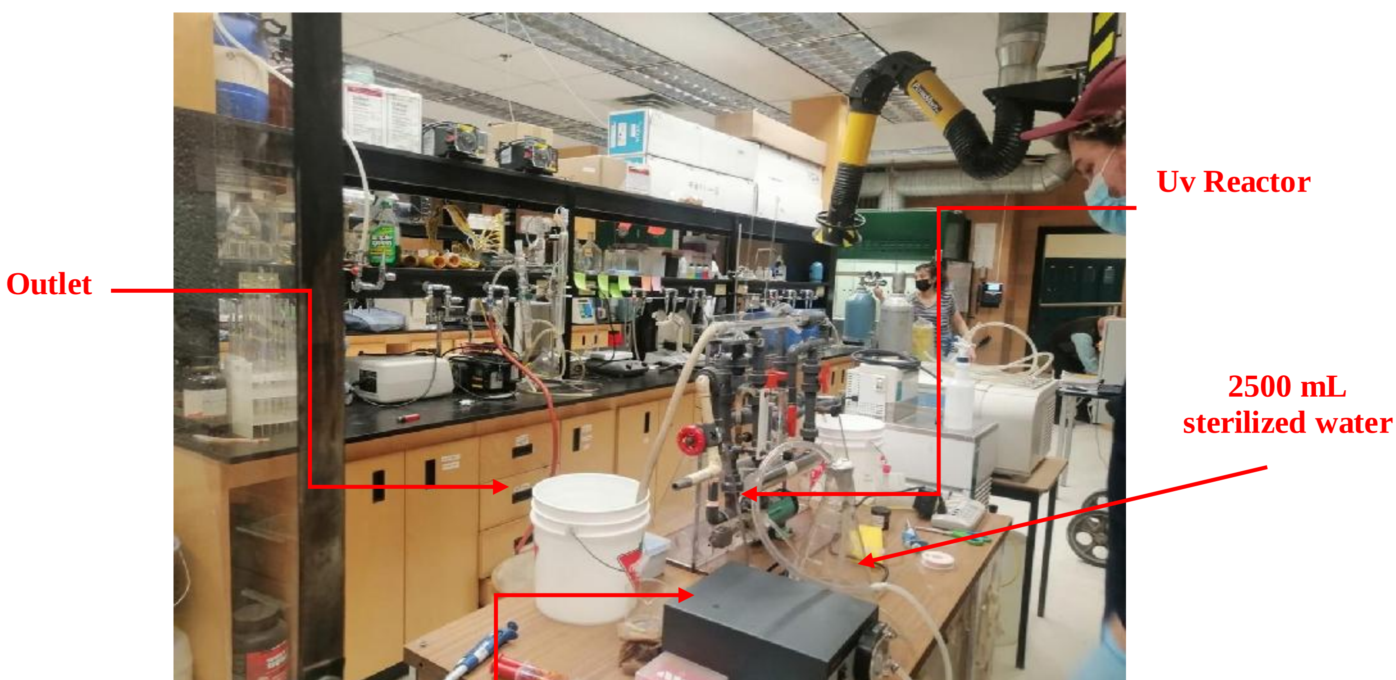


Figure 6.16. Laboratory of Wastewater Treatment Technologies at TMU, Canada.

<u>**Cleaning procedure**</u>

Step 1: Flushing the system in dark mode (absence of bacteria/chlorine):

1. The flame of a burner was lit to decontaminate the environment (refer to Figure 6.17).

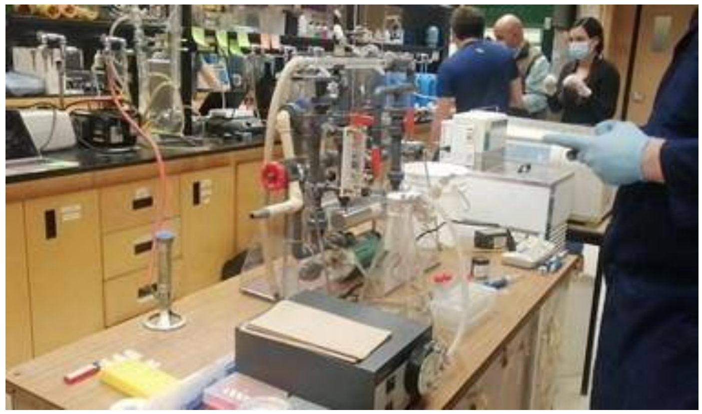


Figure 6.17. Flame of a burner at the Laboratory of Wastewater Treatment Technologies at TMU, Canada.

2. Pump was set to a desired flowrate/speed (speed 17).
3. The experiment was run with 2500 mL of distilled water in the beaker to feed the setup for 30 min and the water was recirculated to clean the setup.
4. Took a sampling of distilled water at inlet into a sterile 1.5 mL centrifuge tube. This was the 10^0 dilutions.
5. Aseptically pipetted 0.1 mL of the 10^0 dilutions onto sterile solid bacterial growth medium (10 percent TSB plate). Spread the liquid on the agar until it was evenly dispersed across the entire surface of the plate with the L shaped spreader. It was distributed turning it on the plate until resistance was felt, constantly rotating the plate. This was the blank (No bacteria).
6. Repeated step 5 using an additional plate to obtain 2 replicates. These plates were used to confirm that water did not have bacteria. To confirm that there was no chlorine in the system, the bacteria must not die.
7. Placed the plates into a standing (non-shaking) incubator at 37°C for 24 hours.

8. Analyzed the samples at inlet and outlet of the photoreactor and compared the results (same results prove absence of bacteria in the system). Only counted the plates with between 30-300 colonies.

Step 2: Flushed the system when UV lamp was on:

1. Turned on the UV light when distilled water was pumping, let the system run for 1 hour on for the water to recirculate and cleaned the setup (Speed 3 for Hydraulic Retention Time (HRT) of 45 minutes).
2. Let the system run for an additional 15 min with UV on and took samples in outlet at speed 8 for HRT of 5 minutes.
3. Transferred 0.1 mL of the 10^0 for t= 5 minutes onto sterile solid bacterial growth medium (10 percent TSB plate). Spread the liquid on the agar until it was evenly dispersed across the entire surface of the plate with the L shaped spreader. It was distributed, turning it on the plate until resistance was felt, constantly rotating the plate.
4. Repeated step 3 using an additional plate to obtain 2 replicates. These plates were used to confirm that water did not have bacteria.
5. Placed the plates in a standing (non-shaking) incubator at 37°C for 24 hours.
6. Analyzed the samples at outlet of the photoreactor. Counted the number of colonies that appear on your plates. Beige bacteria were expected. Only counted the plates with between 30-300 colonies.

After getting the results of step 1 and step 2, I made sure there were no bacteria or chlorine in the system.

UV Procedure with *E. coli* in agar plates

Step 1: Without UV light

1. Lighted the flame of the burner to decontaminate the environment.
2. Set the pump on the desired flowrate/speed (speed 8 for HRT of 5 min, speed 5 for HRT of 10 min, and speed 4 for HRT of 15 min).
3. Placed 3 mL of the cultured bacteria in a beaker with a density of 8X104 CFU/mL.
4. Placed the bacterial culture (3800 mL distilled water in the beaker) through the setup for 5 minutes without UV and transferred 1 mL sample to a tube.

Step 2: With bacteria (Tubes) – HRT= 0 minutes

1. Took samples at t=0 min.
2. Aseptically transferred an aliquot of the sample to a sterile 1.5 mL centrifuge tube. This was the 10^0 dilutions.
3. Diluted 0.1 mL of the 10^0 dilutions in 0.9 mL sterile Phosphate Buffered Saline (PBS) with pipette tips. This was the 10^{-1} dilution.
4. Vortexed the tube well.
5. Transferred 0.1 mL of the solution to a new container tube with 0.9 mL of sterile Phosphate Buffered Saline (PBS). This was the 10^{-2} dilution.
6. Vortexed the tube well.
7. Aseptically pipetted 100 µL (0.1 mL) of 10^{-2} dilution onto sterile solid bacterial growth medium (10 percent TSB plate). Spread the liquid on the agar until it was evenly dispersed across the entire surface of the plate with the L shaped spreader. It was distributed by turning the L shaped spreader on the plate until resistance was felt, constantly rotating the plate.
8. Repeated step 7, using to additional two plates, to obtain 3 replicates.
9. Repeated step 7 and 8 with the remaining dilutions (i.e., 10^{-1}).
10. Placed the plates into a standing (non-shaking) incubator at 37°C for 24-48 hours (refer to Figure 6.18).

Figure 6.18. C25KC classic incubator used for placed the plates at 37°C for 24-48 hours

Step 3: With UV light

With bacteria (Tubes) – HRT = 5 minutes

1. Turned on the UV light.
2. Switched inlet off peristaltic pump from distilled water to the sample. Speed 8 for HRT of 5 minutes.
3. After 5 minutes, aseptically transferred an aliquot of your sample to a sterile 1.5 mL centrifuge tube. This was the 10^0 dilutions.
4. Vortexed the tube well.
5. Diluted 0.1 mL of the 10^0 in 0.9 mL PBS with pipettes tips. This was the 10^{-1} dilution.
6. Vortexed the tube well.
11. Aseptically pipetted 0.1 mL of the 10^0 dilutions onto sterile solid bacterial growth medium (10 percent TSB plate). Spread the liquid on the agar until it is evenly dispersed across the entire surface of the plate with the L shaped spreader. It is distributed by turning the L shaped spreader on the plate until resistance was felt, constantly rotating the plate.
7. Repeated step 7, using an additional two plates to obtain 3 replicates.

8. Repeated step 7 and 8 with the remaining dilutions (i.e., 10^0).
9. Placed the plates into a standing (non-shaking) incubator at 37°C for 24-48 hours (refer to Figure 114).

With bacteria (Tubes) – HRT = 10 minutes and HRT 15 minutes.

1. Switched inlet off peristaltic pump from distilled water to Speed 5 for HRT of 10 minutes and speed 4 for HRT of 15 minutes. Repeated the same steps for T 5 minutes.

Recommendations

After finishing the experiment, the waste was placed in a beaker with bleach.

6.1.3 Phase 3: Presence or absence of bacteria *E. coli* O157: H7 ATCC 700927

After incubating the plates for 24 to 48 hours, the number of colonies that appeared on your plates was counted. Beige bacteria were expected. Only plates between 30-300 colonies were counted.

Taking all previous dilutions into account, the CFU/mL that survived the UV treatment was calculated (CFU/mL = average plate count/ [plate volume * dilution]).

6.2 ANALYSIS RESULT

6.2.1 UV light

Laboratory tests for the disinfection of *E. coli* with Ultraviolet Light for five months with a periodicity of every week, to achieve the disinfection results. The tests were carried out from March to July, where the following problems occurred:

- In the tests carried out from March to May, not enough bacteria (*E. coli*) grew, as established by the McFarland scale, which for an optical density of 0.1 would be expected to be around $1x10^8$ CFU.
- Contamination in the reactor and the environment for the cultivation of bacteria.
- Death of bacteria before disinfection with UV light.

  In some tests, when the agar plates with the culture of the *E. coli*, the agar was dried due to the lack of sealing tape for the agar plate.

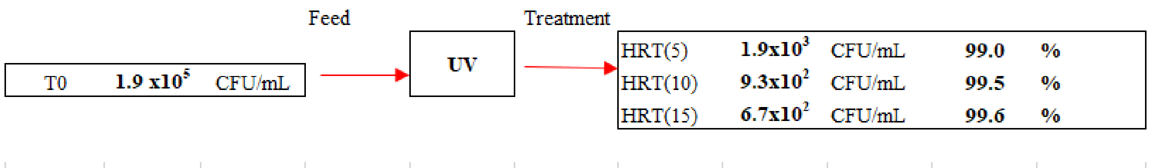
Therefore, different tests were carried out until the optimal conditions for the growth of the *E. coli* bacteria were achieved before carrying out the disinfection with UV light and guaranteeing that there was no contamination in the reactor. In the month of June and part of July, three repeated tests were carried out with the conditions shown in the results of tests 1, 2, and 3 of Tables 6.1, 6.2, and 6.3.

