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Recreational Water Safety in Hotels: Lessons from the COVID-19 Pandemic and the Way Forward for a Safe Aquatic Environment

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Abstract: The recreational waters of hotels are widely used by locals and travelers all around the world, and this impacts public health. In this regard, the WHO frequently offers recommendations—especially during the COVID-19 era—that operators and managers of public pools, hot tubs, or splash pads should continue to follow. This study aims to evaluate the microbiological results of COVID-19 sanitation protocols in recreational waters in hotels during the summer periods post-COVID-19 (2020–2022) and compare them with those pre-COVID-19 (2019). Of the samples tested during the pre-pandemic period, less than 1/5 were positive for *total coliforms*, *common aerobic bacteria*, and *P. aeruginosa*, while less than 3% of the samples tested were positive for *E. coli*. During the pandemic years, the percentages dropped by half for *total coliforms*, *common aerobic bacteria*, and *E. coli*, while only the percentage for *P. aeruginosa* remained the same. The relative risk (RR) for the presence of *P. aeruginosa* in recreational waters was greatly affected by chlorine levels, pH values, and water temperature. Our results elucidate the impact of sanitation protocols on the safety of recreational waters in hotels during public health crises. Moreover, the challenges operators face in maintaining long-term implementation of these protocols are highlighted, which in turn dictates the appropriate choice of preventive and applicable measures to ensure health and safety.

Keywords: hotels; recreational waters; COVID-19; health protocols; swimming pools; total microbial flora; *Pseudomonas aeruginosa*; *E. coli*



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1. Introduction

Recreational water has long been recognized for its substantial influence on health and wellness. Seaports, lakes, rivers, pools, and spas exemplify clean, well-managed recreational water resources that function as community centers and economic catalysts for visitors and athletic activities. Nonetheless, additional freshwater and coastal beaches are susceptible to pollution from untreated sewage discharges, runoff of animal waste from adjacent farms, or algal blooms induced by excessive nutrient influx owing to heightened human activity and climate change [1–6].

Regular checks for chemical contaminants and disease-causing microbes during recreational activities, such as swimming, are necessary to prevent any negative impact on human health. Current recreational water-quality guidelines, intended to protect swimmers from illness due to exposure to disease-causing microorganisms in these waters, have a solid foundation thanks to scientific studies [7].

Pool water can transmit several diseases, but the likelihood of acquiring an illness in a well-maintained pool is minimal. Individuals could harbor germs, viruses, and parasites on their skin, both inside and outside. It is possible to introduce certain organisms into the pool

water to infect other swimmers [8–10]. Organisms can enter the body via the oral cavity, nasal passages, auditory canals, and ocular openings. Breaks in the skin can serve as a pathway for transmission as well [11–13]. Before entering a pool, individuals should shower to remove any pollutants from their skin [14]. Numerous nations, notably European Union Member States and the United States, consistently assess the microbiological quality of recreational water to safeguard public health [15–17]. The majority of countries worldwide have implemented legislation or health rules in accordance with the guidelines set forth by the World Health Organization (WHO) to enhance swimming pool safety. These procedures typically encompass routine inspections, obligatory disinfection methods, and extensive training for personnel. By following these principles, nations seek to mitigate the risk of waterborne diseases and guarantee a safe environment for all swimmers [18].

Water quality is regularly monitored to prevent any negative impact on human health during recreational activities like swimming or boating. This includes the monitoring of chemical contaminants and disease-causing bacteria [19–22].

The current study establishes a robust scientific basis for current guidelines on recreational water quality, which aim to safeguard swimmers from becoming sick as a result of being exposed to disease-causing microorganisms in recreational waters [23].

From 2000 to 2014, the Centers for Disease Control and Prevention (CDC) received reports of 493 outbreaks associated with treated recreational water [24,25].

Even though the COVID-19 disease does not appear to be transmissible to humans through fresh or marine water (lakes, rivers, ponds, and seas), hot tubs, splash pads, or any other type of pool or spa water, operators and managers must ensure that pools, hot tubs, and splash pads are properly disinfected with chlorine or bromine to render the virus inactive [26–32]. In every case where a swimming pool is used, the water must be disinfected, and stringent health precautions must be followed. To ensure that these measurements are implemented correctly, the residual chlorine concentration in the water must be precisely measured and maintained within the range of 0.4 to 0.7 mg/L. During the COVID-19 pandemic, WHO guidelines recommend maintaining the residual chlorine concentration in tank water between 1 and 3 mg/L for swimming pools and up to 5 mg/L for spas to protect against SARS-CoV-2 [18,33].

