Analysis of swimming pool water disinfection technologies in the Piscilago Water Park Girardot – Cundinamarca

1st Diana Vega
Environmental Engineering Program
Universidad de Cundinamarca
Girardot Colombia
dcvega@ucundinamarca.edu.co

2nd Yuly Sánchez
Professor of Center for Environment Studies
Escuela Colombiana de Ingeniería
Bogotá, Colombia
yuly.sanchez@escuelaing.edu.co

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Resumen - Esta investigación se basa en el análisis de la efectividad de las tecnologías de desinfección utilizadas en diez (10) piscinas del Parque Acuático Piscilago Girardot - Cundinamarca (cloro, ozono y radiación UV), mediante la caracterización fisicoquímica y microbiológica del agua. . Este análisis se realizó mediante dos muestras de agua por sitio, en diferentes estaciones (alta y baja) con el objetivo de comparar las características del agua con un caudal alto y bajo de usuarios [1]. Asimismo, se recopilaron datos históricos del seguimiento mensual del Parque desde agosto de 2016 hasta diciembre de 2019.

Entre las principales conclusiones del estudio, se destaca que todos los métodos de desinfección tienen una eficiencia del 100% en cuanto a parámetros microbiológicos como coliformes totales y E. Coli. Sin embargo, debido a su estabilidad molecular, el cloro continúa desinfectando incluso después de la aplicación por lo que para los métodos de ozono y radiación UV, se aplica una dosis mínima de cloro para asegurar el efecto residual. Asimismo, es evidente que la eficiencia del tratamiento del agua en piscinas depende principalmente del funcionamiento del sistema. Si existe algún exceso o defecto en la aplicación del método de desinfección, esto incide directamente en el incumplimiento de los parámetros analizados contemplados en la normativa vigente.

Palabras clave—*desinfección, cloro residual, coliformes, ozono, piscinas, UV.*

***Abstract*—This research is based on the analysis of the effectiveness of the disinfection technologies used in ten (10) pools of the Piscilago Girardot – Cundinamarca Aquatic Park (chlorine, ozone, and UV radiation), through the physicochemical and microbiological characterization of the water. This analysis was carried out by means of two water samples per site, at different seasons (high and low), with the objective of comparing the characteristics of the water with a high and low flow of users [1]. Similarly, historical data was collected from the monthly monitoring of the park from August 2016 to December 2019.**

Among the main conclusions of the study, it stands out that all disinfection methods have 100% efficiency in terms of microbiological parameters such as total coliforms and E. Coli. However, due to its molecular stability, chlorine continues to disinfect even after applied, for which, to the ozone and UV radiation methods, a minimum dose of chlorine is applied to guarantee the residual effect. Likewise, it is evident that the efficiency of the water treatment in the swimming pools depends mainly on the operation of the system. If there is any excess or defect in the application of the disinfection method, this directly affects the non-compliance of the analyzed parameters contemplated in current regulations.

Keywords—*disinfection, residual chlorine, coliforms, ozone, pools, UV.*

I. Introduction

Swimming pools are a very common element in modern life, whether for recreation, swimming, diving, therapy, or competition [2]. Due to the pleasant climate of the tropics, they are an important part of the recreational culture in Colombia, and they are now a popular weekend activity for Colombian families [3]. For this reason, it is essential to ensure the quality of the water that guarantees compliance with the water quality parameters established in Resolution 1618 of 2010 [4].

To ensure compliance with these regulations, all recreational centers must have a treatment system, especially large water parks, which handle a high flow of people per day. Said treatment systems are conditioned to the needs of the parks, the purchasing and technical capacity, as well as the type of water used [1]. Disinfection processes include chlorination, ozone, UV radiation, as well as iodine or bromine. The main objective of these methods is the elimination of pathogens potentially dangerous to human health [5].

In accordance with the aforementioned, the most used technology in disinfection is based on chlorination systems, due to its easy acquisition and proven effectiveness. However, it causes a notable negative impact on the environment as it is a bioaccumulating chemical compound [6]. For this reason, some researchers focus their work on finding disinfection alternatives that can replace chlorination, with the aim of reducing the impact that chlorine generates on the environment. Among the most studied are the previously mentioned ozone and UV radiation methods, which are effective at disinfection upon contact, but require complementary use of a residual effect disinfectant to ensure the safety of the water for a prolonged period. Therefore, chlorination is still used but in a much lower concentration.

