Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2023.29301

288 (2023) 140–150
March

Water quality analysis in a municipal outdoor swimming pool complex before and during the COVID-19 pandemic

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Received 6 December 2022; Accepted 15 January 2023

ABSTRACT

Like all public utility, swimming pools had been treated with special procedures during the COVID-19 pandemic. In addition to the basic rules (social distance + hand disinfection + masks), applicable to all citizens, the managers of swimming pools were obliged to reduce the number of swimmers and to increase the effects of water treatment. Monitoring, control and rapid response to unfavourable changes in the quality of swimming pool water are the basis for minimizing the risk of disease transmission or exposure of bathers to pathogens. The main purpose of this work is to analyse and compare the quality of swimming pool water in a municipal outdoor swimming pool complex, before (2018–2019) and during the COVID-19 pandemic (2020–2021). Water samples taken from a paddling pool for children (CP), a recreational pool (RP), and a sports pool (SP) were analysed. The results of the research, based on real case studies, were compared with the documents on water quality in swimming pools in force at the time. An analysis was carried out to determine the relationships between swimming pool water quality before and during the COVID-19 pandemic. The tested parameters determining the quality of water were physico-chemical parameters (temperature, pH, redox, turbidity, nitrates, chemical oxygen demand, free chlorine, chloramines and trihalomethane THM) and bacteriological parameters (colony forming units CFU of *Pseudomonas aeruginosa*, *Escherichia coli*, *Legionella* sp.). Based on the results of the analysis of the parameters mentioned-above, the validation of the procedures applied during the COVID-19 hazard and their impact on the quality of swimming pool water were evaluated. The results of the pool water quality tests were discussed with particular emphasis on disinfection by-products (THM and combined chlorine). Detailed analysis showed better water quality in the first year of the pandemic (2020) compared to 2018–2019 (before COVID-19) and 2021 (the second year of COVID-19 pandemic). The following parameters were found to be significantly different: THM (before 0.069 mg/L and during 0.034 mg/L), free chlorine (before 0.86 mg/L and during 0.66 mg/L), and redox potential (before 667 and during 713 mV).

Keywords: Outdoor swimming pool complex; COVID-19 pandemic; Quality of swimming pool water; Monitoring.

1. Introduction

In the first half of 2020, the SARS-CoV-2 coronavirus, responsible for the COVID-19 infectious disease, paralysed almost the entire world. After the first reported cases in November 2019 in China, the SARS-CoV-2 coronavirus has spread rapidly around the world. The total number of reported cases by September 2022 was over 609 million and the total number of deaths was over 6.5 million [1,2].

The COVID-19 pandemic has changed the rules of operation primarily in the medical, business and tourism sectors. Restrictive operating rules has also affected entities

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Presented at the 15th Scientific Conference on Micropollutants in the Human Environment, 14–16 September 2022, Częstochowa, Poland

1944-3994/1944-3986

related to culture, entertainment and sports. In March 2020, public buildings, including municipal swimming pool complexes, were closed for several weeks in most countries.

After the initial shock of successive waves of infections in 2020, based on reports, studies and scientific expertise [3–6], further guidelines were issued regarding the rules of operation of public utility facilities and the procedure for using them.

Numerous public health institutions around the world, including the World Health Organisation (WHO) and the Centre for Disease Control and Prevention (CDC), agree that no cases of SARS-CoV-2 infection have yet been demonstrated through drinking water or quality-controlled recreational water, including water in swimming pools, treated and disinfected.

This position is consistent with previous data on other viruses of the *Coronaviridae* family capable of causing infections in humans, which are transmitted by droplet and direct contact [7,8]. Attention is also drawn to the susceptibility of SARS-CoV-2 as an enveloped virus to disinfectants. Sodium hypochlorite, commonly used to disinfect water in public swimming pools, also effectively eliminates particles of this microorganism [9,10].

In Poland, on the basis of the Act on Preventing and Combating of Infections and Infectious Diseases in Humans, like all public facilities, swimming pools were subject to special procedures for use during the COVID-19 pandemic [11,12].

In addition to the basic injunctions (DDM, that is, Social Distance + Hand Disinfection + Masks), applicable to all citizens, pool facility managers were obliged to limit the number of simultaneous bathers and to increase the treatment effects of the circulating water treatment by, for example, more frequent washing of filter beds, introduction of an additional disinfection step, more frequent cleaning and disinfection of the walls, bottom and pool beach, use of disinfectants with high effectiveness in destroying viruses, bacteria and fungi [13,14].

According to the guidelines for the operation of swimming pools and saunas during the SARS-CoV-2 epidemic issued by the Ministry of Development and the Chief Sanitary Inspectorate[13] and in accordance with the position of the National Institute of Public Health – National Institute of Hygiene on the use of swimming pools during the COVID-19 pandemic [14], the usual water treatment and disinfection procedure used in public swimming pools, ensuring that the concentration of free chlorine, the pH value and the redox potential of water in the swimming pool basin are maintained within limits that comply with the requirements set out in the Regulation of the Minister of Health of 9 November 2015. (Journal of Laws 2015, Item 2016) [15] is sufficient to ensure the microbiological quality of the water, including the elimination of SARS-CoV-2.