Table 6.1. Results of test 1 performed on June 21st, 2022, in differences HRT (5, 10 and 15 minutes) and bacterial culture dilutions.

Disinfection with UV reactor										
Date: June 21th, 2022										
Results		**Without UV**			**UV treatment after 5 min**		**UV treatment after 10 min**		**UV treatment after 15 min**	
		T0x 10^0	**T0x 10^{-1}**	**T0x 10^{-2}**	**T5 x 10^0**	**T5 x 10^{-1}**	**T10 x 10^0**	**T10 x 10^{-1}**	**T15 x 10^0**	**T15 x 10^{-1}**
		CFU/mL	**CFU/mL**	**CFU/mL**	**CFU/mL**	**CFU/mL**	**CFU/mL**	**CFU/mL**	**CFU/mL**	**CFU/mL**
24 hours	Plate 1	TNTC	3.8×10^4	1.5×10^5	$8.6.x10^2$	$1.2x10^3$	$9.0x10^2$	$6.0x10^3$	$3.0x10^2$	$1.8x10^3$
	Plate 2	TNTC	3.0×10^3	1.7×10^5	$6.0x10^2$	$5.0x10^2$	$4.8x10^2$	4.4x103	$7.7x10^2$	$1.2x10^3$
	Plate 3	TNTC	Damage	1.5×10^5	$1.8x10^3$	$2.8x10^3$	$1.2x10^3$	$1.0x10^2$	$4.2x10^2$	$1.0x10^2$
48 hours	Plate 1	TNTC	2.5×10^3	3.0×10^4	$1.0x10^3$	$2.0x10^2$	$4.0x10^1$	$3.1x10^3$	$1.6x10^2$	$1.5.x10^3$
	Plate 2	TNTC	3.7×10^4	$5.0x10^4$	$3.0x10^2$	$2.0x10^2$	$8.0x10^1$	$5.0x10^2$	$3.0x10^2$	$6.0x10^2$
	Plate 3	TNTC	Damage	$1.0x10^4$	$1.0x10^3$	$3.7x10^3$	$7.0x10^1$	$0.0x10^0$	5.0x101	$1.0x10^2$
Results	Plate 1	-		$1.8x10^5$	$1.9.x10^3$	-	$9.4x10^2$	-	$4.6x10^2$	-
	Plate 2	-		$2.2x10^5$	$9.0.x10^2$	-	$5.6x10^2$	-	$1.1x10^2$	-
	Plate 3	-		$1.6x10^5$	$2.8x10^3$	-	$1.3x10^3$	-	$4.7x10^2$	-
Results	**Average**	-		**$1.9x10^5$**	**$1.9x10^3$**	**-**	**$9.3x10^2$**	**-**	**$6.7x10^2$**	-

TNTC: Too numerous to count.

Dilutions were made and only dishes with 30 to 300 colonies were considered. In this case, it was verified that without the presence of UV, the growth of the bacteria occurred. With a light exposure at 5, 10, and 15 minutes of Hydraulic Retention Time, there was an efficient removal of *E. coli* in the dishes without dilution. In Figure 6.19, the percentage of *E. coli* killed was around 99.0 to 99.6 %.



HRT: Hydraulic Retention Time.

Figure 6.19. Bacteria removal scheme, test.

Figures 6.20 to 6.28 show the results of Table 6.1 of each of the tests carried out in the laboratory.

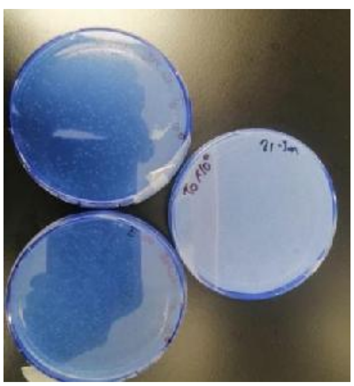


Figure 6.20. T0x 10^0 test 1

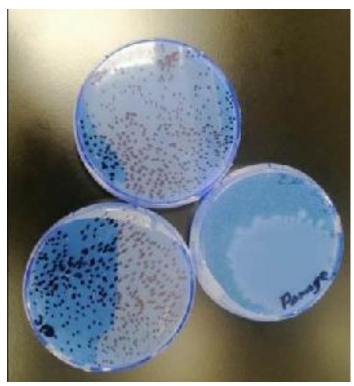


Figure 6.21. T0x 10^{-1} test 1

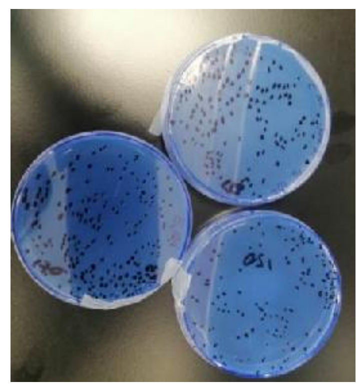


Figure 6.22. T0x 10^{-2} test 1

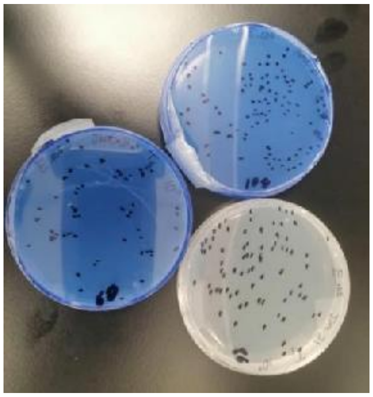


Figure 6.23. T5x 10^0 test 1

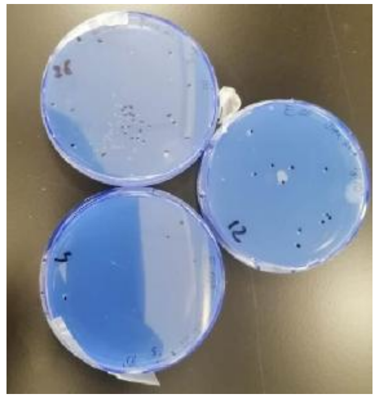


Figure 6.24. T5x 10^{-1} test 1

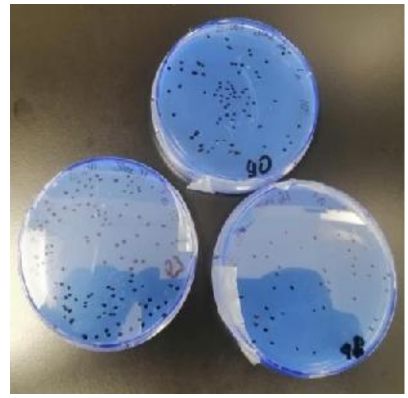


Figure 6.25. T10x 10^0 test 1

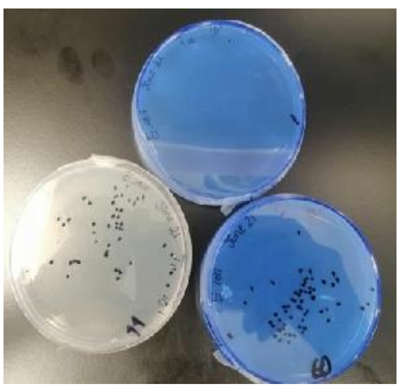


Figure 6.26. T10x 10^{-1} test 1

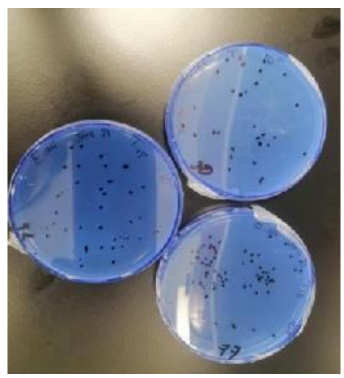


Figure 6.27. T15x 10^0 test 1

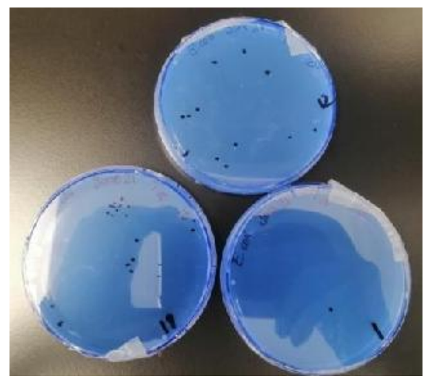


Figure 6.28. T15x 10^{-1} test 1

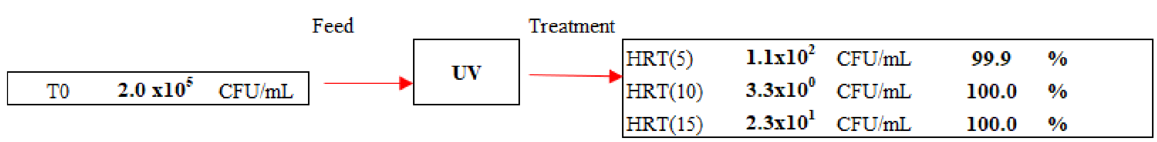
Table 6.2. Results of test 2 (June 28th, 2022)

Disinfection with UV reactor

Date: June 21th, 2022										
Results		**Without UV**			**UV treatment after 5 min**		**UV treatment after 10 min**		**UV treatment after 15 min**	
		$T0x 10^{0}$ CFU/mL	**$T0x 10^{-1}$ CFU/mL**	**$T0x 10^{-2}$ CFU/mL**	**$T5 x 10^{0}$ CFU/mL**	**$T5 x 10^{-1}$ CFU/mL**	**$T10 x 10^{0}$ CFU/mL**	**$T10 x 10^{-1}$ CFU/mL**	**$T15 x 10^{0}$ CFU/mL**	**$T15 x 10^{-1}$ CFU/mL**
24 hours	Plate 1	TNTC	TNTC	$2.8x 10^{5}$	$0.0x10^{0}$	$0.0x10^{0}$	$0.0x10^{0}$	$0.0x10^{0}$	$1.0x10^{1}$	$0.0x10^{0}$
	Plate 2	TNTC	TNTC	$1.2x10^{5}$	$0.0x10^{0}$	$0.0x10^{0}$	$0.0x10^{0}$	$0.0x10^{0}$	$1.0x10^{1}$	$0.0x10^{0}$
	Plate 3	-	TNTC	$2.1x10^{5}$	$0.0x10^{0}$	$0.0x10^{0}$	$0.0x10^{0}$	$0.0x10^{0}$	$2.0x10^{1}$	$1.0x10^{2}$
48 hours	Plate 1	TNTC	TNTC	$0.0x10^{0}$	$4.0x10^{1}$	$0.0x10^{0}$	$0.0x10^{0}$	$0.0x10^{0}$	$1.0x10^{1}$	$0.0x10^{0}$
	Plate 2	TNTC	TNTC	$4.0x10^{3}$	$1.0x10^{2}$	$0.0x10^{0}$	$0.0x10^{0}$	$0.0x10^{0}$	$0.0x10^{0}$	$0.0x10^{0}$
	Plate 3	-	TNTC	$0.0x10^{0}$	$2.0x10^{2}$	$0.0x10^{0}$	$1.0x10^{1}$	$1.0x10^{2}$	$2.0x10^{1}$	$1.0x10^{2}$
Results	Plate 1	-		$2.8x10^{5}$	$4.0.x10^{1}$	-	$0.0x10^{0}$	-	$2.0x10^{1}$	-
	Plate 2	-		$1.2x10^{5}$	$1.0.x10^{2}$	-	$0.0x10^{0}$	-	$1.0x10^{1}$	-
	Plate 3	-		$2.1x10^{5}$	$1.9x10^{2}$	-	$1.0x10^{1}$	-	$4.0x10^{1}$	-
Results	**Average**	-		**$2.0x10^{5}$**	**$1.1x10^{2}$**	-	**$3.0x10^{0}$**	-	**$2.3x10^{1}$**	-

TNTC: Too numerous to count.

In test 2, dilutions were made and, in this case, the dishes without dilution presented colonies of less than 30, for which the removal of the bacteria varied between 99.9% and 100%, as shown in Figure 6.29.



HRT: Hydraulic Retention Time.