Recreational water diseases (RWIs) result from the presence of microorganisms and chemical substances in the water that we swim or engage in recreational activities in, such as swimming pools, water parks, hot tubs, splash pads, lakes, rivers, or oceans [5]. In 1998, Rigas et al. examined samples from 11 indoor and outdoor swimming pools in Greece based on physicochemical, health-related, microbiological, and technological factors. They indicated inadequate compliance to all examined measures compared to established standards. The primary factors contributing to inadequate water quality were redox potential, turbidity, and the presence of certain pathogenic bacteria (*Staphylococcus aureus* and *Pseudomonas aeruginosa*). The deficiencies were ascribed to the inadequate design of pools and insufficient vocational training for the technical workers managing the water treatment facilities [34].

In the summer of 2020–2022, strict COVID-19 health procedures affected the hotel business in Crete, Greece, focusing on microbiological hygiene and physicochemical water parameters. Although the importance of several parameters for the safety of swimmers on indoor and outdoor swimming pools has been examined in the literature, to the best of our knowledge, a systematic study of the effect of the physicochemical, health-related, microbiological, and technical parameters on the recreational pools of hotels in Greece within the context of COVID-19 measures for three continuous years of the pandemic has not been reported so far.

2. Materials and Methods

2.1. Sample Collection

The study examined 23 pools from inspected hotels in Crete, where 708 water samples were collected and tested for microbial indicators according to national legislation

and public health agency guidelines. For hotel unit self-control, we collected and tested 175 samples in 2019, 151 in 2020, 222 in 2021, and 160 in 2022. The staff of the Department of Clinical Microbiology and Microbial Pathogenesis, School of Medicine, University of Crete, collected all samples. In compliance with data protection requirements, the laboratory maintains a database that encompasses the annual results of chemical and microbiological studies, along with measurements of the physicochemical characteristics of the water for each hotel. This enabled the authors to carry out the present investigation by juxtaposing data gathered prior to and subsequent to the COVID-19 epidemic.

Water samples were obtained in compliance with ISO 19458:2006 [35]. The collection of samples of recreational water was conducted between 9 a.m. and 12 p.m. utilizing the following procedure: Two samples were collected from the swimming pools and stored in 500 mL bottles. The samples were collected from the pool's basin at locations adjacent to the outflows (skimmers or gutters). Sodium thiosulfate was utilized in an 80 mg/L aqueous solution. The chosen sampling spots included the tank's entry point, the water exit point, the midpoint of the tank (20 cm beneath the water's surface), and locations before and after the filters. The samples were tagged and temporarily stored in a cold box at a temperature of $5(\pm 3)$ °C, shielded from direct light, prior to rapid delivery to the laboratory within 24 h of sampling.

2.2. Microbiological Detection Analysis

Escherichia Coli (*E. coli*) and coliform bacteria were counted in accordance with ISO 9308-1:2014 AMD 1:2016 [36]. Membrane filtration served as the foundation for the procedure, which also included chromogenic medium cultivation and a final computation of the desired microorganism count in the water sample. Waters with low bacterial populations, which will produce <80 colonies on the CCA chromogenic substrate, were very well suited for this approach. These samples included treated water, swimming pool disinfected water, and drinking water. Certain β -D-glucuronidase-negative strains of *Escherichia coli*, such as O157, were not identified as *Escherichia coli*. On this chromogenic agar, the strains manifest as coliforms if they are β -D-galactosidase-positive.