In view of the current sanitary-epidemiological situation and the related rules of conduct for the operation of swimming pool facilities, water quality monitoring in swimming pool circuits is of particular importance. Accurate control of the treatment and disinfection process and quick response to adverse changes in water quality are the basis for minimising the risk of disease transmission or exposure to pathogens for bathers [16–19].

The subject of the work is the analysis of the pool water quality parameters in the municipal open-air (outdoor) swimming pool complex during the time before (2018–2019) and during (2020–2021) the COVID-19 pandemic. Based on the analysis, an attempt was made to assess the impact of the rigorous reduction in the number of bathers and the changes introduced in water treatment technology during the COVID-19 pandemic on the improvement of pool water quality parameters.

2. Monitoring and assessment criteria for swimming pool water quality in public outdoor swimming pools in Poland

According to the Sports Act of 25 June 2010 (Journal of Laws 2010, No. 127, Item 857), ensuring the health safety of swimmers is the responsibility of the legal and natural persons operating in this area. Therefore, those in charge of swimming pool facilities should ensure the best possible quality of swimming pool water and control it [20].

The basic and first criterion for the suitability of swimming pool water for bathing is its appropriate bacteriological quality. The supplementary and second criterion is appropriate physicochemical quality [21]. In the event that the sanitary inspection authorities detect colony-forming units of indicator bacteria above defined as acceptable in pool water samples, the test must first be repeated to verify laboratory errors and confirm the detected water contamination. If the water is found to be contaminated again, shock chlorination is required, that is, chlorination of the water with large doses of disinfectant. If the shock disinfection performed does not bring the expected result in a short time, out of concern for the health of the swimming pool users, it is ordered to close the swimming pool facility and ensure that procedures in the event of microbiological contamination of the water pool are carried out. On the other hand, if the values of physicochemical parameters are exceeded, corrective procedures are established [21,22].

The list of indicators and regularly monitored water quality parameters in open pools according to the 2015 Ministry of Health Regulation is summarised in Table 1.

Conducting continuous water quality monitoring in the swimming pool basin makes it possible to quickly detect deviations of water quality parameters from legal recommendations. Important data for monitoring and archiving are also attendance, the need for additional water losses in the pool circuit and the duration of filtration cycles [17,23–26].

3. Materials and methods

3.1. Tested outdoor pools and water treatment systems

The tested municipal outdoor swimming pool complex includes: recreational swimming pool (RP), children's pool (CP), sports swimming pool (SP) and a water playground (Fig. 1). The pool complex is open during the summer season.

The facility has two closed water treatment systems (WTS): WTS I for the sports swimming pool (SP) and a water playground, and WTS II for the recreational pool (RP) and the pool for children (CP). WTSs are equipped with retention tanks with a capacity of 30 m^3, and filtration systems. The water was filtered by the open vacuum washed with diatomaceous earth filters. Before the COVID-19 pandemic, the filters were rinsed every 3 d and during COVID-19 every 2 d. In order to increase the treatment efficiency in the first year of pandemic (in 2020), dusty activated carbon was dosed into the filter tank as an additional filter medium. Water disinfection was carried out with a 14.5% sodium hypochlorite solution. If the pH of the water required adjustment, a 30% solution of sulfuric acid was used. Algaecide was periodically added to prevent algal blooms. The parameters characteristic for the tested pools are summarized in Table 2, and the scheme of the WTS is shown in Fig. 2.

3.2. Principles of operation of the swimming pool complex during the COVID-19 pandemic

In accordance with the guidelines for the operation of swimming pools and saunas during the SARS-CoV-2 outbreak in Poland, the necessary precautions had to be

Table 1
Physico-chemical and bacteriological requirements for water quality in outdoor swimming pools (based on [21])

Parameter	Water in the pool basin		Water in swimming pool basins equipped with water aerosol generating devices	
	Minimum	Maximum	Minimum	Maximum
Nitrates (mg·NO_3^-/L)	–	20	–	20
Free chlorine (mg·Cl_2/L)	0.3	1.0	0.7	1.0
Combined chlorine (mg·Cl_2/L)	–	0.3	–	0.3
Chloroform (mg/L)		0.03	–	0.03
Turbidity (NTU)	–	0.5	–	0.5
pH (–)	6.5	7.6	6.5	7.6
Redox potential (mV)				
6.5 < pH > 7.3	750	–	750	–
7.3 < pH > 7.6	770	–	770	–
Chemical oxygen demand (mg·O_2/L)	–	4	–	4
THM[a] (mg/L)	–	0.1	–	0.1
Escherichia coli (CFU[b]/100 mL)	0		0	
Legionella sp. (CFU[b])/100 mL)	0		0	
Pseudomonas aeruginosa (CFU/100 mL)	0		0	

[a]THM – the sum of the concentrations of the compounds: bromodichloromethane, dibromochloromethane, tribromomethane, trichloromethane (chloroform).
[b]CFU – colony-forming unit.