Figure 6.29. Bacteria removal scheme, test 2

Figures 6.30 to 6.38 show the results of Table 6.2 of each of the tests carried out in the laboratory.

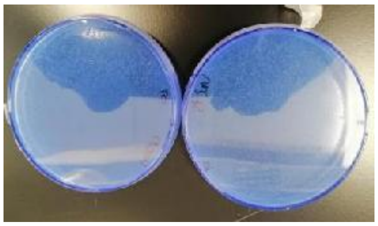


Figure 6.30. T0x 10^0 test 2

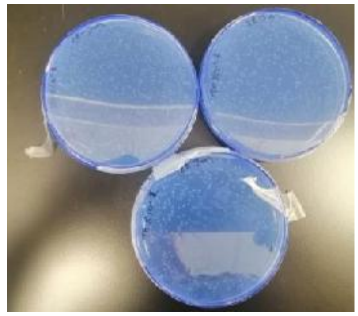


Figure 6.31. T0x 10^{-1} test 2

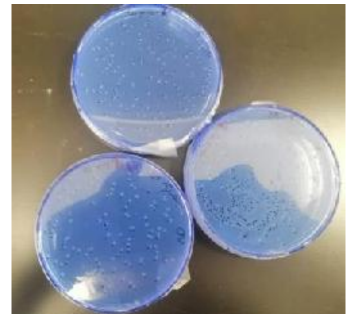


Figure 6.32. T0x 10^{-2} test 2

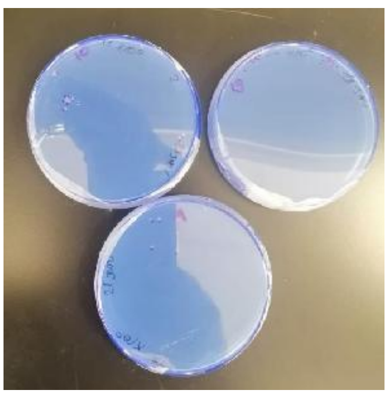


Figure 6.33. T5x 10^0 test 2

Figure 6.34. T5x 10^{-1} test 2

Figure 6.35. T10x 10^0 test 2

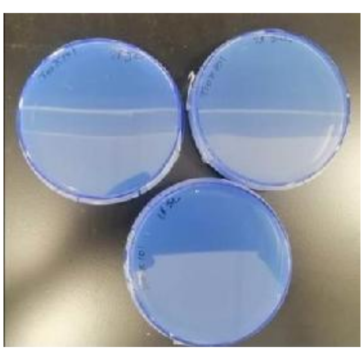


Figure 6.36. T10x 10^{-1} test 2

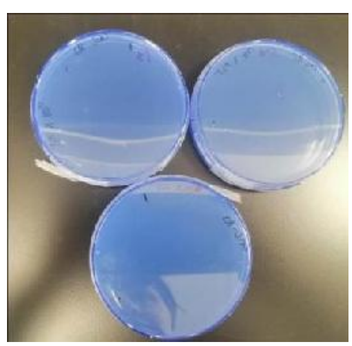


Figure 6.37. T15x 10^0 test 2

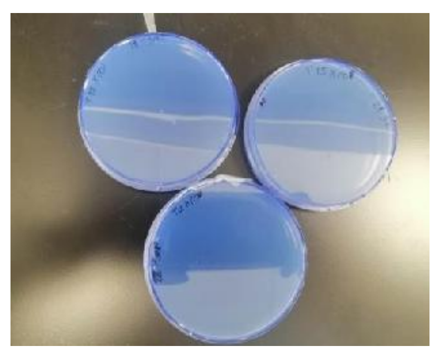
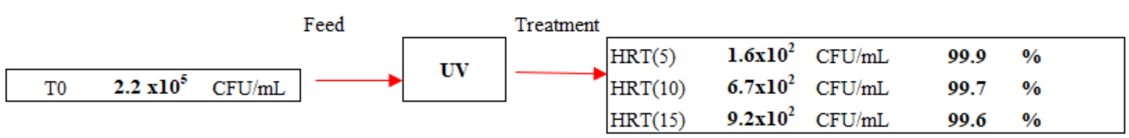


Figure 6.38. T15x 10^{-1} test 2

Table 6.3. Results of test 3 (July 5th, 2022)

Disinfection with UV reactor										
Date: July 5th, 2022										
Results		**Without UV**			**UV treatment after 5 min**		**UV treatment after 10 min**		**UV treatment after 15 min**	
		T0x 10^0 (See Figure 36)	**T0x 10^{-1} (See Figure 36)**	**T0x 10^{-2} (See Figure 36)**	**T5 x 10^0 (See Figure 36)**	**T5 x 10^{-1} (See Figure 36)**	**T10 x 10^0 (See Figure 36)**	**T10 x 10^{-1} (See Figure 36)**	**T15 x 10^0 (See Figure 36)**	**T15 x 10^{-1} (See Figure 36)**
		CFU/mL	**CFU/mL**	**CFU/mL**	**CFU/mL**	**CFU/mL**	**CFU/mL**	**CFU/mL**	**CFU/mL**	**CFU/mL**
24 hours	**Plate 1**	TNTC	TNTC	$3.5x\ 10^5$	$2.0x10^1$	$1.0x10^2$	$4.2x10^2$	$2.0x10^3$	$1.2x10^2$	$1.5x10^3$
	Plate 2	TNTC	TNTC	$3.0x\ 10^5$	$1.4x10^2$	$1.0x10^2$	$4.2x10^2$	$4.5x10^3$	$1.3x10^2$	$2.4x10^3$
	Plate 3	TNTC	TNTC	$0.0x10^0$	$5.0x10^1$	$2.0x10^2$	$6.6x10^2$	$1.1x10^3$	$0.0x10^0$	$4.4x10^3$
48 hours	**Plate 1**	TNTC	TNTC	$0.0x10^0$	$6.0x10^1$	$0.0x10^0$	$1.3x10^2$	$8.0x10^2$	$3.0x10^1$	$1.1x10^4$
	Plate 2	TNTC	TNTC	$0.0x10^0$	$1.7x10^2$	$0.0x10^0$	$9.0x10^1$	$1.1x10^4$	$2.0x10^3$	$4.0x10^2$
	Plate 3	TNTC	TNTC	$0.0x10^0$	$5.0x10^1$	$0.0x10^0$	$2.9x10^2$	$6.0x10^2$	$4.7x10^2$	$1.4x10^3$
Results	**Plate 1**	-	-	$3.5x\ 10^5$	$8.0x10^1$	-	$5.5x10^2$	-	$1.5x10^2$	
	Plate 2	-	-	$3.1x\ 10^5$	$3.1x10^2$	-	$5.1x10^2$	-	$2.1x10^3$	
	Plate 3	-	-	$0.0x10^0$	$1.0x10^2$	-	$9.5x10^2$	-	$4.7x10^2$	
Results	**Average**	-	-	$2.2x\ 10^5$	$1.6x10^2$	-	$6.7x10^2$	-	$9.2x10^2$	

Dilutions were made and, in this case, the dishes without dilution presented colonies of less than 30, for which the removal of the bacteria varied between 99.6% and 99.9%, as shown in Figure 6.39.

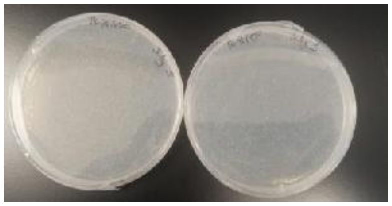


HRT: Hydraulic Retention Time.

Figure 6.39. Bacteria removal scheme, test 3

In the three tests, it can be observed that with the Hydraulic Retention Time of 5 minutes, there was an efficiency of 99.0 % to 100.0 %, which guarantees a death of the E - Coli bacteria for the concentrations found in 5 Chapter. To ensure data quality, a pump calibration was performed as shown in Appendix H.

Figures 6.40 to 6.48 show the results of Table 6.3 of each of the tests carried out in the laboratory.



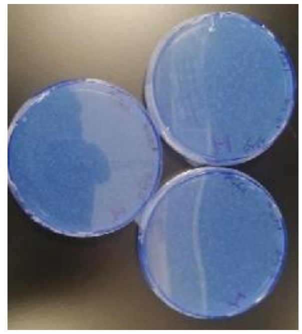
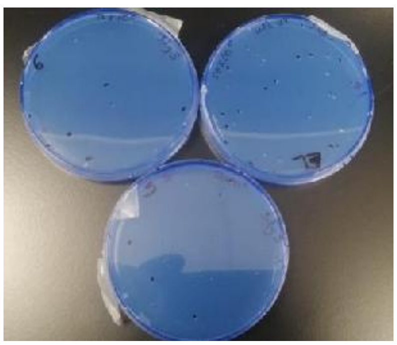
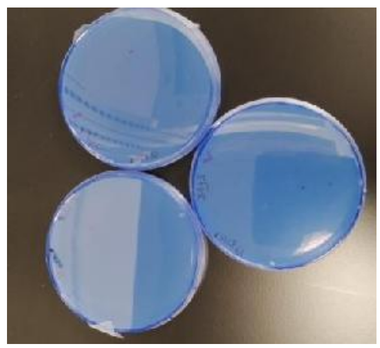


Figure 6.40. T0x 10^0 test 3 **Figure 6.41.** T0x 10^{-1} test 3 **Figure 6.42.** T0x 10^{-2} test 3





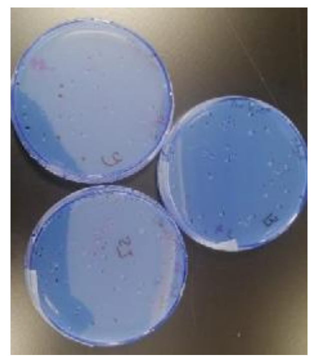
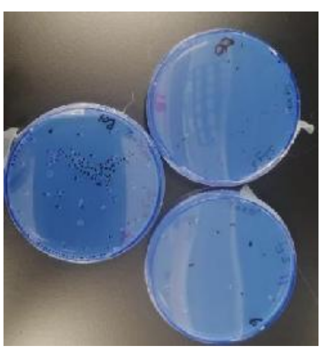
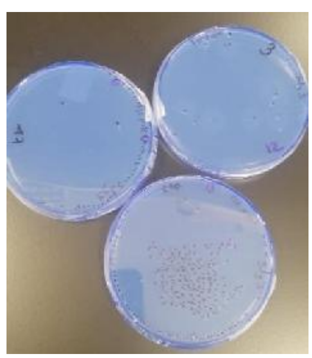


Figure 6.43. T5x 10^0 test 3 **Figure 6.44.** T5x 10^{-1} test 3 **Figure 6.45.** T10x 10^0 test 3





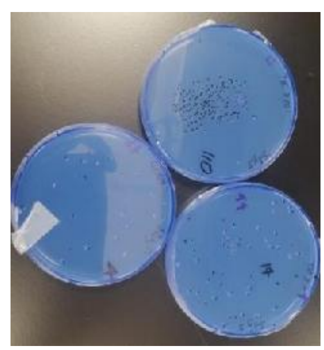


Figure 6.46. T10x 10^{-1} test 3 **Figure 6.47.** T15x 10^0 test 3 **Figure 6.48.** T15x 10^{-1} test 3

Reviewing literature on studies of Ultraviolet-c radiation in drinking water with conventional 10 W lamps, inactivation of total and thermotolerant coliforms of 99.89 % were achieved (Rossel et al., 2020). Expected results compared to those obtained in the laboratory.

6.2.2 Chlorine demand

Additionally, chlorine demand tests were carried out with the hot springs of the study in the Environmental Laboratory of the Colombian School of Engineering Julio Garavito University to determine the dose of chlorine necessary for hot springs in this study using chemical products as an alternative to disinfectant.

The chlorine demand test was carried out as established by Standard Methods 2350 with three replicates of the test, where the following results were obtained for a contact time of 10 minutes with a concentration of chlorine of 100.47 mg/L Cl_2. The results are presented in Table 6.4.