Enterobacteriaceae, which include coliforms, are known to express β -D-galactosidase. *Enterobacteriaceae*, which include *E. coli*, express both β -D-glucuronidase and β -D-galactosidase. The process involved passing a predetermined amount of water (often 100 mL) through a sterile membrane filter with a 0.45 μ m pore size that could hold microorganisms. After filtration, the samples were incubated at 36 ± 2 °C for 21 to 24 h on a solid chromogenic substrate (Coliform Chromocult Agar, Chromocult Coliform Agar, 1.10426, Merck Millipore). Next, colonies that showed positive results for β -D-galactosidase (pink-red colonies) were counted as potential non-*E. coli* coliforms. Negative oxidase response evidence was used to validate questionable colonies to prevent false-positive outcomes. Additionally, positive colonies for β -D-glucuronidase and β -D-galactosidase (dark blue-violet) were considered as *E. coli*. The sum of oxidase-negative pink-red colonies and dark blue-violet colonies determined the total number of coliforms.

The laboratory employed membrane filtering methodology in accordance with ISO 16266:2006 [37]. An accurately measured 100-milliliter water sample, or a diluted version of the sample, was filtered through a 0.45-micrometer sterile membrane filter. The selective medium was covered with the membrane filter, and it was incubated for 44 h and 4 h at 36 ± 2 °C according to the medium manufacturer's instructions.

Following incubation, the quantity of unique colonies on the membrane filter was enumerated to ascertain the number of *P. aeruginosa* assumed. The membrane filter is used to create subcultures of colonies that need to be confirmed on nutrient agar plates. After being incubated at 36 ± 2 °C for 22 h and 2 h, non-fluorescent cultures were subjected to an oxidase reaction test, and cultures that tested positive for oxidase were evaluated for fluorescence and ammonia production from acetamide. The capacity of initially fluorescent cultures to generate ammonia from acetamide was examined. We quantified the verified *P.*

aeruginosa colonies in the filtered water volume by enumerating the typical colonies on the membranes and factoring in the proportion of confirmatory tests performed.

2.3. Data Collection

During the sample process, physicochemical parameters including water temperature, pH level, and residual chlorine concentration were documented. Temperature, residual chlorine, and pH levels were all measured with calibrated instruments. More precisely, temperatures were measured using a calibrated thermometer placed in the center of the swimming pool. The levels of free chlorine and pH were measured with a calibrated portable photometer powered by a microcontroller. The specimens were collected in aseptic 1 L receptacles containing 20 milligrams of $\text{Na}_2\text{S}_2\text{O}_3$ to neutralize oxidizing biocides and chlorine.

2.4. Statistical Analysis

Statistical analyses were performed using the Epi-Info 2000 version 7.2.6 (Centers for Disease Control and Prevention, Atlanta, GA, USA) [38], and the free electronic version of the MedCalc Relative Risk Statistical Calculation Software version 23.0.6, Ostend, Belgium [39] was also utilized. The relative risk (RR) was computed using a 95% confidence interval (CI). A significance level of $p < 0.05$ was used to determine if there was a statistically meaningful difference. The linear correlation was calculated using Pearson's coefficient (r). Statistical significance was established with a p -value of less than 0.05, while a p -value of less than 0.0001 indicated high significance.

3. Results

3.1. Water Samples' Physicochemical Characteristics

Residual chlorine levels. Primarily, the residual chlorine was measured as the most important parameter, for which the threshold was legally elevated during the pandemic in compliance with Greek legislation and the recommendations of the WHO and CDC. Comparing the tourist seasons between 2019 and 2022, it appears that in 2019, 145 (87.88%) samples were found within limits and 20 (12.12%) out of the limits, as determined by the national legislation for the parametric values of 0.4 mg/L. Next, in the 2020 tourist season, 142 (95.95%) samples were within and 6 (4.05%) were out of the limits; in the 2021 tourist season, 201 (94.77%) were within and 12 (5.63%) were out of the limits; and finally, in 2022, 134 (86.45%) were within and 21 (13.55%) were out of limits. As a result, there is a 67% reduction in non-conformities regarding the residual chlorine in swimming pools for 2020 compared to the pre-COVID levels and a 53.55% reduction for 2021, whereas there was an increase for 2022 (Figure 1). The non-conformities in residual chlorine in the years 2019 (pre-COVID-19) until 2022 (COVID-19 era) for the parametric values of 0.4, 1, 2m and 3 mg/L are presented in Table 1.

Table 1. Comparison of residual chlorine values <0.4, <1, <2, and <3 mg/L between 2019 and 2022, and the estimated reduction in non-conformities for chlorine values <0.4 mg/L.