This research is based on the evaluation of the characterization of the physical, chemical, and microbiological parameters of ten swimming pools and the development of an analysis between the disinfection technologies, the characteristics of each one of the swimming pools and the tourist season in which each are found.

II. METHODOLOGY

A. Place of Study

The Piscilago water park is located at km 105 of the Bogota – Girardot highway, with an average temperature of 28°C. It has 49 attractions designed for the conservation of the local fauna and flora and a capacity to receive over 10,000 visitors per day. Of the total attractions, 16 are water attractions between pools and slides.

Its aqueduct is based on an autonomous system that takes the water directly from the central lake of the park, which is fed by the Sumapaz River. From this lake, the water is transported to the purification plant composed of a sludge blanket clarifier, and then passes to a high-rate filtration system, and subsequently to storage. From there, the water is distributed to the entire park network to be used in all activities such as restaurants, administrative areas, and each of the attractions. It should be noted that in this park, water is recirculated to maximize its use. In addition, each aquatic attraction has an individual treatment system composed of a two-pump pumping system (day and night use), a high-rate filtration system and a disinfection system.

B. Sampling Points

The selection of the sampling points was carried out by taking into account the most frequented aquatic attractions, number of users per day, and the water disinfection method. Out of a total of 16 pools, 6 pools for public use and 4 pools with a slide were chosen.

As previously mentioned, two water samples were taken per site, on different dates, the first in July 2018, the second in September 2018 (high and low season respectively). Additionally, historical data was collected from August 2016 to December 2019, taken from the park (monthly monitoring), to increase the veracity of the result.

C. Parameters of Interest

The physicochemical parameters (pH, Temperature, Residual Chlorine, Combined Chlorine and Turbidity) were determined using in situ tests with a portable chlorine test kit and a pH meter, and the microbiological tests (Total Coliforms and E. coli), were performed using the methodological guide "*Determination of total Coliforms and E. Coli in waters by means of the defined substrate technique, colilert by the Most Probable Number method*", of the Institute of Hydrology, Meteorology and Environmental Studies - Subdirectorate of Hydrology - Laboratory Group of Environmental Quality, carried out at the facilities of the company ACUAGYR SA ESP.

Finally, a comparison was made of the disinfection efficiency between each of the treatment systems and compliance with the current standard (Resolution 1618 of 2010) [4], based on the results obtained.

III. RESULTS

All of the data collected for this study was used as a counter sample of the average of the previous year's monthly historical samplings, comparing the degree of dispersion of the results and analyzing the possible causes of the data collected.

A. Physicochemical tests

Data comparison for pH

Due to the conditions of the treatment system, most pools have a constant pH value (Fig 1) within the neutral pH range with a tendency to alkalinity. However, a pH value of less than seven is noted in the "El Mirador" pool during low season but it is not related to any of the other results, that is, it could have been an extraordinary event due to conditions external to the water treatment [7]. However, it is not a value that represents a danger to human health, since it is not very far from the minimum limit [8], which would be controlled with the addition of an alkalizing medium that neutralizes volatile acids present in the water [9].

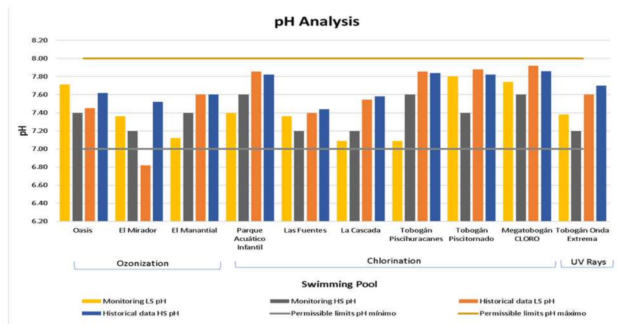

Fig 1. Average pH values obtained from monthly samplings of the last year taken by the park, compared with the results of the counter-sample carried out in this study (for high and low season) and the respective disinfection system implemented for each pool.

Regardless, there are no significant differences in the pH value for each of the treatment systems, that is, this parameter is not affected by the disinfection system used since a pH stabilization process is carried out in the treatment system prior to disinfection.