Table 6.4. Results of hot spring 1, tests 1, 2, and 3

Dose mg/L	Test 1, November 5th, 2022				Test 2, November 5th, 2022				Test 3, November 5th, 2022			
	Free chlorine mg/L	**Total chlorine mg/L**	**Combined chlorine mg/L**	**Chorine Demand mg/L-CL_2**	**Free chlorine mg/L**	**Total chlorine mg/L**	**Combined chlorine mg/L**	**Chorine Demand mg/L-CL_2**	**Free chlorine mg/L**	**Total chlorine mg/L**	**Combined chlorine mg/L**	**Chorine Demand mg/L-CL_2**
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	0.1	0.5	0.4	0.0	0.1	0.5	0.4	0.0	0.1	0.5	0.4	0.0
1.0	0.1	1.0	0.9	0.0	0.1	1.0	0.9	0.0	0.1	1.0	0.9	0.0
2.0	0.2	2.0	1.8	0.0	0.2	2.0	1.8	0.0	0.2	2.0	1.8	0.0
3.0	0.3	2.7	2.4	0.3	0.3	2.7	2.4	0.3	0.3	2.7	2.4	0.3
4.0	0.3	3.0	2.7	1.0	0.3	3.0	2.7	1.0	0.3	3.0	2.7	1.0
5.0	0.8	1.3	0.5	3.7	0.6	0.9	0.3	4.1	1.0	1.6	0.6	3.4
6.0	1.3	1.7	0.4	4.3	1.7	2.0	0.3	4.0	1.7	2.0	0.3	4.0
7.0	2.3	3.3	1.0	3.7	2.6	3.0	0.4	4.0	2.6	3.3	0.7	3.7
8.0	4.0	4.3	0.3	3.7	3.6	3.8	0.2	4.2	3.8	4.1	0.3	3.9
9.0	4.9	5.1	0.2	3.9	4.5	4.9	0.4	4.1	5.0	5.1	0.1	3.9
10.0	5.8	6.0	0.2	4.0	5.5	5.8	0.3	4.2	6.0	6.1	0.1	3.9

Graphing the above results, it is found that the Total Chlorine break point corresponds to a dose of 5 mg/L, as shown in Figures 6.49, 6.50, and 6.51.

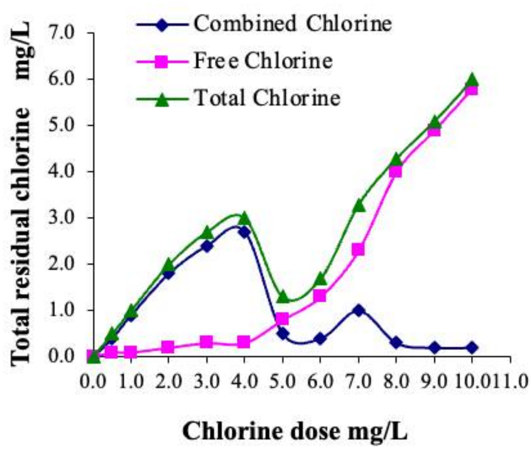


Figure 6.49. Chlorine demand curve - test 1

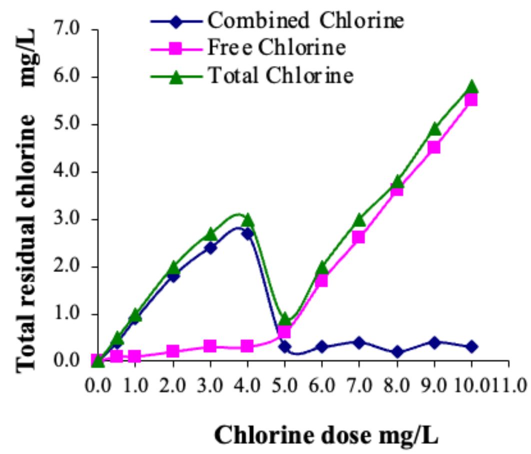


Figure 6.50. Chlorine demand curve - test 2

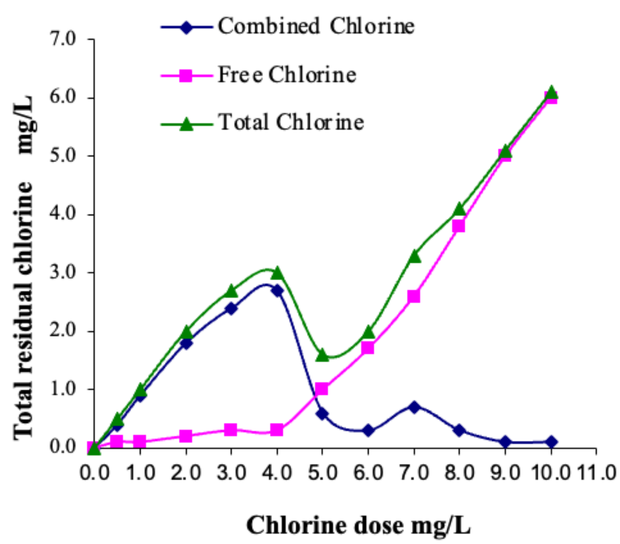


Figure 6.51. Chlorine demand curve- test 3

Table 6.5. Results of hot spring 2, tests 1, 2, and 3

Dose mg/L	Test 1, November 28th, 2022				Test 2, November 28th, 2022				Test 3, November 28th, 2022			
	Free chlorine mg/L	**Total chlorine mg/L**	**Combined chlorine mg/L**	**Chorine Demand mg/L-CL_2**	**Free chlorine mg/L**	**Total chlorine mg/L**	**Combined chlorine mg/L**	**Chorine Demand mg/L-CL_2**	**Free chlorine mg/L**	**Total chlorine mg/L**	**Combined chlorine mg/L**	**Chorine Demand mg/L-CL_2**
0.0	0.0	0.0	0	0	0.0	0.0	0.0	0	0.0	0.0	0.0	0
0.5	0.2	0.4	0.2	0.1	0.1	0.4	0.3	0.1	0.1	0.4	0.3	0.1
1.5	0.7	1.3	0.6	0.2	0.7	1.2	0.5	0.3	0.7	1.2	0.5	0.3
2.5	2.0	2.2	0.2	0.3	1.5	2.1	0.6	0.4	1.6	2.1	0.5	0.4
3.5	3.0	3.2	0.2	0.3	2.1	2.7	0.6	0.8	2.5	2.8	0.3	0.7
4.5	3.7	4.0	0.3	0.5	3.3	3.7	0.4	0.8	3.5	3.9	0.4	0.6
6.0	4.8	5.1	0.3	0.9	5.1	5.5	0.4	0.5	4.8	5.2	0.4	0.8
8.0	6.2	6.7	0.5	1.3	6.2	6.7	0.5	1.3	6.2	6.7	0.5	1.3
10.0	8.2	9.0	0.8	1.0	8.2	9.0	0.8	1.0	8.2	9.0	0.8	1.0
12.0	10.9	11.1	0.2	0.9	10.9	11.1	0.2	0.9	10.9	11.1	0.2	0.9

In Figures 6.52, 6.53, and 6.54, it can be seen that the combined chlorine curve does not descend, due to the high organic load of the hot spring.

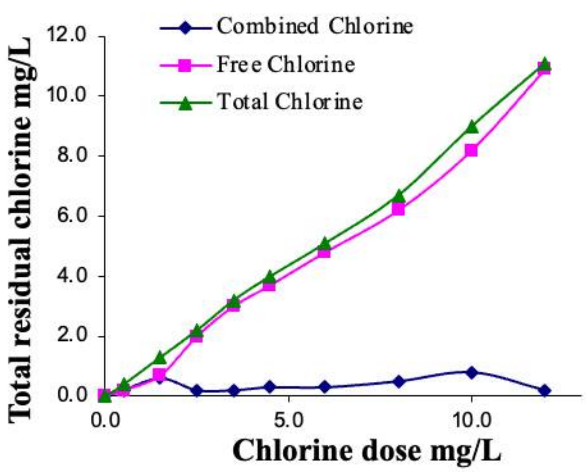


Figure 6.52. Chlorine demand curve, test 1

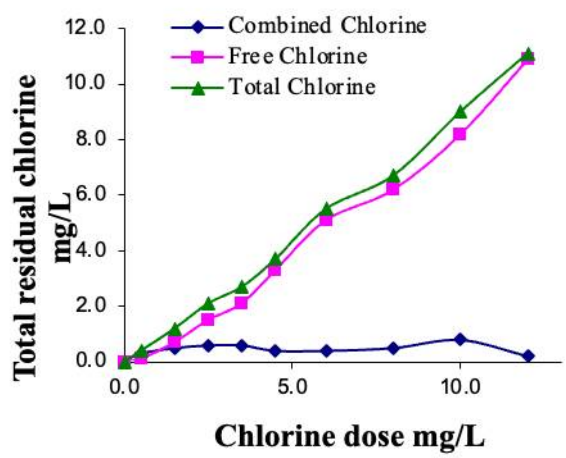


Figure 6.53. Chlorine demand curve, test 2

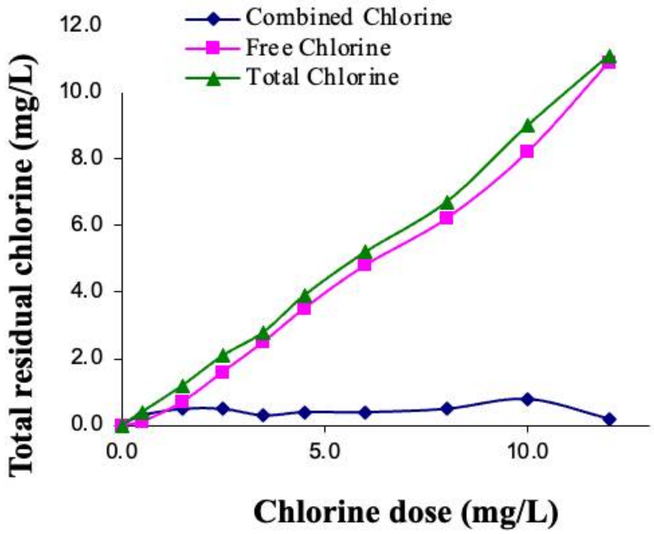


Figure 6.54. Chlorine demand curve, test 3

In the laboratory, additional tests were carried out with concentrations of up to 12 mg/L and high values were obtained as shown in Table 6.6. Therefore, it is important in future work to investigate how disinfection with chemical products could be carried out in this type of ferruginous hot spring, to know the breaking point of the chlorine demand curve (See Figure 6.58 of the literature review).

Table 6.6. Result of hot spring 2, dose 15 and 20 mg/L

Dose mg/L	Free chlorine mg/L	Total chlorine mg/L	Combined chlorine mg/L	Chorine Demand mg/L-CL_2
15.0	14.9	14.9	0.0	0.1
20.0	19.2	19.2	0.0	0.8

It would be important to review more powerful disinfectants and oxidizers to treat combined chlorine. To give depth on this topic, we will participate in this congress:

Proceedings of the 7th International Conference of Recent Trends in Environmental Science and Engineering (RTESE 2023)". June 4 to 6, 2023. Carleton University, Ottawa, Canada to be presented in:

Speaker and Abstract: "***Chlorine demand in bicarbonated and ferruginous hot springs in the Cundinamarca region, Colombia***". Authors: Yuly Sánchez, Mehrab Mehrvar, Lynda McCarthy, Edgar Quiñones, Luis Cheu, Alexander Reuß, Jairo Romero. In process.

6.2.3 Implementation of engineered wetlands

A constructed wetland (CW) is an artificial swamp. It can be implemented in wastewater treatment systems for the control of bacteria and viruses in recreational water, because it is a natural treatment that involving wetland vegetation, soil, and their associated microbials (Tucci, 2018), (Martinez, et al., 2018).

Although there are many investigations on the implementation of constructed wetlands, the vegetation that the CW should have been not entirely clear in using native non-invasive macrophyte methods (Tucci, 2018).

The use of *T. latifolia* and other species known to be invasive are commonly used in constructed wetlands under high rates of nutrient loading and would impose significant environmental risk in watersheds that have not been impacted by invasive species. (Mark, 2013). Therefore, it is important that for the implementation of CW in wastewater hot spring, non-invasive species are determined for its treatment.