Residual Chlorine mg/L	2019		2020		Reduction %	2021		Reduction %	2022		Reduction %
	n	%	n	%		n	%		n	%	
<0.4	20	12.12%	6	4.05%	67%	12	5.63%	53.55%	21	13.55%	−11.80%
<1	53	32.12%	26	17.57%		36	16.90%		30	19.35%	
<2	126	76.36%	79	53.38%		102	47.89%		69	44.52%	
<3	145	87.88%	110	74.32%		149	69.95%		109	70.32%	

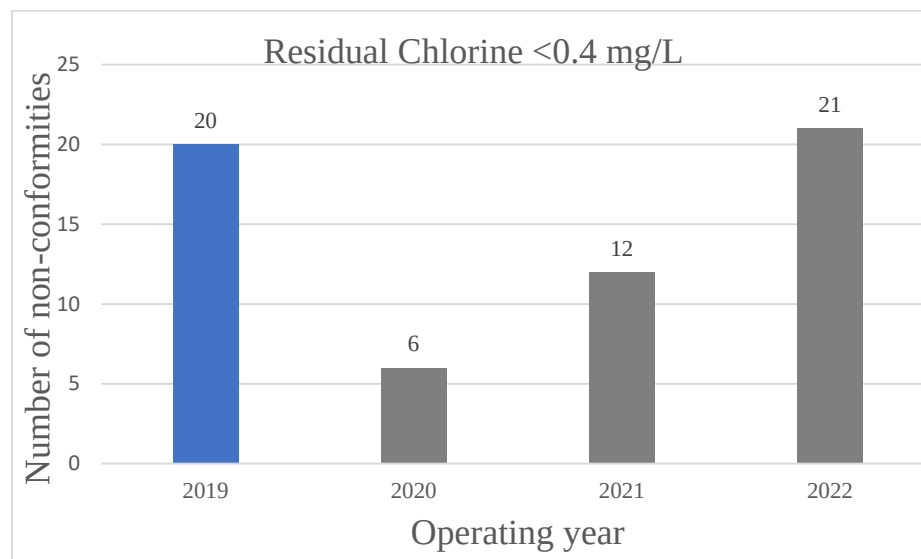


Figure 1. Comparison between non-conformities in the residual chlorine values < 0.4 mg/L before the COVID-19 pandemic (blue column) and for the years 2020, 2021, and 2022 (gray columns, COVID-19 era).

pH values. There was a total of 255 pH measurements during the 2019–2022 period. Of the total 51 samples in 2019, 33 (64.71%) were inside proper limits (< 7.2 and > 7.8), while 18 (35.29%) were not. In 2020, out of the 54 samples measured, 48 (88.89%) were within limits, while 6 (11.11%) were not. In 2021, 80 samples were measured with 52 (65%) within limits and 28 (35%) out of limits. Finally, in 2022, out of the 70 samples measured, 46 (65.71%) were within limits, while 24 (34.29%) were not. The analysis of pH values during the three years of COVID-19 and pre-COVID-19 indicated a 69% decrease in non-conformities in 2020, characterized by the most stringent protocols, followed by a 1% drop in 2021 and a 3% reduction in 2022 (Figure 2). In 2019, the relative risk (RR) associated with inappropriate pH on effective chlorination was relatively high ($RR = 1.03$; $p = 0.47$). However, from 2020 to 2022, due to a smaller sample size and elevated chlorination levels, the RR was found to be nonexistent ($RR = 0.00$; $p = 0.44$) concerning the impact of inappropriate pH on effective chlorination.