Data comparison for turbidity

The turbidity parameter complies in 80% of the cases. This could be due to favorable conditions of the inlet water quality on the dates of the sampling or a high level of efficiency of the filtration system on dates close to taking the counter sample, due to the optimization made in this process [11, 12]. However, there is an exception in the pools "Piscihuracanes" and "Oasis" during high season, where the value of the counter sample is higher than the historical average (Fig 2). This could be explained by a higher degree of use of the attraction for that date [13] resulting in non-compliance with the maximum limit established by Resolution 1618 of 2010 [4] for both the counter sample and the historical average of samplings, contrasting the linearity of the results.

On the other hand, turbidity is directly related to the filtration process implemented [7] and has a direct influence on the disinfection process, since it linearly affects the demand for chlorine in untreated and treated water and in the potential formation of disinfection by-products that can compromise the microbiological quality of the water. [14].

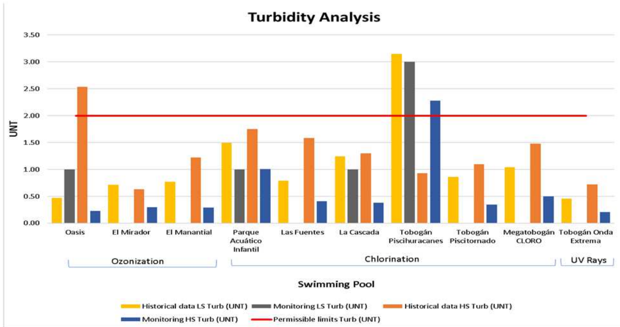

Fig 2. Average turbidity values obtained from monthly samplings of the last year taken by the park, compared with the results of the counter-sample carried out in this study (for high and low season) and the respective disinfection system implemented for each pool.

Data comparison for residual chlorine

The residual chlorine parameter is essential to ensure the gradual disinfection of the water, which guarantees the optimal concentration to not affect human health [15, 16]. This is because it can cause acute effects such as chest pain, irritation of the skin and eyes or respiratory tract, including chronic effects such as irritation of the lining of the lung cells (respiratory problems) and the immune system, especially in children [6, 9, 17] as well as minimal pollution of the environment by chlorine [18].

It is important to clarify that the ozone and UV disinfection methods complement their process with chlorine, but in small concentrations, which is why a residual effect is evident in the pools that implement these two systems. On the other hand, this parameter depends mostly on the operation of the disinfection system [6], that is, the applied dose, application frequency and the mode of application used [15]. For this reason, the non-compliance of the parameter is observed in some data, either by excess or by defect.

Most of the results comply with the permissible range for this parameter (Fig 3), with the exception of both data from the "Piscitornado" pool slide, an excessively high concentration (4 mg / L) for the pool "La Cascada" from the historical average in low season, and a concentration of 3.6 mg/L in the “Megatobogán” for counter sampling in high season.

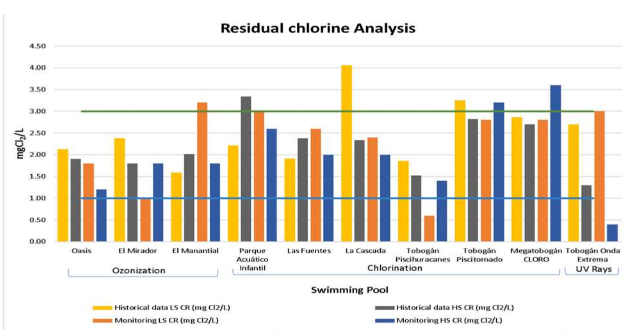

Fig 3. Average residual chlorine values obtained from monthly samplings of the last year taken by the park, compared with the results of the counter-sample carried out in this study (for high and low season) and the respective disinfection system implemented for each pool.

Data comparison for combined chlorine.

Combined chlorine is the result of the reaction of chlorine in solution with ammonia and organic nitrogenous compounds, forming compounds known as chloramines. Its main forms are monochloramine (NH_2Cl), dichloramine ($NHCl_2$) and trichloramine (NCl_3), which have a lower disinfection capacity compared to that of residual chlorine [9,19].