Table 2
Characteristic parameters for the tested outdoor pools and water treatment systems

Parameter	WTS I		WTS II	
	Sport pool (SP)	Water playground	Recreational pool (RP)	Children pool (CP)
Dimensions of the pool basin (m × m)	24.95 × 12.37	24.9 × 20.8	24.35 × 12.2	24.9 × 20.8
Depth of the pool basin (m)	1.2	0	0.8–1.2	0.1–0.6
Usable area (m^2)	285	90	268	420
Volume of the pool basin (m^3)	342	0	268	147
Filtration flow (m^3/h)	190		470	
Length of the filtration cycle before COVID-19 (d)	3		3	
Length of the filtration cycle during COVID-19 (d)	2		2	
Maximum number of bathers before COVID-19 (person/h)	68	30	72	80
Maximum number of bathers during COVID-19 (person/h)	24	10	25	28

The pool water treatment systems are equipped with automatic reagent dosing and control of basic water quality parameters (temperature, pH, redox potential, free chlorine, and combined chlorine).

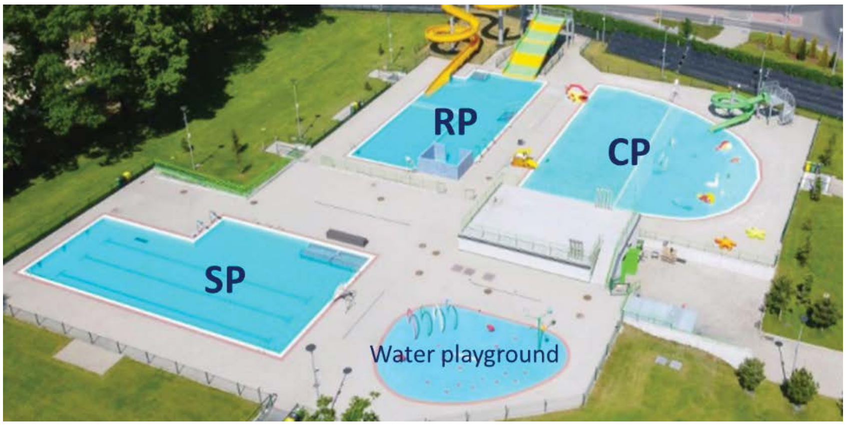

Fig. 1. Tested municipal outdoor swimming pool complex.

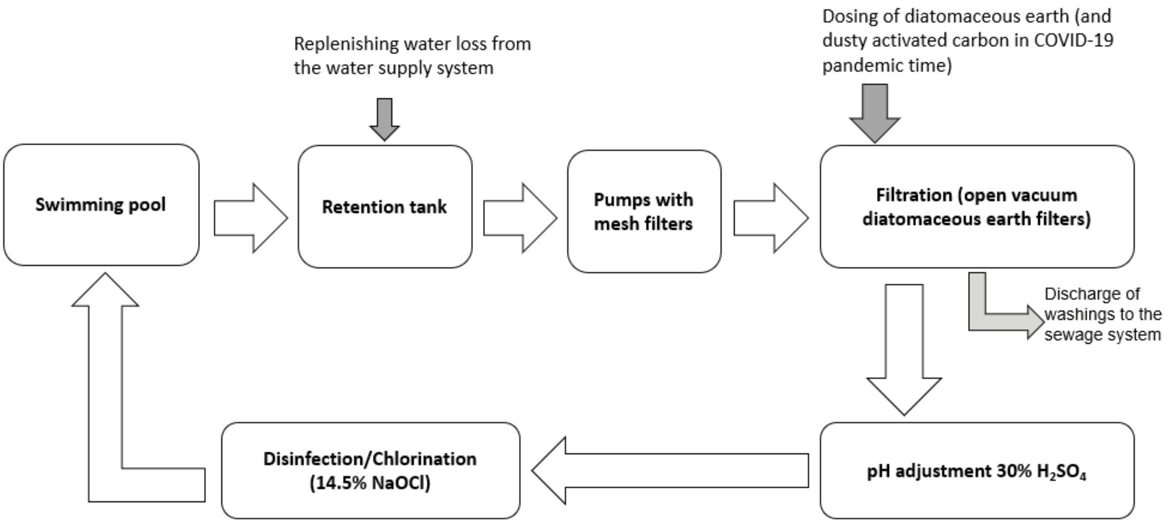

Fig. 2. Pool water treatment system in a municipal outdoor swimming pool complex.

implemented in each swimming pool facility to minimise the risk of infection [13,14,27,28].