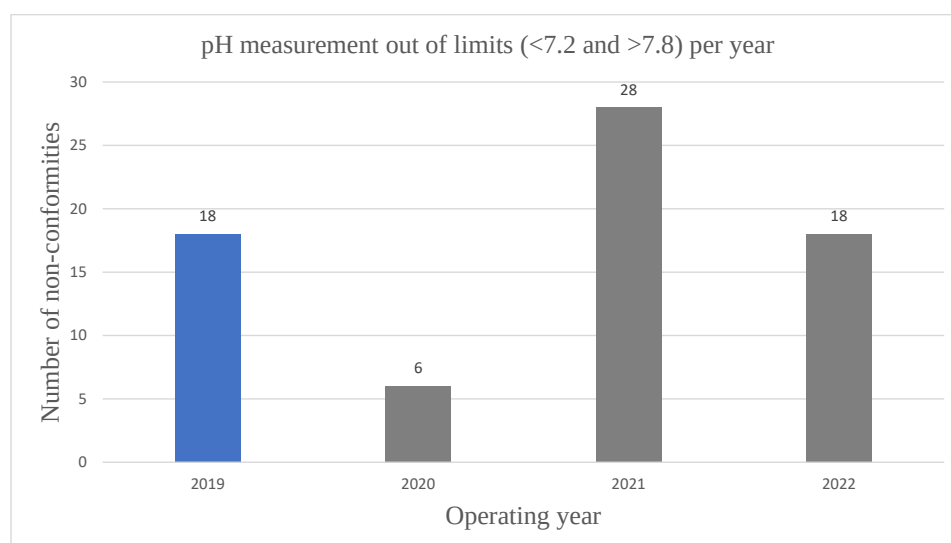


Figure 2. Comparison between non-conformities in the pH values (< 7.2 and > 7.8) before the COVID-19 pandemic (blue column) and for the years 2020, 2021, and 2022 (gray columns, COVID-19 era).

Water temperature. We recorded the water temperature in a total of 209 samples during the 2019–2022 period (Figure 3). In 2019, the water temperature was measured in 49 samples, and 23 (46.94%) were within acceptable limits ($<25^{\circ}\text{C}$), while 26 (53.06%) were above that limit. In 2020, we tested 26 samples, finding only 6 (23.08%) below 25°C and 20 (76.92%) above it. Next, in 2021, the water temperature was recorded in 99 samples, and 21 (30.43%) were within acceptable limits ($<25^{\circ}\text{C}$), while 48 (69.57%) were above that limit. Finally, in 2022, the water temperature was tested in 65 samples, and 14 (21.54%) were within acceptable limits ($<25^{\circ}\text{C}$), while 51 (78.46%) were above that limit.

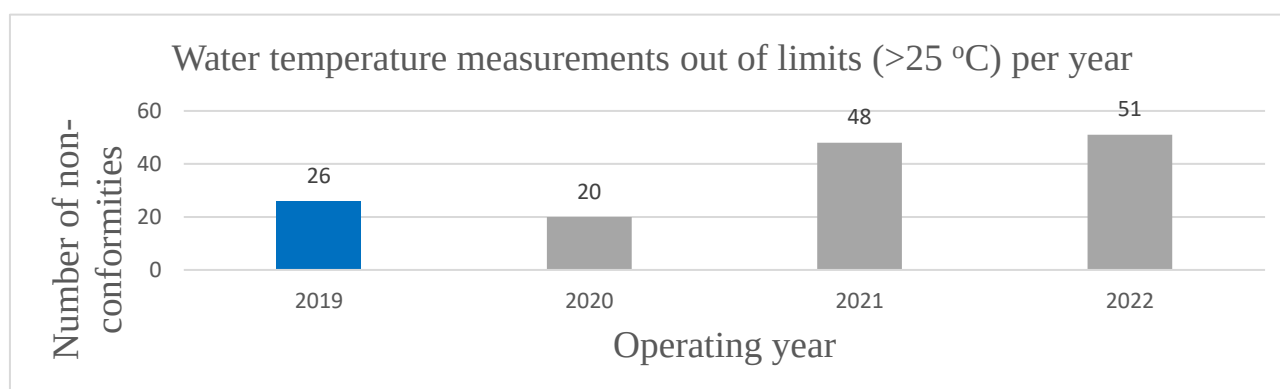


Figure 3. Comparison between non-conformities in the water temperature limits before the COVID-19 pandemic (blue column) and for the years 2020, 2021, and 2022 (gray columns, COVID-19 era).

3.2. Water Samples' Microbiological Parameters

The subsequent limitations were considered for the evaluation of water microbiological parameters: *E. coli* and *P. aeruginosa*, <1 CFU/100 mL; *total microbial flora*, <200 CFU/mL; and *total coliforms*, >15 CFU/100 mL. The non-conformities in the microbiological parameters in the years 2019 (pre-COVID-19) until 2022 (COVID-19 era) are presented in Table 2.