This parameter is used as an indicator of the presence of nitrogenous nutrients in the water, whether caused by urine, sweat or dirt from bathers. That is, a high concentration of this parameter indicates an inadequate level of chlorine in the water or poor conditions of the treated water. Therefore, it is mandatory to reduce the concentration of combined chlorine, which can be done by super-chlorination, using a form of chlorine without stabilizer, or using active oxygen in water treatment [21, 22].

The data obtained (Fig 4) shows the non-compliance of the maximum permissible limit of this parameter in most of the swimming pools [4], with the exception of the “Onda Extrema” pool slide, which uses UV radiation as the method of disinfection, with the addition of a minimum of chlorine, reducing the formation of chlorination by-products, such as combined chlorine [10, 23]. On the other hand, in pools where ozone is used, despite the fact that the maximum limits are not met, it is clear that the values are not far from the limit. Because ozone does not react with ammonia, no by-products are produced when compared to chlorine [24]. As a result, the chlorine concentration is lowered.

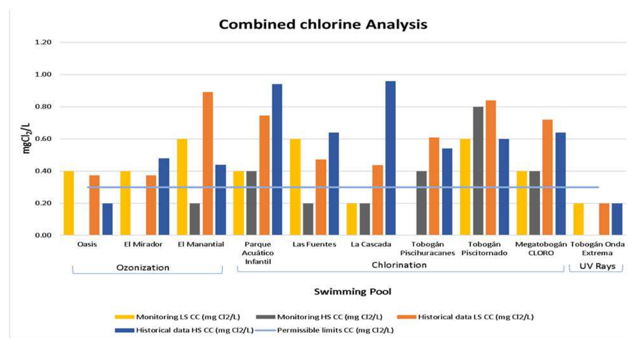

Fig 4. Average combined chlorine values obtained from monthly samplings of the last year taken by the park, compared with the results of the counter-sample carried out in this study (for high and low season) and the respective disinfection system implemented for each pool.

B. Microbiological tests

Untreated water, in general, contains pathogens harmful to human health, which is why a disinfection process is necessary to neutralize these microorganisms [25]. The chlorination technique as a disinfection method is the most used in the treatment of swimming pools, due to its low cost and high effectiveness. Thanks to its residual effect, it guarantees the elimination of pathogens for a longer time [21, 26]. The following table shows the relationship of the residual chlorine concentration with the presence of total coliforms and E. Coli (Table 1).

In the park, the treatment of the swimming pools begins with a filtration process, using high-rate filters, which guarantees the preparation of the water for the disinfection process. Filtration fulfills two fundamental objectives: i) to reduce the bacterial load and ii) to make disinfection processes more efficient [27].

In the pools' treatment system, aluminum sulfate (type A) is added by means of injectors, which pump the coagulant into the influent pipe of the filter. This guarantees better efficiency in the pathogen elimination process [28].

In general, the park complies with the regulations for pathogens in swimming pools [4, 29, 30], although non-compliance is evidenced in some cases, due to external conditions and the operation of the treatment. In the "Piscihuracanes" pool slide, in which chlorine is used as a disinfection method, an abnormality is observed in the coliforms during low season in the counter sampling, a value that is neglected taking into account that the attraction at the time of the sampling was out of service because the treatment system was not working. However, this value confirms the importance of implementing an optimal treatment system for swimming pools, without which similar data would be found putting the health of users at risk [31].

In the "Onda Extrema" pool slide, which has a UV radiation disinfection system, complemented with a minimum dose of chlorine, a high value is found for total coliforms and E. coli in the high season for counter-sampling. This could be explained by the high flow of people, the increase in water temperature or the reduced dose of residual chlorine found at the moment of taking the sample, since it does not comply with the minimum dose of residual chlorine established by the current standard [4].

TABLE I. CHLORINE PARAMETER RELATIONSHIP WITH THE PRESENCE OF WATER PATHOGENS FOR LOW AND HIGH SEASONS (HISTORICAL DATA)