The following precautions were taken in the open-air pool complex under consideration:

- the number of persons allowed in the complex was reduced to 35%, that is, from the permitted 3,500 to 1,200 persons/d;
- the number of people using a particular swimming pool at the same time was monitored and limited to 35% of the permitted number (summarised in Table 2);
- the water playground, water slides and other water attractions producing water aerosol such as hydro-massage loungers and fountains were excluded from use;
- resting quarters on the beach are separated to allow a minimum distance of 1.5 m between people;
- frequent disinfection of door handles, benches, water taps, sanitary utensils and any other surfaces in the sanitary facilities and changing rooms with which pool users may have come into contact is carried out;
- instructions on proper hand washing and disinfection, showering and the wearing of face masks when moving around the complex, excluding bathing time, are displayed in prominent places;
- the filtration cycle was reduced from the pre-pandemic 3–2 d;
- in order to increase the filtration effect of the water, dusty activated carbon was used as an additional material for coating the filter cartridges;
- in order to detect as soon as possible deviations of the water quality parameters from the legal recommendations, constant monitoring of the pool water quality was carried out, attendance, the need for replenishing water losses and the duration of filtration cycles were controlled.

3.3. Samplings and methods of analysis

Based on the results of laboratory tests carried out at two-time intervals (before and during the COVID-19 pandemic), the water quality of the municipal outdoor swimming pool complex was assessed and compared to the applicable requirements in this regard (Table 1).

The first interval covered the time from 28 May to 18 September 2018 and from 6 June to 5 September 2019. The second interval covered the time from 22 June to 20 August 2020 and from 10 June to 17 August 2021. The SP, RP and CP pool basins were sampled once every two weeks. Six water samples taken from each pool were analysed in each year.

Water sampling was performed in accordance with the guidelines of the standard PN-EN ISO 5667-3: 2013-05 (Water Quality – Sampling – Part 3: Fixation and Handling of Water Samples). The swimming pool water samples were taken from a depth of approx. 30 cm below the surface and approx. 50 cm from the edge of the pools. The authors, guided by the experiments from previous studies, took samples at five characteristic basin points and used a mixed sample for analysis [17,29,30].

Each sample was analysed three times, the presented results are the average values of these repetitions. The standard deviations of the repetitions did not exceed 5%, indicating a high repeatability of the results.

A Microsoft Excel spreadsheet and Statistica software from StatSoft were used to compare pool water quality parameters in the considered time intervals and to determine the relationship between them. The purpose of the statistical analysis was to evaluate the significance of differences in water quality before and during the COVID-19 pandemic and to try to assess the reasons for their occurrence. A significance level of $\alpha = 0.05$ was used for the calculations. The presence of statistically significant differences between water quality parameters was found when the probability of the p-test was below the adopted significance level ($p < \alpha$). Finally, significant differences ($p < 0.05$) of parameters were evaluated using the Mann–Whitney test.

The analysed physicochemical parameters were: nitrates and chemical oxygen demand (photometric method, DR 3900 spectrophotometer with RFID technology, Hach®, Loveland, CO, USA), free chlorine and combined chlorine (photometric method, Pocket Colorimeter II DeviceTM, Hach®, Loveland, CO, USA), chloroform (trichloromethane) and the sum of THMs (trichloromethane, bromodichloromethane, dibromochloromethane, tribromomethane), (gas chromatography method, Agilent Technologies GC7890B chromatograph with MSD5977A mass detector, USA), temperature, redox potential and pH (potentiometric method, SensION meter + MM150 DL, Hach®, Loveland, CO, USA), and turbidity (nephelometric method, TN-100 turbidimeter, Eutech®, Singapore).

The analysed bacteriological parameters were colony forming units (CFU) of *Escherichia coli* (membrane filtration according to PN-EN ISO 9308-1:2014-12/A1:2017-04), *Pseudomonas aeruginosa* (membrane filtration method according to PN-EN ISO 16266:2009), and *Legionella* sp. (membrane filtration method according to PN-EN ISO 11731:2017). Bacteriological tests were performed by an accredited laboratory.

4. Results and discussion

The average values of the physicochemical pool water quality parameters from all water samples taken in a given year and during the considered time interval are shown in Table 3. The average values of the physicochemical pool water quality parameters in individual pools and during a given time interval are shown in Fig. 3.

The occurrence of statistically significant differences between the analyzed parameters of swimming pool water quality before and during COVID-19 pandemic was found when the test probability was lower than the adopted level of significance ($p < \alpha$; $\alpha = 0{,}05$). The calculated through the Mann–Whitney test p-values are summarized in Table 4.