The application of CW in wastewater treatment is used for the removal of nutrients and the removal of pollutants (metals, industrial such as winery wastewater and emerging pollutants including pharmaceutical compounds) (Martinez et al., 2018; Johnson & Mehrvar, 2019).

Environment Canada (1996) provided the possible list of species that may be used in wetland restoration and constructed wetland (See Table 6.7) (Fernandes, 2015).

Table 6.7. Macrophyte Selection Criteria for the Sixteen Different Emergent Species on the Environment Canada (1996) List

Scientific Name **Common Name**	***Scientific Name*** **Common Name**
Alisma plantago-aquatica Water plantain	*Pontederia cordata* Pickerelweed
Asclepias incarnata Swamp milkweed	*Sagittaria latifolia* Arrowhead
Carex spp. Sedge	*Scirpus acutus* Hard-stem bulrush
Chelone glabra Turtlehead	*Scirpus atrovirens* Black bulrush
Eleocharis spp. Spike rushes	*Scirpus validus* Soft-stem bulrush
Equisetum fluviatile Water horsetail	*Sparganium eurycarpum* Giant bur-reed
Iris versicolor Wild blue flag	*Typha spp.* Cattails
Juncus spp. Rushes	*Veronica americana* American brooklime

6.3 CONCLUSIONS

The use of UV light allows a disinfection to the hot springs without chemicals, conserving its physical and chemical properties of the water, the tests carried out in the laboratory for the removal of bacteria such as *E. coli* where removal efficiencies of up to 99.9% were obtained.

In the future it is important to replicate the methodology of this chapter with different types of hot springs and determine if the efficiency of UV light is maintained. Considering that UV light can be an expensive treatment for small spas, it is important not only to preserve the chemical properties of the water, but also to ensure the absence of pathogenic microorganisms in the water and to use disinfectants such as chlorine.

Depending on the type of hot spring, it is important to determine the dose of chlorine that is required for its disinfection in case of opting for disinfection with chemicals. In the case of the bicarbonate thermal, a dose of approximately 5 mg/L is necessary, and for the ferruginous it was not possible to find the breaking point of the chlorine demand curve. Tests up to 30 mg/L were carried out and the break point was not found, therefore, more research is required for future work.

Implementing CW in the treatment of wastewater from hot springs is important due to its great benefit of removing even heavy metals and low operating costs. Because it is a natural treatment, it is important to carry out future research on the type of plantation to be implemented, considering that some plants may be invasive in one country and native in another.

Chapter 7

BASELINE CONCENTRATION OF LIMIT PARAMETERS OF THE HOT SPRINGS

This chapter shows the fulfillment of the third objective of the doctoral *"To study a baseline concentration of limited parameters in hot springs as future potential indicators of risk to human health and aquatic ecosystems".*

Considering what has been developed in the previous chapters, it is important to highlight that since there are different types of hot springs, each hot spring has its own characteristics, such as: ferruginous, chlorinated, sulphurous, sulphated, bicarbonate, and radioactive. In the present study, two types of bicarbonate and ferruginous hot springs were analyzed, therefore, to establish general limit parameters in the physical-chemical quality of the water, it is important to know its composition.

Thus, to establish limit concentrations of each of the types of hot springs, it is important to consider that more robust monitoring tests are required, to have a more solid database for decision-making and statistical tests can be carried out with a greater number of data. Regarding the presence of heavy metals in the monitoring carried out, their presence was not detectable.

Therefore, it is important to carry out an initial test where your water is characterized and is determined if it exceeds limit values with drinking water regulations. Therefore, it would be important for government entities to carry out clinical/epidemiological studies and regular monitoring and control measures, to verify the prevalence of diseases caused by ingestion and dermal contact with water.

The World Health Organization (WHO, 2021) establishes reference values for the microbial quality of water. The reference value threshold for the no observed adverse effect level or lowest observed adverse effect level for gastrointestinal illnesses and acute febrile respiratory illnesses is 200 cfu/100 mL (See Table 7.1).

Table 7.1 Guideline values for microbial quality of coastal and freshwater recreational waters

Intestinal enterococci (95th percentile value per 100 mL [rounded values]) Basis of derivation Estimated risk per exposure	Basis of derivation	Estimated risk per exposure
≤40 A	This range is below the NOAEL in most epidemiological studies. Low risk or low probability of adverse effects.	• <1% GI illness risk. • <0.3% AFRI risk. • The upper 95th percentile value relates to an average probability of less than 1 case of gastroenteritis in every 100 exposures. The AFRI burden would be negligible.
41–200 B	The 200/100 mL value is above the threshold of illness transmission reported in most epidemiological studies that have attempted to define a NOAEL or LOAEL for GI illness and AFRI.	• 1–5% GI illness risk. • 0.3–1.9% AFRI risk. • The upper 95th percentile value relates to an average probability of 1 case of gastroenteritis in 20 exposures. The AFRI illness rate at this upper value would be less than 19 per 1000 exposures, or less than approximately 1 in 50 exposures.
201–500 C	This range represents a substantial elevation in the probability of all adverse health outcomes for which dose– response data are available.	• 5–10% GI illness risk. • 1.9–3.9% AFRI risk. • This range of 95th percentiles represent a probability of 1 in 10 to 1 in 20 of gastroenteritis for a single exposure. Exposures in this category also suggest a risk of AFRI of 19–39 per 1000 exposures, or approximately 1 in 50 to 1 in 25 exposures.
>500 D	Above this level, there may be significant risk of high levels of minor illness transmission.	• >10% GI illness risk. • >3.9% AFRI risk. • There is a greater than 10% chance of gastroenteritis per single exposure. The AFRI illness rate at the 95th percentile value of >500/100 mL would be greater than 39 per 1000 exposures, or greater than approximately 1 in 25 exposures.

A–D: microbial water quality assessment categories (refer to section 4.3) used in the classification procedure; AFRI: acute febrile respiratory illness; GI: gastrointestinal; LOAEL: lowest-observed-adverse-effect level; NOAEL: no-observed-adverse-effect level.

The results of the characterizations of the hot springs, the presence of total coliforms, fecal coliforms (*E. coli*), *Legionella*, *P. aeruginosa*, molds and yeasts were detected, for which the disinfection of its waters must be guaranteed so that they do not represent a risk to the bather. In the literature there is evidence of risk indicator methodologies for recreational waters, as shown in numeral *2.7.1 Methodologies for the Calculation of Risk Indicators*, as in Colombia, Argentina, and the United States.

Below is a baseline of the limit objectives for hot springs, considering the results of chapter 5 and the laboratory tests carried out in chapter 6 for recreational use.

Physical-chemical parameters

In chapter 5, the physical-chemical parameters were analyzed. It is observed that the physical-chemical parameters to regulate for a hot spring should be for analysis and results because the parameters are specific to each type of hot spring.

In the case of discharge of hot spring wastewater, the limits established by the discharge regulations must be met. A treatment system must be implemented to remove parameters such as iron, chlorides, etc., according to the predominance of the wastewater each hot spring.

Microbiological parameters

The presence of bacteria in the water should be zero, to guarantee the health of the bather, in the parameters of fecal coliforms (*E. coli*), *Legionella*, and *P. aeruginosa* in the case of primary contact with the bather, for which systems should be implemented disinfection in the hot springs.

In the case of discharge of hot spring wastewater, the limits established by the discharge regulations must be complied with.

Control of quality of the hot springs

Users may differ in their susceptibility to potential hazards, as the bather may accidentally swallow water or older, immunocompromised bathers may be more susceptible to pathogenic microorganisms. Therefore, they are at greater risk of side effects, adverse to health due to microbial contamination of water (WHO, 2021). It is important that a quality control of the hot springs be carried out, considering the following criteria:

- Seasonal changes: due to environmental conditions and seasons of use, considering that a greater flow of bathers may be experienced in summer, increasing the pollutant load and may lead to the need for more frequent use. By carrying out monthly controls, it allows detecting and addressing any water quality problem before it becomes a risk to the health of bathers.

- **Accumulation of contaminants:** by bathers such as sweat, urine, body oils, etc. Monthly monitoring allows you to assess and adjust levels of disinfectant and other chemicals to maintain proper water quality.

- **Prevention of disease outbreaks:** because hot springs can be a favorable environment for the proliferation of pathogenic microorganisms, such as bacteria, viruses and fungi. Carrying out monthly controls, which include microbiological analysis, helps detect the presence of these microorganisms and take corrective measures immediately to avoid outbreaks of waterborne diseases (WHO, 2021).

- Compliance with regulations: In many countries, there are regulations and standards that specify the frequency of water quality control in recreational facilities, such as swimming pools and hot springs. These regulations usually establish the minimum periodicity for monitoring and may require monthly or even more frequent checks.

7.1 CONCLUSIONS

In terms of water quality control, it is essential to consider the physical-chemical parameters specific to each type of hot spring and comply with discharge regulations for hot spring wastewater. Disinfection systems should be implemented to ensure the absence of bacteria in hot spring waters. Regular monitoring is crucial to detect any water quality issues, adjust disinfectant and chemical levels, prevent disease outbreaks, and ensure compliance with regulations.

Factors such as seasonal changes, accumulation of contaminants from bathers, prevention of disease outbreaks, and compliance with regulations should be considered in the quality control of hot springs. Monthly monitoring and analysis, including microbiological assessments, enable prompt detection of potential risks and the implementation of corrective measures to maintain a safe and healthy environment for bathers.

Chapter 8

CONCLUSIONS AND RECOMENDATIONS

Not all hot springs are equal, each hot spring has its own characteristics.

Considering the lack of legislation that defines the quality criteria of hot springs in balnearies with recreational and medicinal purposes, a regulation must be established that protects the health of the bather. If the use of a hot spring is recreational, it must be considered that its use is for dermal contact, so it is not reasonable for hot springs to be regulated the same as drinking water because the use given to them in Colombia is not for human consumption.

The hot springs of the study show some physical and chemical characteristics of each type of water, in this case hot spring 1 is bicarbonate and hot spring 2 is ferruginous.

The normal temperature of the human body is 37 °C and considering that mesophilic bacteria develop at temperatures between 20 and 35 °C, they represent a risk for the bather. For this reason, the hot spring baths will need to disinfect their waters. In the case of the hot spring wastewater, natural treatment systems, such as engineered wetlands, are an alternative to conventional wastewater treatment.

It is important that government entities carry out clinical/epidemiological studies and periodic monitoring and control measures to verify the prevalence of diseases caused by ingestion and dermal contact with hot springs. For this reason, surveys, interviews or medical reviews can be carried out to identify any adverse health effects associated with exposure to hot spring water.

Future Works

Further research can include:

- Hot spring discharge analysis with COVID–19.
- Implementation of engineered wetlands for analysis of wastewater from hot springs.
- Chlorine demand analysis for different types of hot springs.
- Implementation of hot spring quality models, including the transport of contaminants.
- Carry out tests with a UV reactor, simulating hot springs with temperatures between 20 °C and 35 °C and their chemical and physical properties, especially turbidity, suspended solids, colour, iron, manganese, and pH for ferruginous hot springs.
- Perform tests with natural ultraviolet radiation.
- Continuation of the thesis "Approach to a Mathematical Model for the Evaluation of Thermal Aquifers: Paipa Geothermal System Case Study" for other hot spring aquifers in Colombia.

Acronyms

BCDMH	Bromochlorodimethylhydantoin.
BDO	Biochemical Oxygen Demand.
CFU	Colonies Form Unit.
COD	Chemical Oxygen Demand.
DO	Dissolved Oxygen.
ECDC	European Center for Disease Prevention and Control.
ELAP	Emerging Leaders in the Americas Program.
EPA	Environmental Protection Agency United States.
HRT	Hydraulic Retention Time.
NTU	Nephelometric Turbidity Unit
TC	Total Carbon.
TDS	Total Dissolved Solids.
TIC	Total Inorganic Carbon.
TNTC	Too Numerous to Count.
TOC	Total Organic Carbon.
TSA	Tryptic Soy Agar
TSS	Total Suspended Solids.
UV	Ultraviolet.
WHO	World Health Organization

Bibliography

Alberta (Canada), Public Health Act. Alberta Regulation 204/2014. Public Swimming Pools Regulation. Available in: <https://www.qp.alberta.ca/1266.cfm?page=2014_204.cfm&leg_type=Regs&display=html>. (Accessed on 30 March 2020).