Pool	Disinfection Treatment	Historical Data						Counter Samples					
		High Season			Low Season			High Season			Low Season		
		Cl_2 Res (mg Cl_2/L)	Tot Col (UFC/ 100cm^3)	E. Coli (UFC/ 100cm^3)	Cl_2 Res (mg Cl_2/L)	Tot Col (UFC/ 100cm^3)	E. Coli (UFC/ 100cm^3)	Cl_2 Res (mg Cl_2/L)	Tot Col (NMP/ 100mL)	E. Coli (NMP/ 100mL)	Cl_2 Res (mg Cl_2/L)	Tot Col (NMP/ 100mL)	E. Coli (NMP/ 100mL)
Oasis	Ozone	1,9	0	0	2,1	0	0	1,2	< 1	< 1	1,8	< 1	< 1
El Mirador		1,8	0	0	2,4	0	0	1,8	< 1	< 1	1,0	< 1	< 1
El Manantial		2,0	0	0	1,6	1	0	1,8	< 1	< 1	3,2	< 1	< 1
Parque Acuático Infantil	Chlorine	3,3	0	0	2,2	1	0	2,6	3	< 1	3,0	< 1	< 1
Las Fuentes		2,4	0	0	1,9	0	0	2,0	< 1	< 1	2,6	< 1	< 1
La Cascada		2,3	0	0	4,1	2	0	2,0	< 1	< 1	2,4	< 1	< 1
Slide Piscihuracanes		1,5	0	0	1,9	1	0	1,4	< 1	< 1	0,6	1203,3	< 1
Slide Piscitornado		2,8	0	0	3,3	0	0	3,2	< 1	< 1	2,8	< 1	< 1
Megatobogán		2,7	17	0	2,9	0	0	3,6	13,4	< 1	2,8	< 1	< 1
Slide Onda Extrema	UV Radiation	1,3	0	0	2,7	0	0	0,4	13,2	3,1	3,0	< 1	< 1

On the other hand, in the "Megatobogán" pool, where the presence of total coliforms is manifested both in the historical average and in the counter-sampling for the high season, there is evidence of a residual chlorine concentration above the permissible limit. There is no probable reason for this result, even more so when it is similar in both samplings, although it can be inferred that total coliforms, being a bacterial consortium, generate greater resistance to disinfection than other pathogens, because they produce bacterial spores that, due to being in a state of latency due to the partial dehydration of their protoplasm, only develop when they find the optimal conditions for their growth [25, 32]. However, the possibility of a deficiency in the disinfection process of said pool should also be considered.

Finally, in the case of the children's pool, the presence of total coliforms is found, in low and high seasons, from the historical average. This is possibly due to the fact that, as the pool is used by children, there is a greater probability of fecal accidents, vomiting, bleeding, and urine, among others [26, 30].

IV. CONCLUSIONS

The result of this study indicates that the disinfection efficiency in each of the methods used in the park's swimming pools is not significantly different from each other. For all disinfection methods (ozone and UV radiation) a minimum of chlorine is added, which allows the residual effect required for disinfection to be obtained.

The pH for all attractions complies with the range allowed by current regulations, which indicates that the selection of the disinfectant used as a chlorination method (sodium hypochlorite) is adequate since as a base, it tends to neutralize water with acid pH.

For turbidity, of all the values analyzed between the historical data and the counter-samples for each of the seasons, only 10% is above the range established by the current regulations. This indicates that for some attractions, the filtration process has shortcomings, generating possible problems in the subsequent disinfection process. By not complying with the minimum limits, it can have a linear effect on chlorine demand and the potential formation of by-products, resulting in greater protection for microorganisms and their elimination.

For the residual chlorine analysis, it is necessary to take into account that of all the data, 15% is above the range established by the standard, while 7.5% is below the range. This shows that for the cases of disinfection by chlorine, the park tends to use a higher dose of chlorine than necessary for disinfection, while for the ozone and UV radiation methods, this dosage is found in much lower concentrations.

Regarding combined chlorine, with the exception of the UV radiation method that fully complies with the permissible limits and the ozone method that is very close to this permissible limit, 75% of the attractions that use chlorine as a disinfection method present values above the maximum allowable ranges. This shows one of the major disadvantages of chlorine, which is the formation of by-products due to the reaction with other compounds present in swimming pools, in this case ammonia and nitrogenous compounds.

Regarding the comparison between disinfection methods, the concentration of residual chlorine and the presence of total coliforms and E. coli, the attractions that presented residual chlorine values below the permissible limits, which in the case of swimming pools for public use is of 1 mg Cl_2/L, show the presence of total coliforms in 10% of the data. This indicates the importance of adding a minimum concentration of chlorine, regardless of the disinfection method used, in order to guarantee a residual effect that allows the disinfection contact time to be longer, and therefore increases the efficiency of the process.

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