4.1. Physicochemical parameters

4.1.1. Temperature

The tested outdoor pools were filled with water from expansion tanks into which tap water at a temperature not higher than 14°C flowed and then it was heated in heat

Table 3
The mean values of physicochemical parameters of swimming pool water quality in studied pools before and during COVID-19 pandemic

Parameter (unit)	Before COVID-19			During COVID-19		
	2018	2019	2018–2019	2020	2021	2020–2021
Temperature (°C)	24.3	23.3	23.8	21.9	24.1	23.0
pH (–)	7.36	7.18	7.27	7.32	7.17	7.24
Redox potential (mV)	682	652	667	732	694	713
Turbidity (NTU)	0.43	0.26	0.35	0.29	0.60	0.40
Nitrates (mg·NO_3^-/L)	7.85	6.49	7.17	6.74	8.36	7.55
COD[a] (mg·O_2/L)	1.77	1.88	1.83	1.89	1.75	1.82
Free chlorine (mg·Cl_2/L)	0.78	0.95	0.86	0.64	0.68	0.66
Combined chlorine (mg·Cl_2/L)	0.16	0.21	0.19	0.17	0.29	0.23
Chloroform (mg/L)	0.047	0.078	0.062	0.017	0.043	0.030
THM[b] (mg/L)	0.057	0.080	0.069	0.023	0.045	0.034

[a]COD – chemical oxygen demand.
[b]THM – the sum of the concentrations of the compounds: bromodichloromethane, dibromochloromethane, tribromomethane, trichloromethane (chloroform).

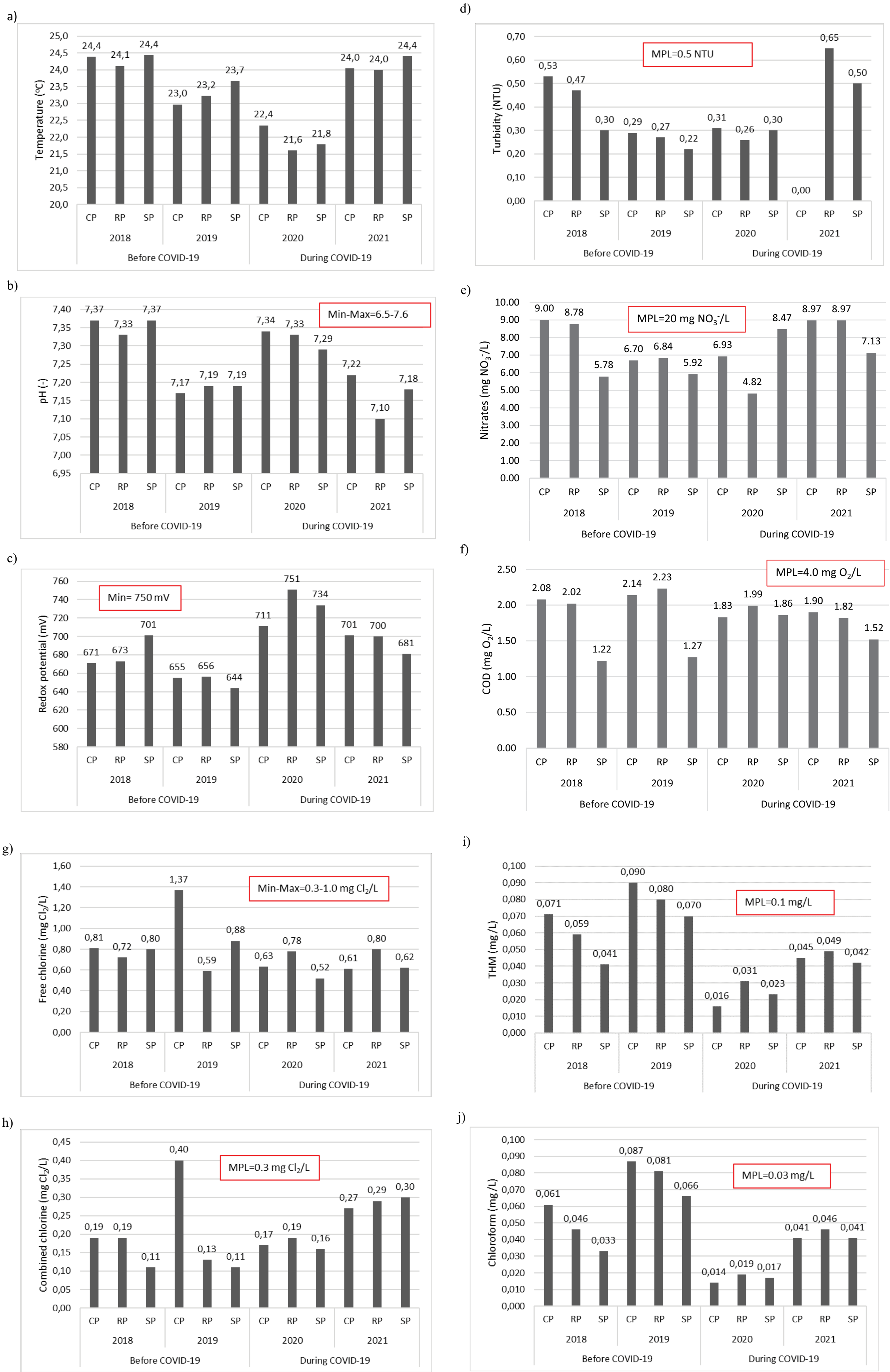

Fig. 3. The mean values of swimming pool water quality parameters before and during COVID-19 pandemic: (a) temperature, (b) pH, (c) redox potential, (d) turbidity, (e) nitrates, (f) COD, (g) free chlorine, (h) combined chlorine, (i) chloroform, and (j) THM.
Notes: MPL – Maximum permissible limit.