Alberta (Canada), Environmental Protection and Enhancement Act. (2013). Wastewater and Storm Drainage (Ministerial) Regulation. Canada. Available in: <https://www.canada.ca/en/environment-climate-change/services/wastewater/regulations.html>. (Accessed on 30 March 2020).

Almeida, C., Gonzalez, SO., Maella, M., and Gonzalez., P. (2012). A recreational water quality index using chemical, physical and microbiological parameters. Environ Sci Pollut Res Int. 2012 Sep;19(8):3400-11. doi: 10.1007/s11356-012-0865-5. Epub 2012 Apr 14. PMID: 22528988.

Andueza, F., Chaucala, S., Vinueza, R., Escobar, S., Medina, G., and Araque, J. (2020). Calidad microbiológica de las aguas termales del balneario “El Tingo”. Pichincha. Ecuador. Ars Pharm. Vol.61 no.1. https://dx.doi.org/10.30827/ars.v61i1.8378.

APHA, AWWA, WEF. (2017). Standard Methods for the Examination of Water and Wastewater, 23rd edition, American Public Health Association, Washington, D.C.

Ara, M., Zaballos, P., Simal, E., and Zubiri, M. (2003). Pseudomonas aeruginosa folliculitis. Actas Dermo-Sifiliográficas. Vol. 94, pp107-109. doi.org/10.1016/S0001-7310 (03)79235-7.

Armijo, M., and San Martín, J. (1994). Clasificación de las aguas mineromedicinales. En: Curas Balnearias y Climáticas. Talasoterapia y Helioterapia, Ed. Computense, Madrid, 93-99. Available in: <http://www.sld.cu/galerias/pdf/sitios/rehabilitacion-bal/clasificacion_aguas_minerales.pdf>. (Accessed on 30 March 2019).

Badhai, J., Ghosh, T., and Das, S. (2015). Taxonomic and functional characteristics of microbial communities and their correlation with physicochemical properties of four geothermal springs in Odisha, India. Frontiers in Microbiology. Vol. 6:1166, pp 1 – 15. doi.org/10.3389/fmicb.2015.01166.

Barrera, M. (2011). Master Thesis “Photochemical Treatment of Organic Constituents and Bacterial Pathogens from Synthetic Slaughterhouse Wastewater by Combining Vacuum-UV and UV-C”. Ryerson University.

Barrera, M., Mehrvar, M., Gilbride, K., McCarthy, L., Laursen, A., Bostan, V., and Pushchak, R. (2012). Photolytic treatment of organic constituents and bacterial pathogens in secondary effluent of synthetic slaughterhouse wastewater. Chemical Engineering Research and Design. Vol. 90, pp 1335–1350. doi.org/10.1016/j.cherd.2011.11.018.

Bayona, H. (2005). Operación y Manejo de Piscinas, Editorial Lemoine, Bogotá – Colombia.

Bayona, H. (1993). Piscinas, Editorial de Cafam, Bogotá – Colombia.

Berivan, A. and Asia, S. (2017). Isolation and identification of yeasts from indoor swimming pools in duhok city with special concern to the effect of some disinfectant agents. Science Journal of University of Zakho. Vol. 5, No 2, pp 154 – 157. DOI:10.25271/2017.5.2.360.

Bolton, J., and Cotton, C. (2022). Ultraviolet (UV) Disinfection for Water Treatment. Second Edition. AWWA, American Water Works Association.

British Columbia, Ministry of Water, Land and Air Protection. (1998). Water Quality Ambient Water Quality Criteria for Organic Carbon in British Columbia. Available in: <https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/water-quality-guidelines/approved-wqgs/organic-carbon-tech.pdf>. (Accedes on 23 January 2023).

Byappanahalli, M., Nevers, M., Korajkic, A., Staley, Z., Harwood, V. (2012). Enterococci in the environment. Microbiol Mol Biol Rev. Vol 76(4), pp 685-706. Doi:

10.1128/MMBR.00023-12. PMID: 23204362; PMCID: PMC3510518.

Cantabria (Spain). Law 2 of 1988, of October 26. On the Promotion of the Management and Use of Spas and Mineral-medicinal and / or Thermal Waters of Cantabria. Available in: <https://www.boe.es/buscar/pdf/1988/BOE-A-1988-28707-consolidado.pdf>. (Accessed on 30 March 2020).

Catalonia (Spain) Department of Health and Social Security. Decree 271 of October 9, 2001. By establishing the technical-sanitary requirements for balneotherapy and hydrotherapy services. Available in: < https://vlex.es/vid/cumplir-balneoterapia-hidroterapia-331036622>. (Accessed on 30 March 2020).

CDCP. Centers for Disease Control and Prevention. Coronavirus Disease 2019 (COVID-19)- Section Water”. Available in: <https://www.cdc.gov/coronavirus/2019ncov/faq.html?CDC_AA_refVal=https%3A%2F%2Fwww.cdc.gov%2Fcoronavirus%2F2019-ncov%2Fphp%2Fwater.html#COVID-19-and-Water>. (Accessed on 20 June 2020).

Chilean Ministry of Health. (2012). Decree 209. Regulation of pools for public use. Available in: < https://comoadministrarcondominios.cl/wp-content/uploads/2021/05/Reglamento-de-piscinas-DTO-209_08-NOV-2003.pdf>. (Accessed on 20 June 2022).

Cheema, W., Kaarsholm, K., and Andersen, R. (2017). Combined UV treatment and ozonation for the removal of by-product precursors in swimming pool water. Journal Water Research. Vol. 110, pp141-149. doi.org/10.1016/j.watres.2016.12.008.

Colombia, Ministry of Social Protection. (2010). By which Decree 2171 of 2009 is partially regulated. Available online: < http://corpouraba.gov.co/sites/default/files/resolucion1618de2010.pdf>, (accessed on 01 March 2022).

Colombia, Ministry of Social Protection and Ministry of environment, housing and territorial development. (2007). Resolution 2115. By means of which characteristics, basic instruments and frequencies are indicated of the control and surveillance system for the quality of water for human consumption. Available online: < https://laboratoriodeanalisis.lasalle.edu.co/wcm/connect/LIAC/d951c109-a227-44a3-8a42-1d1f87db2b43/Resoluci%C3%B3n_2115-2007.pdf?MOD=AJPERES&CVID=lMo0SFe>, (accessed on 01 March 2022).

Colombia, Congress of Colombia. Bill 62 of 2015. Available in: <https://www.funcionpublica.gov.co/eva/gestornormativo/norma.php?i=61202>. (Accessed on 20 May 2019).

Colombia, Ministry of Health and Social Protection. Article 6, Decree 554 of 2015. Available in: <https://vlex.com.co/vid/proyecto-ley-62-2015-581011182>. (Accessed on 20 May 2019).

Colombia, Ministry of the Environment and Sustainable Development. Resolution 631 of 2015. Available in: <https://rds.org.co/es/recursos/resolucion-631-de-2015-parametros-vertimientos>. (Accessed on 20 May 2019).

Colombia, Ministry of the Environment and Sustainable Development. Decree 1076 of 2015. Available in: < https://www.minambiente.gov.co/documento-normativa/decreto-1076-de-2015/>. (Accessed on 20 May 2019).

Colombian Geological Service. National Inventory of Hydrothermal Manifestations. Available in: <http://hidrotermales.sgc.gov.co/invtermales/>. (Accessed on 20 May 2019).

CTV News Canada. (2020, June 8). Is it safe to swim in a pool during the COVID–19 pandemics? Available in: <https://www.ctvnews.ca/health/coronavirus/is-it-safe-to-swim-in-a-pool-during-the-covid-19-pandemic-1.4975060>. (Accessed on 10 June 2020).

Cuba. (1998). NC93-09:85, NC 93-28:88. Sanitary water control subprogram. Available in: <http://www.sld.cu/galerias/pdf/sitios/rehabilitacion-bal/subprograma_control_sanitario_del_agua.pdf>. (Accessed on 30 March 2020).

Dalzochio, T., Zimmermann, G., Evandro, I., Gehlen, G., and Basso, L. (2016). The use of biomarkers to assess the health of aquatic ecosystems in Brazil: a review.

International Aquatic Research. Vol. 8, pp 283–298. doi.org/10.1007/s40071-016-0147-9.

De la Rosa Jorge, M., and Mosso, M. (n.d). Microbial diversity of thermal mineral waters. Madrid. Available in: <http://aguas.igme.es/igme/publica/pdfart3/diversidad.pdf>. (Accessed on 23 March 2019).

Devore, J. (2001). Probability and Statistic for Engineering and the Sciences, 5th Edition. Thomson Learning.

Díaz, D., Castro, F., Bocos, E., Montenegro, C., and Gonzalez, R. (2019). 2008–2017 Bogota River Water Quality Assessment based on the Water Quality Index. Sustainability, MDPI, Open Access journal, vol. 11(6), pp 1-21. doi: 10.3390/su11061668.

Durowoju, OS., Ekosse, GE., and Odiyo., JO. (2020). Occurrence and Health-Risk Assessment of Trace Metals in Geothermal Springs within Soutpansberg, Limpopo Province, South Africa. International Journal of Environmental Research and Public Health, vol. 17 (12), pp 1 – 20. Doi: 10.3390/ijerph17124438.

ECDC, European Centre for Disease Prevention and Control. "Interim guidance for environmental cleaning in non-healthcare facilities exposed to SARS-CoV-2", 2020. Available in: <https://www.ecdc.europa.eu/sites/default/files/documents/coronavirus-SARS-CoV-2- guidance-environmental-cleaning-non-healthcare-facilities.pdf >. (Accessed on 30 July 2020).

ECOQUIMSA. (n.d). Laboratorio Ecológico y Químico. Grasas y Aceites. Available in: < https://www.ecoquimsa.com.gt>. (Accessed on 14 January 2023).

El Espectador. (2020). Seven Hot springs in Colombia to relax and enjoy nature. Available in: <https://www.elespectador.com/noticias/mundo-destinos/turismo-en-colombia-7-termales-para-relajarse-y-disfrutar-de-la-naturaleza/>. (Accessed on 14 April 2021).

Encyclopedia of Analytical Science. (2005). Water Analysis/ Chemical Oxygen Demand. Second Edition, pp 325-330.

EPA, United States Environmental Protection Agency. (n.d).5.8 Total Solids. Available in:

<https://archive.epa.gov/water/archive/web/html/vms58.html>. (Accessed on 20 January 2023).

EPA, United States Environmental Protection Agency. (1993). Method 351.2, Revision 2.0: Determination of Total Kjeldahl Nitrogen by Semi-Automated Colorimetry. Available in: < https://www.epa.gov/sites/default/files/2015-08/documents/method_351-2_1993.pdf>. (Accessed on 20 January 2023).

EPA, United States Environmental Protection Agency. (n.d). Indicators: Enterococci. Available in: < https://www.epa.gov/national-aquatic-resource-surveys/indicators-enterococci>. (Accessed on 20 January 2023).

EPA, United States Environmental Protection Agency. (n.d). Water: Monitoring & Assessment: Phosphorus. Available in: < https://archive.epa.gov/water/archive/web/html/vms56.html>. (Accessed on 20 January 2023).

EPA, United States Environmental Protection Agency. (2012). Recreational Water Quality Criteria (RWQC) for Bacterial Indicators of Fecal Contamination. Available in: < https://www.epa.gov/wqc/recreational-water-quality-criteria-and-methods>. Accessed on 20 May 2023).

Erfurt, P., and Cooper, M. (2009). Health and Wellness Tourism Spas and Hot Springs. Channel View Publications, Vol. 40 of Aspects of tourism, pp 139.

Evans, H. (1997). Water Distribution in Ancient Rome: The Evidence of Frontinus. University of Michigan Press. pp. 9, 10. ISBN 0-472-08446-1.