Table 4
Test probability p for the assessment of the significance of differences between the parameters of water quality before COVID-19 and during COVID-19 pandemic time

Parameter (unit)	p
Temperature (°C)	0.44101
pH (–)	0.14640
Redox potential (mV)	0.00002
Turbidity (NTU)	0.00708
Nitrates (mg·NO_3^-/L)	0.06722
COD (mg·O_2/L)	0.30578
Free chlorine (mg·Cl_2/L)	0.00012
Combined chlorine (mg·Cl_2/L)	0.00124
Chloroform (mg/L)	0.00002
THM (mg/L)	0.00000

exchangers to a temperature of 22°C. However, the water temperature was strongly dependent on weather conditions, including sunshine and wind strength, ranged from 21.6°C to 24.4°C (Fig. 3a)

The way of swimming pools using during the COVID-19 pandemic did not affect the changes in water temperature and thus swimming comfort. However, controlling the water temperature in the pool circuit is important for the efficiency of the water treatment processes, primarily disinfection and pH correction, and for the potential of the disinfection by-product (DBP) formation [31,32]. In basins with elevated pool water temperature, where according to studies [33–35], there is an increased release of body secretions and metabolic activity products of users, as a result, higher organic compound content is observed.

4.1.2. pH

To ensure optimum effectiveness of the sodium hypochlorite used for water disinfection and the lowest possible DBP formation potential, the pH of the water requires constant adjustment [31,36]. Since pH adjustment within the recommended range of 7.0–7.4 was carried out by automatic dosing of a 30% sulfuric acid solution and based on the indications of the measuring apparatus, its values did not differ significantly. Before the pandemic, the average water pH was 7.27 and during the pandemic it was 7.24 (Fig. 3b).

4.1.3. Redox potential

The redox potential is a parameter determining the reducing and oxidising capacity of water, it allows to assess the course of the chlorination process and the rate of bacterial destruction. A high potential value indicates that bathers are well protected against the risk of infection while bathing. Water in both indoor and outdoor pools requires a very high redox potential (≥ 750 mV) [21,37]. In all water samples tested in pre-pandemic period, redox values did not exceed 750 mV and ranged from 596 to 735 mV in 2018 and from 514 to 750 in 2019. During the pandemic, redox was much higher, it ranged from 630 to 780 mV in 2020 and from 615 to 775 mV in 2021 (Fig. 3c). The average redox at pre-pandemic period was 667 mV and during the pandemic period 713 mV. Despite the significantly lower load on the facility during the pandemic, redox values did not reach the required minimum value in most water samples. The results of studies on the disinfection effects of swimming pool water indicate that swimming pools, in which the disinfection process with sodium hypochlorite is not supported by ozonation, UV irradiation or oxidising mixtures, is not possible to ensure such a high redox potential [26,38–40].

4.1.4. Turbidity

Monitoring swimming pool water turbidity is required primarily because of its aesthetic qualities and the assessment water filtration effectiveness. However, from a hygienic point of view, the turbidity factor is important because elevated water turbidity is a quick indicator of poor water quality and an increased likelihood of pathogenic microorganisms developing in the water [41–43]. In the considered time intervals, the lowest turbidity values were determined in water samples in 2019 (before COVID-19, average 0.26 NTU) and in 2020 (during COVID-19, average 0.29 NTU). Turbidity values above the limit value of 0.5 NTU were determined in August in 2018 (0.52–1.30 NTU) and in July 2021 (0.67–1.10 NTU). In the case of outdoor pools, water turbidity below 0.5 NTU is much more difficult to ensure than in the case of indoor pools due to the introduction of suspended solids by bathers from around the pool beach, the lack of clearly demarcated “footwear” and “barefoot” zones and the lack of an order to shower before entering the pool. In the pool complex under consideration, the average water turbidity from all water samples taken before COVID-19 was 0.35 NTU and during COVID-19 0.44 NTU (Fig. 3d). The elevated turbidity values in both analysed periods did not affect bathing comfort and did not increase the growth of microorganisms.

4.1.5. Nitrates

Nitrates in swimming pool water are formed both by chlorination of organic nitrogen compounds from swimmers, such as hair, sweat and urine, and by biological processes. The direct exposure of water in open pools to sunlight and the introduction of pollutants from the pool beach into the water are responsible for the greater growth of algae and biofilms (on the walls of the pool basins, in the piping and filters), which are a source of organic and oxidisable nitrogen, compared to indoor pools. In addition, nitrate is a product of the photodecay of NCl_3 [41,44,45]. Thus, the nitrate content of pool water informs about the degree of organic matter contamination, the effects of treatment and disinfection, and if the permissible concentration is exceeded, the need to supplement the pool circuit with fresh tap water [16,17,44,46].

For the studied pool waters, a successive increase in nitrate concentrations was found during all bathing seasons. From 0.9 to 19.0 mg·NO_3^-/L in 2018. From 1.1 to 13.0 mg·NO_3^-/L in 2019. From 1.1 to 16.2 mg·NO_3^-/L in 2020 and from 3.9 to 12.0 mg·NO_3^-/L in 2021. Thanks to constant monitoring and regular washing of the filter beds and supplementation of water losses (refreshing of the pool circuit), nitrate concentrations did not exceed the limit value of 20 mg·NO_3^-/L in any of the seasons. The average nitrate concentrations in water samples from the individual pools before COVID-19 (from 5.78 to 9.00 mg·NO_3^-/L) and during COVID-19 (from 4.82–8.97 mg·NO_3^-/L) were not significantly different (Fig. 3e).

4.1.6. Chemical oxygen demand

Chemical oxygen demand (COD) is an indicator used to quantify the contamination of swimming pool water with fresh organic matter entering the pool water, correlated with the amount of precursors of disinfection by-products and the function of the pool. Most often, elevated COD values have been found in recreational pools, children's pools and pools for swimming lessons, that is, pools typically with a high bathing load [17,34,41,45,47]. This dependence was also observed in the case of the studied pool complex. The smallest COD values were measured in water from SP, that is, in the pool usually least loaded because it is intended strictly for swimming in separate lanes. On the other hand, the highest COD values were measured in water with CP and RP, that is, in pools intended mainly for play (Fig. 3f). Both at full pool load (before COVID-19) and at reduced load to approximately 35%, the COD values did not exceed the permissible value, that is, 4 mg·O_2/L. The average COD values from all collected water samples, in both time intervals, did not differ significantly and amounted to 1.83 and 1.82 mg·O_2/L, respectively.

4.1.7. Free chlorine and combined chlorine

Both free and combined chlorine determine the antiseptic properties of the disinfectant. Since free and combined chlorine can occur simultaneously, determining the form of residual chlorine is very important for the course and effect of water disinfection and for the organoleptic and health properties of the water [48–50]. The minimum concentration of free chlorine in outdoor sports-type pools should be 0.3 mg·Cl_2/L, and in recreational-type pools and those equipped with hydromassage facilities it should be 0.7 mg·Cl_2/L. The maximum free chlorine concentration in both cases is 1.0 mg·Cl_2/L. In contrast, the maximum permissible level (MPL) of combined chlorine, regardless of the type of pool, is 0.3 mg·Cl_2/L [15].

Automatic dosing of NaOCl solution for water disinfection is used in the tested swimming pool complex. The amount of the solution used depends primarily on the load of bathers, and in the case of outdoor pools, on weather conditions. In the period before the COVID-19 pandemic, the average concentration of free chlorine (from all samples taken) was 0.86 mg·Cl_2/L, and during the pandemic it was 0.66 mg·Cl_2/L. With the exception of the CP pool water samples collected in 2019 (average: 1.37 mg·Cl_2/L, Fig. 3g), the free chlorine limit was not exceeded. The same was true for concentrations of combined chlorine. Only in the samples from the CP pool it was found above the limit value (average: 0.4 mg·Cl_2/L, Fig. 3h). In the first year of the pandemic (2020), a layer of dusty activated carbon was used as an additional filtering layer. The use of such a procedure had, on the one hand, (negatively) higher consumption of the NaOCl solution (by about 20% compared to 2019 and no attendance limit), on the other hand (positively), relatively low concentrations of combined chlorine (0.16–0.19 mg·Cl_2/L, Fig. 3h). In the second year of the pandemic (2021), activated carbon dosing was discontinued and, with attendance comparable to that in 2020, the combined chlorine concentrations were higher at 0.27–0.30 mg·Cl_2/L, Fig. 3h).

The results of research on the possibility of reducing chloramines in swimming pool waters, carried out, among others, by the authors of the paper [51,52], confirm that, in order to keep the content of combined chlorine below the value of 0.3 mg·Cl_2/L, it is recommended to support final disinfection with sodium hypochlorite by ozonation, UV irradiation or the use of high-efficiency filtration using filter membranes or exactly activated carbon [32,53,54].

4.1.8. THM and chloroform

In addition to combined chlorine, trihalomethanes (THM) are an indicator of DBP in pool water. THM parameter is the sum of the concentrations of trichloromethane (chloroform), bromodichloromethane, dibromochloromethane and tribromomethane. They are highly toxic and hardly biodegradable compounds and, by accumulating in the cells of organisms, exhibit carcinogenic, mutagenic and teratogenic effects, among others [49,55,56]. Chloroform accounts for the largest share of total THM in pool waters [17,57,58], therefore its concentration is also specified for continuous monitoring in pool waters. The MPL for THM is 0.1 mg/L and for chloroform is 0.03 mg/L [15,50]. In the tested pool water samples, chloroform ranged between 61% and 100% of the THM content. On average, its proportion was 87%. The difference in THM and chloroform content at the time before and during the pandemic was clearly noticeable (Fig. 3i and j). In this case, the reduced permissible attendance during the pandemic significantly reduced the content of total THM and chloroform. The average chloroform content before the pandemic was 0.062 mg/L (well above the limit value) and during the pandemic 0.030 mg/L (within the limit value). In contrast, the average THM content before the pandemic was 0.069 mg/L and during the pandemic 0.034 mg/L. In addition, the use of activated carbon in the filtration process in 2020 resulted in approximately 50% less THM and chloroform content compared to 2021.