Fang, Z., Mehrvar, M., and Mozafarri, F. (2008). Mixing time in an agitated multi-lamp cylindrical photoreactor using electrical resistance tomography. Journal of Chemical Technology & Biotechnology. Vol. 83, pp 1676–1688. doi.org/10.1002/jctb.1986.

Fernandes, F. (2015). Evaluating Macrophyte Selection and Germination Protocols to Enhance Nutrient Sequestration in Engineered Wetland Models. Thesis of Ryerson.

Fioravanti, A., Giannitti, C., Bellisai, B., Lacoponi,F., and Galeazzi,M. (2012). Efficacy of balneotherapy on pain, function and quality of life in patients with osteoarthritis of the knee. International Journal of Biometeorology.Vol.56, pp 583-590. doi.org/10.1007/s00484-011-0447-0.

Galicia (Spain) Ministry of Health and Social Services. Order of November 5, 1996. Which regulate the sanitary authorization of the spa establishments of the Autonomous Community of Galicia. Available in: <https://www.xunta.gal/dog/Publicados/1996/19961120/AnuncioE01A_es.html>. (Accessed on 30 March 2020).

Galvez, I., Torres, S., and Ortega, E. (2018). Balneotherapy, Immune System, and Stress Response: A Hormetic Strategy? International Journal of Molecular Sciences. Vol. 19, pp 1-19. doi.org/10.3390/ijms19061687.

García, N., Pedraza, J., Montalvo, J., Martínez, M., and Leyva, J. (2012). Evaluación preliminar de riesgos para la salud humana por metales pesados en las bahías de Buenavista y San Juan de los Remedios, Villa Clara, Cuba. Revista Cubana de Química. Available in:< https://revistas.uo.edu.cu/index.php/cq/article/view/324/318>. (Accesed on 14 April 2020).

Germany. BGBl. I 2016, 476. (2016). Ordinance on the quality of water intended for human consumption. (Drinking Water Ordinance - TrinkwV). Available in: < https://www.gesetze-im-internet.de/trinkwv_2001/BJNR095910001.html>>. (Accessed on 20 February 2020).

Germany. DIN 19643-1. (1997). Treatment of water of swimming pools and baths –Part 1. Available in: <https://www.beuth.de/de/norm/din-19643-1/2936483>. (Accessed on 20 February 2020).

Ghilamicael, A., Boga, H., Anami, S., Mehari, T., and Budambula, N. (2017). Physical and Chemical Characteristics of Five Hot Springs in Eritrea. Journal of Natural Sciences Research. Vol 7, No 12, pp 88-94. ISSN (Paper) 2224-3186 ISSN (Online) 2225-0921.

Gonzales, R., Nakagama, K., Hasegawa, S., Matsuoka, A., Kumagai, K., Yoshioka, T., and

Matsuyama, H. (2023). Ammoniacal Nitrogen Concentration by Osmotically Assisted Reverse Osmosis.Journal Membrane Science. Volume 665, pp 1-8. DOI: https://doi.org/10.1016/j.memsci.2022.121122.

Government of British Columbia. (n.d). Guideline Overview and Technical Reports. Available in: < https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/water-quality-guidelines/approved-water-quality-guidelines>. (Accedes on 23 January 2023).

Government of Canada. (2009). Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Hardness. Available in: < Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Hardness - Canada.ca>. (Accessed on 23 January 2023).

Government of Canada. (2014). Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Nitrate and Nitrite. Available in: < https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidelines-canadian-drinking-water-quality-guideline-technical-document-nitrate-nitrite/page-2-guidelines-canadian-drinking-water-quality-guideline-technical-document-nitrate-nitrite.html>. (Accessed on 23 January 2023).

Government of Canada. (2014). Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Sulphide (as H2S). Available in: < https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidelines-canadian-drinking-water-quality-guideline-technical-document-sulphide-as-h2s.html>. (Accessed on 23 January 2023).

Government of Canada. (1991). Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Total Dissolved Solids (TDS). Available in: < https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidelines-canadian-drinking-water-quality-guideline-technical-document-total-dissolved-solids-tds.html>. (Accessed on 20 January 2023).

Government of Canada. (2012). Guidelines for Canadian Recreational Water Quality. Third

Edition. Available in: < https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidelines-canadian-recreational-water-quality-third-edition.html>. (Accessed on 20 February 2020).

HACH. (n.d). Dissolved oxygen. Available in: < https://ca.hach.com/parameters/dissolved-oxygen>. (Accessed on 18 January 2023).

HACH. (n.d). Color, True and Apparent. Available in: < https://images.hach.com/asset-get.download.jsa?id=7639983708>. (Accessed on 23 January 2023).

HACH. (n.d). Chemical Oxygen Demand (COD). Available in: < https://au.hach.com/parameters/chemical-oxygen-demand>. (Accessed on 23 January 2023).

Hannover (Germany). (2016). Abwassersatzung für die Landeshauptstadt Hannover. (Gem. Abl. 2016, S. 189 Zuletzt geändert durch Satzung vom 29.09.2022, Abl. 2022, S. 431). Available in: < https://www.hannover.de/Media/01-DATA-Neu/Downloads/Landeshauptstadt-Hannover/Umwelt/Wasser-Abwasser/Stadtentw%C3%A4sserung/Satzungen/Abwassersatzung-der-Stadtentw%C3%A4sserung-Hannover>. (Accessed on 13 February 2023).

Health Canada, (2020). Guidelines for Canadian Drinking Water Quality. Available online: <https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/ewh-semt/alt_formats/pdf/pubs/water-eau/sum_guide-res_recom/summary-table-EN-2020-02-11.pdf>, (accessed on 01 March 2022).

Health Canada. (2020). Guidelines for Canadian Drinking Water Quality: Guideline technical document – Total coliforms. Available in: < https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidelines-canadian-drinking-water-quality-guideline-technical-document-total-coliforms.html>. (Accessed on 20 January 2023).

Hot springs. (n.d). Tourist sites Colombia. Available in: <https://www.sitiosturisticoscolombia.com/category/termales/>. (Accessed on 30 September 2020).

INGEOMINAS. (2003). Inventory of hot springs in the department of Cundinamarca. Available in: <http://recordcenter.sgc.gov.co/B3/12006000002744/documento/pdf/0101027441101000.pdf>. (Accessed on 21 April 2019).

Itanna, F. (2019). Can hot springs pollute the environment? Electronic Journal Freiberg Online Geology. Vol.24, pp 61-65.

IDEAM, Instituto de Hidrología, Meteorología y Estudios Ambientales. (n.d). Guía para el Monitoreo de Vertimientos, Aguas Superficiales y Subterráneas.

IDEXX. (2019). Colilert Procedure. Available in: <https://www.idexx.com/en/water/water-products-services/colilert/>. (Accessed on 21 April 2021).

IDEXX. (2019). Enterolert Procedure. Available in: <https://www.idexx.com/en/water/water-products-services/enterolert/>. (Accessed on 21 April 2021).

IDEXX. (2019). Legiolert Procedure. Available in: <https://www.idexx.com/en/water/water-products-services/legiolert/>. (Accessed on 21 April 2021).

IDEXX. (2019). Pseudalert Procedure. Available in: <https://al.idexx.com/es-xl/water/water-products-services/pseudalert/>. (Accessed on 21 April 2021).

Japan. (2014). Hot spring Law. Available in: <https://elaws.e- gov.go.jp > (in Japanese). (Accessed on 9 December 2022).

Johnson, M. B., and Mehrvar, M. (2019). Winery wastewater management and treatment in the Niagara region of Ontario, Canada: A review and analysis of current regional practices and treatment performance. The Canadian Journal of Chemical Engineering, 98(1), 5-24. https://doi.org/10.1002/cjce.23657.

Komatina, M. (2004). Medical geology: Effects of geological environments on human health Vol.2, Elsevier Science, Amsterdam, pp 14, 147-157.

Kumar, R., and Ramesh, C. (2019). Microbial diversity and physico-chemical attributes of two hot water springs in the Garhwal Himalaya, India". Journal of Microbiology, Biotechnology and Food Sciences. Vol. 8(6), pp 1249-1253. ISSN:1338-5178.

Kumar, R., Sharma, S., Mahiya, S., and Chandra, M. (2014). Heavy Metals in Water: Presence, Removal and Safety. Edition: 1, Publisher: Royal Society of Chemistry, Editor: Sanjay Sharma. ISBN: 9781849738859.

Labcompare. (n.d). Total Inorganic Carbon Analyzer (TIC Analyzers). Available in: <https://www.labcompare.com/Laboratory-Analytical-Instruments/6177-Total-Inorganic-Carbon-Analyzer-TIC-Analyzers/>. (Accesed on 23 January 2023).

Lenart, A., Wolanin, A., Jelonkiewicz, L., Chmielewska, Daria, and Żelazny, M. (2016). Spatiotemporal Variability in Microbiological Water Quality of the Białka River and Its Relation to the Selected Physicochemical Parameters of Water. Water Air Soil Pollut. Vol, 227: 22, pp 1-12. doi.org/10.1007/s11270-015-2725-7.

Lugares Turisticos. (n.d). 10 Termas en Cundinamarca. Available in: <https://www.lugaresturisticos.org/termas-en-cundinamarca/>. (Accesed on 14 April 2021).

Mark, H. (2013). TYPHA LATIFOLIA response to oligotrophic and eutrophic nitrogen and phosphorus loading rates under laboratory conditions. Thesis of Ryerson University.

Martinez, J., Ortiz, A., Estrada, M., and Vera, I. (2015). Physical-Chemical and Therapeutic Properties of Hot Springs and Hydrothermal Waters. International Journal of Research and Innovations in Earth Science Volume 2, pp 1-12. ISSN (Online): 2394-1375.

Martinez, E., Castillo, J., Gude, V. (2018). Wetlands for Wastewater Treatment. Water Environ. Vol 90(10), pp 1537-1562. Doi: 10.2175/106143018X15289915807281.

MILLIPORE. (2005). Análisis Microbiológico, Madrid- España.

Ministry of Environment and Sustainable Development of Colombia. (2015). Resolution 631 of 2015. By which the parameters and maximum permissible limit values are established in specific discharges to bodies of surface water and public sewage systems and other provisions are issued. Available in: < https//www.minambiente.gov.co/wp-content/uploads/2021/11/resolucion-631-de-

2015.pdf>. (Accessed on 13 February 2021).

Ministry of Environment and Sustainable Development of Colombia. (2015). Decree 1076 of 2015 Environment and Sustainable Development Sector. Available in: < https://www.minambiente.gov.co/documento-normativa/decreto-1076-de-2015/>. (Accessed on 13 February 2022).

Ministry of the Enviroment Government of Japan. (2015). National Effluent Standards. Available in: < https://www.env.go.jp/en/water/wq/nes.html>. (Accessed on 13 February 2023).

Ministry of the Environment and Climate Change of Ontario. (2014). Water Pollution Control Plant serving the City of Thunder Bay. Available in: <http://tbaywpcp-sops.info/sites/tbaywpcp-sops.info/files/ECA%206927-9QDM2P%20for%20Atlantic%20Ave.%20WWTP_0.pdf>. >. (Accessed on 10 February 2023).

Murcia (Spain) Department of Health and Social Policy. Decree 55 of July 11, 1997. On the sanitary conditions of Spas, Thermal Baths and Thalassotherapy Establishments and the application of Peloids. Available in: <https://www.murciasalud.es/legislacion.php?id=15238&idsec=1935>. (Accessed on 30 March 2020).

Oliver, B., and Clapes, R. (n.d). Quality control of mineral-medicinal waters. Current panorama of mineral-medicinal waters in Spain. Available in: <http://www.sld.cu/galerias/pdf/sitios/rehabilitacion-bal/oliverrodes_cb.pdf>. (Accessed on 23 February 2019).

Ontario (Canada), Ministry of Health and Long-Term Care. (2019). Recreational Water Reference Document. Available in: <http://www.health.gov.on.ca/en/pro/programs/publichealth/oph_standards/docs/reference/recreational_water_en.pdf>. (Accessed on 30 March 2020).