The problem of chloroform content in swimming pool water above the limit is much more common in outdoor pools than indoors. The reason for this is the disproportionately greater amount of pollutants leached into the water in the form of cosmetics, sunscreen creams, oils and contaminants introduced into the water with various swimming accessories or its degradation under specific conditions occurring in swimming pool installations [16,31,35,59–61].

4.2. Bacteriological parameters

Each swimmer may introduce up to a billion bacteria, including pathogenic ones, into the pool water, which find there a favourable environment for growth, which, when the pool is heavily loaded, can lead to a very rapid spread of infection [50,62,63].

Colony-forming units (CFU) of indicator bacteria, that is, *Pseudomonas aeruginosa*, *Escherichia coli* and *Legionella* sp.

are used to assess the risk of bacteriological contamination of water in outdoor pools. [21,64–66].

Bacteriological analyses carried out for the tested pools did not show the presence of bacterial CFU above the values specified in the regulations in this area [21,50]. Neither before nor during the COVID-19 pandemic was the presence of *Escherichia coli*, *Pseudomonas aeruginosa* and *Legionella* sp.

5. Conclusions

Accurate and careful control of the swimming pool water treatment and disinfection process and a quick response to adverse changes in water quality are of fundamental importance in minimising the risk of disease transmission or exposure swimmers to pathogens. In connection with the new sanitary and epidemiological regulations introduced almost all over the world after the outbreak of the COVID-19 pandemic, monitoring of water quality and hygienic conditions in swimming pool facilities has become particularly important.

Considering the constant operation of the analyzed pool circuits, the drastically reduced number of bathers, the sanitary regime during the COVID-19 pandemic and additional efforts taken (especially in 2020) to increase the effects of water treatment, it was possible to assume a much better water quality during pandemic.

The assumptions were confirmed primarily in the analysis of the very important ones for assessing the risk of health exposure of bathers, which are redox potential and DBP (chloroform and THM). For temperature, pH, nitrates and COD, no significant differences in their values were shown. However, in the case of turbidity, free and combined chlorine, their values were less positive during the pandemic, but nevertheless did not exceed acceptable values and were as acceptable as possible.

Additionally, based on the analysis performed, it was found that:

- Selected indicators of swimming pool water pollution differed significantly before and during the pandemic period of COVID-19. Mainly, the difference in THM, chloroform content and the redox potential were observed. These are parameters strongly connected with the disinfection (chlorination process) of swimming pool water.
- The application of a layer of dusty activated carbon as an additional filtering layer had both negative and positive impact, causing higher consumption of the NaOCl solution but reducing the concentrations of combined chlorine, the THM and chloroform content and the share of chloroform in total THM.
- The higher potential values of redox potential during the pandemic period indicates that swimmers are more effectively protected against the risk of infection during the pandemic period.
- Reduction in the number of people able to use the facility during the pandemic and the shortening of the filtration cycle did not have a positive effect on the turbidity of the pool water. Its values in the period before pandemic were lower than during the pandemic. This indicates that the specific nature of outdoor swimming pools makes it very difficult to maintain low water turbidity, regardless of the actions taken to improve water quality.

According to the authors, the application of more frequent washing of filter beds (shortening the filter cycle) during the COVID-19 pandemic, with dramatically reduced attendance, did not have a significant impact on pool water quality. In turn, the dosing of dusty activated carbon, as an additional filtration layer, was an effective action to reduce the concentration of combined chlorine and chloroform – harmful DBP to the health of bathers.

The presented analysis of swimming pool water quality parameters in the municipal complex of outdoor swimming pools before (2018–2019) and during (2020–2021) the COVID-19 pandemic provides new information on the impact of the changed pool facility operating rules on swimming pool water quality.

Author contributions

JWK: conceptualization, methodology, formal analysis, investigation, data collection, original draft preparation, review and editing of the manuscript, and visualization. MD: supervision, formal analysis and writing review. ALR: methodology, investigation, data collection, and writing review. Authors contributed to the article and approved the submitted version.

Funding

This work was supported by the Ministry of Education and Science of the Republic of Poland within statutory funds and by the Polish National Science Centre (No. 2018/29/N/ST/01352).

Data availability

The datasets generated and analysed during the current study are available from the corresponding author on reasonable request.

Conflict of interest

The authors declare that the research was conducted in the absence of commercial or financial relationships that could be construed as a potential conflict of interest.

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