Ontario, (Canada). (2003). “Technical Support Document for Ontario Drinking Water Standards, Objectives and Guidelines”. Available online: <https://cvc.ca/wp-

content/uploads/2011/03/std01_079707.pdf>, (accessed on 08 March 2022).

Ontario, (Canada). (2003). “Ontario Regulation 169/03, Ontario Drinking – Water Quality Standards”. Available online: <https://www.ontario.ca/laws/regulation/030169>, (accessed on 08 March 2022).

Ontario, (Canada). (1990). Health Protection and Promotion Act. “R.R.O. 1990, Reg. 565: Public Pools”. Available online: < https://www.ontario.ca/laws/regulation/900565>, (accessed on 01 March 2022).

Ossa, C., Echeverri, M., Santos, Z, García, M., Agudelo, Y., Ramírez, F., and Ospina, S. (2014). Risk factors for multidrug-resistant Pseudomonas aeruginosa infection, in a tertiary hospital in Colombia. Revista Chilena de Infectologia. Vol.31 no.4, pp 393 – 399. doi: 10.4067/s0716-10182014000400003.

Porowski, A. (2019). Mineral and Thermal Waters. Part of the Encyclopedia of Sustainability Science and Technology Series book series (ESSTS), pp 166.

Portugal Ministries of Economy and Health. (2000). Ordinance No. 1220/2000 of December 29. Establishes rules regarding the conditions that natural mineral waters and spring waters, in catchment, must obey in order to be considered bacteriologically proper. Available in: <https://dre.pt/pesquisa/-/search/662105/details/maximized>. (Accessed on 30 March 2020).

RAC of Colombia. (2020). Regional Autonomous Corporation of Cundinamarca. Agreement No. 20 of December 23, 2020, of Bogota River. Available in: <https://www.car.gov.co/uploads/files/6213c21c0bab1.pdf>. (Accessed on 30 March 2021).

Rahel, C., Adriyani, R., and Arie, H. (2021). Health Risk in Hot Springs: A Literature Review. Journal of Health Science and Prevention. Volumen 5, pp 88 – 99. Doi: 10.29080/jhsp. v5i2.524.

Reyes, J., Ortiz, A., Estrada, M., and Vera, I. (2015). Physical-Chemical and Therapeutic Properties of Hot Springs and Hydrothermal Waters. International Journal of Research and Innovations in Earth Science. Volume 2, pp10-12. ISSN (Online):

2394-1375.

Rip, G. (1995). Chemistries of Ozone for Municipal Pool and Spa Water Treatment. Facts and Fallacies. Rice International Consulting Enterprises. Journal of the Swimming Pool and Spa Industry. Vol 1, pp 25–44.

Romano, V. (2017). Hot spring water in pool: The personalization of treatment from MFDNA Fingerprinting to nanotechnologies. Public Health Unit – University of Rome "Foro Italico", Italy. Present in 7th International Conference on Swimming Pool and Spa, Greece.

Romero, J. (2004). Tratamiento de aguas residuales. Teoría y principios de diseño. Editorial: Escuela Colombiana de Ingeniería. Third edition, pp 107.

Ronni, W., Orion, E., and Matz H. (2003). Balneotherapy in dermatology. Dermatologic Therapy, Vol. 16, pp 132–140. Doi 10.1046/j.1529-8019.2003.01622.x.

Rossel, L.J., Rossel, L.A., Mayhua, F., Ferro, A., and Zapana, R. (2020). Radiation ultraviolet-c for bacterial disinfection (total and thermotolerant coliforms) in the water treatment. Rev. investig. Altoandin. vol.22 no.1. http://dx.doi.org/10.18271/ria.2020.537.

Sampiere, H., Collado, C., and Lucio, B. (2018). Metodología de la investigación. Mc Graw Hill, sexta edición.

Sánchez Y., and Cheu, L. (2019). Estado del arte de la calidad del agua termal. ACOFI. Available in: <https://acofipapers.org/index.php/eiei2019/2019/paper/view/3018>. (Accessed on 20 May 2020).

Sanchez, Y., and Chivata, N. (2017). Detection of presence of *Pseudomonas aeruginosa* and control measures in thermal waters. Present in 7th International Conference on Swimming Pool and Spa, Greece and 10 th international perspectives on water resources and the environment, IPWE 2018, Cartagena – Colombia, December 3-7, 2018.

Sanchez, Y., Mehrvar, M., McCarthy, L., Quiñones, E., Cheu, L., and Romero, J. (2020). Scientific discussion of selected viruses including COVID-19 in hot springs.

International Congress of Innovation and Trens and Engineering (VI CONIITI 2020), Bogotá, Colombia, September 30-October 2, 2020, pp. 1-6, doi: 10.1109/CONIITI51147.2020.9240267.

Schiliemann, S., Grevstad, N., and Brazeau, R. (2020). Water quality and spatio-temporal hot spots in an effluent-dominated urban river. Hydrological Processes. Vol 35, pp 1-17. doi.org/10.1002/hyp.14001.

Select Latin America. (2016). 8 best natural hot springs for a soak in Latin America. Available in: <https://www.selectlatinamerica.co.uk/blog/8-best-natural-hot-springs-soak-latin-america/>. (Accesed on 14 Apr 2021).

SGC, Colombian Geological Service. (2015). Web Application of the National Inventory of Hydrothermal Manifestations. Geothermal Research and Exploration Working Group. Available in: <https://www2.sgc.gov.co/sgc/mapas/Documents/PDF%20PRESENTACI%C3%93N%20D%C3%8DA%20SIG/AplicativoWeb_INMH.pdf>. (Accessed on 20 June 2019).

Showers, D. (2020). The sentinel records. Study to test Hot Springs' wastewater for COVID-19. Available in: <https://www.hotsr.com/news/2020/jun/18/study-to-test-hot-springs-wastewater-for-covid-19/>. (Accessed on 05 May 2021).

Simhon, A., Pileggi, V., Flemming, C., Bicudo, J., Lai, G., Manoharan, M. (2019). Enteric viruses in municipal wastewater effluent before and after disinfection with chlorine and Ultraviolet light. Journal Water & Health. Vol. 17 (5). Pp 670 – 682. DOI: https://doi.org/10.2166/wh.2019.111.

Sisti, M., Pieretti, B., De Santi, M., and Brandi, G. (2014). Inactivation of pathogenic dermatophytes by Ultraviolet irradiation in swimming pool thermal water. International Journal of Environmental Health Research. International. Vol. 24, No. 5, pp 412–417. doi.org/10.1080/09603123.2013.835034.

South Asian Post. (2013). Top 10 hot spring around the world. Available in: <https://link.gale.com/apps/doc/A325092409/CPI?u=rpu_main&sid=CPI&xid=5e210

36c>. (Accessed 14 Apr 2021).

Spon, R. (June, 2008). Do You Really Have a Free Chlorine Residual? American Water works Association. Vol. 34, No 6, pp 24-27. doi.org/10.1002/j.1551-8701.2008.tb01993.x

Taipei Times, Taiwan News. EPA plans to regulate hot-spring wastewater. October 13 of 2004. Available in: <https://www.taipeitimes.com/News/taiwan/archives/2004/10/13/2003206666>. Accesed on 12 February 2021).

Toronto (Canada). (2000). By-Law No. 457-2000.To regulate the discharge of sewage and land drainage. Available in: <https://www.toronto.ca/legdocs/bylaws/2000/law0457.pdf>. (Accesed on 12 February 2022).

Torres, D., Acosta, C., and Restrepo, E. (2019). Geothermal and Mineral Analysis of Hot Springs in the Purace – La Mina Sector in Cauca, Colombia. Hindawi, Geofluids. Vol 2019, pp 1-20. doi.org/10.1155/2019/3191454.

Tucci, J. (2018). The Continuation of Native Non-invasive Plant Species research of engineered wetlands. Thesis of Ryerson University.

US EPA. (2022). Metals. Available in: < https://www.epa.gov/caddis-vol2/metals>. (Accessed on 12 February 2022).

Valeriani, F., Marika, L., and Spica, R. (2018). Recreational Use of Spa Thermal Waters: Criticisms and Perspectives for Innovative Treatments. International Journal of Environmental Research and Public Health. Vol. 15, pp 1- 22. doi: 10.3390/ijerph15122675.

Verhagen, A., Bierma-Zeinstra, S., Boers, M., Cardoso, J., Lambeck J, de Bie R., and de Vet H. (2015). Balneotherapy (or spa therapy) for rheumatoid arthritis (Review). Cochrane Database, pp. 1-52. doi: 10.1002/14651858.CD000518.pub2.

Verhagen, A., Bierma-Zeinstra, S., Boers, M., Cardoso, J., Lambeck, J., de Bie, R., de Vet, H. (2007). Balneotherapy for osteoarthritis. Cochrane Database, pp 1-30.

doi.org/10.1002/14651858.CD006864.

WHO (2021). World Health Organization. A global overview of national regulations and standards for drinking-water quality. Second edition. Available in: <https://www.who.int/publications/i/item/9789241513760>. (Accessed on 29 September 2020).

WHO (2021). World Health Organization. Guidelines on recreational Water Quality. Volume 1 Coastal and Fresh Waters. Available in: https://www.who.int/publications/i/item/9789240031302. (Accessed on 20 September 2022).

WHO (2006). World Health Organization. Guidelines for safe recreational water environments. Swimming pools and similar environments. Volume 2. Available in: <http://apps.who.int/iris/bitstream/10665/43336/1/9241546808_eng.pdf>. (Accessed on 29 September 2019).

Wyrwas, B., and Zgoła-Grześkowiak, A. (2014). Continuous Flow Methylene Blue Active Substances Method for the Determination of Anionic Surfactants in River Water and Biodegradation Test Samples. Journal of Surfactants and Detergents. Vol 17, pp 191–198.

Wu, S., Carvalho, P. N., Müller, J. A., Manoj, V. R. & Dong, R. (2016). Sanitation in constructed wetlands: A review on the removal of human pathogens and fecal indicators. Science of the Total Environment, 541, 8– 22. DOI:10.1016/j.scitotenv.2015.09.047

Yan, J., Chan, Y., Wen, C., and Hung, W. (2005). Impact of hot spring bathing water on the water quality in the Nan-Shih Creek. Journal of the Chinese Institute of Environmental Engineering, Vol. 15, No. 2, pp. 91-99.

Yibas, B.,Olivier, J.,Tekere, M., and Motlakeng, T. (2011). Preliminary health risk analysis of thermal springs in limpopo province, South Africa based on water chemistry. Kenya Geothermal Conference. Safari Park Hotel, Nairobi, November 21-23, 2011.

Zachaira, C. (2016). Thesis “Balneological Classification of South African Thermal

Springs". Philosophiae Doctor Environmental Sciences. Available in: <https://static1.squarespace.com/static/54306a8ee4b07ea66ea32cc0/t/5910d846f5e2315080fcd4ad/1494276281241/balneological.pdf>. (Accesed on 18 April 2021).

Zhang, J. Z. (2012). Current wet persulfate digestion method considerably underestimates total phosphorus content in natural waters. Environmental Science & Technology. Vol 46(24), pp. 13033– 13034. DOI: https://doi-org.ezproxy.lib.torontomu.ca/10.1021/es304373f.

Zhang, B., Zheng, J., & Sharp, R. (2010). Phytoremediation in engineered wetlands: mechanisms and applications. Procedia Environmental Sciences, 2, 1315-1325. doi:10.1016/j.proenv.2010.10.142.

Appendix

Appendix A: Agreement on Copyright and Intellectual Property Signed Between the Aqueduct and Sewerage Company of Bogota (in Spanish EAAB- ESP) and the Colombian School of Engineering Julio Garavito University (See attached file).

Appendix B: IDEXX Quanti – Tray/ 2000 MPN Table (See attached file).

Appendix C: IDEXX Quanti – Tray/ Legiolert MPN Table (See attached file).

Appendix D: Monitoring campaign (See attached file).

Appendix E: Lab results EAAB-ESP (See attached file).

Appendix F: Statistical analysis of the t-student test (See attached file).

Appendix G: Spectrophotometer calibration (See attached file).

Appendix H: Pump calibration (See attached file).