Table 2. Comparison for non-conformities in the water microbiological parameters of all samples between 2019 and 2022: *E. coli* and *P. aeruginosa*, <1 CFU/100 mL; *total microbial flora*, <200 CFU/mL; and *total coliforms*, >15 CFU/100 mL.

Microbiological Parameters of Water Samples		Operating Years							
		2019		2020		2021		2022	
		No.	%	No.	%	No.	%	No.	%
<i>Total flora</i>	within limits	156	89.14	151	100	221	99.55	154	96.25
	out	19	10.86	0	0	1	0.45	6	3.75
<i>Total coliforms</i>	within limits	157	89.71	140	92.72	209	94.14	144	90
	out	18	10.29	11	7.28	13	5.86	16	10
<i>E. coli</i>	within limits	170	97.14	149	98.68	217	97.75	160	100
	out	5	2.86	2	1.32	5	2.25	0	0
<i>Pseudomonas aeruginosa</i>	within limits	148	84.57	126	83.44	192	86.49	132	82.5
	out	27	15.43	25	16.56	30	13.51	28	17.5

Escherichia coli (*E. coli*). Out of a total of 708 samples collected over the operating years, 696 (98.3%) were compliant, while 12 (1.69%) were non-compliant. In 2019, of 175 samples, 170 (97.14%) were within acceptable limits, while 5 (2.86%) were not. In 2020, out of 151 samples collected, 149 (98.68%) were within permissible limits, while 2 (1.32%) were not. Similarly, in 2021, 222 samples were analyzed with 217 (97.75%) samples within acceptable limits, while 5 (2.25%) were not. Finally, in 2022, over 160 samples were measured, and all samples (100%) were found to be in compliance with the legislative requirements.

Pseudomonas aeruginosa (*P. aeruginosa*). Of the 708 samples analyzed, 598 (84.46%) were considered acceptable and 110 (15.53%) were identified as unacceptable. In 2019, 175 samples were analyzed, of which 148 (84.57%) met acceptable standards, while 27 (15.42%) did not. In 2020, 151 samples were analyzed, with 126 (83.44%) conforming to acceptable standards and 25 (16.56%) failing to comply. Next, in 2021, of 222 samples, 192 (86.49%) were within acceptable limits, while 30 (13.51%) were not. Finally, in 2022, 160 samples were measured, with 132 (82.5%) identified within limits and 28 (17.5%) out of limits.

Total microbial flora. A total of 682 (96.32%) samples fell within limits and 26 (3.67%) deviated from the legislative standards (>200 CFU/mL). More specifically, in 2019, the analysis of 175 water samples revealed that 156 (89.14%) were within limits and 19 (10.86%) out of limits. Next, the analysis of 151 water samples in 2020 led to 151 samples within limits and none out of limits. In 2021, 1 (0.45%) sample out of 222 was found to be out of limits, and finally, in 2022, out of 160 samples, 154 (96.25%) were within and 6 (3.75%) out of limits (Table 2).

Total coliform bacteria. A total of 650 (91.88%) samples were compliant with the legislative limits, while 58 (8.19%) were non-compliant. In 2019, of 175 samples, 157 (89.71%) were within acceptable limits, while 18 (10.29%) were not. In 2020, out of 151 samples collected, 140 (92.72%) were within permissible limits, while 11 (7.28%) were not. Accordingly, in 2021, 222 samples were analyzed, with 209 (94.14%) samples within acceptable limits and 13 (5.86%) not. Finally, in 2022, over 160 samples were measured, and 144 (90%) were found to be in compliance with the legislative requirements and 16 (10%) were not.

The reduction in non-conformities for the microbiological parameters during the pandemic years of 2020–2022 compared to 2019 is presented in Figure 4. First, a reduction of 100% for total flora is shown in 2020, a 96% reduction in 2021, and a 65% reduction in 2022. For total coliforms, a small decrease of 29% is shown in 2020, a further increase of 43%, and then a negligible reduction of 3% in 2022. The reduction in non-conformities of *E. coli* was 54% in 2020, 21% in 2021, and 100% in 2022. Finally, the analysis of samples for *P. aeruginosa* showed an increase in non-conformities in 2020 and 2022 of 7% and 13%, respectively, whereas in 2021, there was a reduction of 12%.

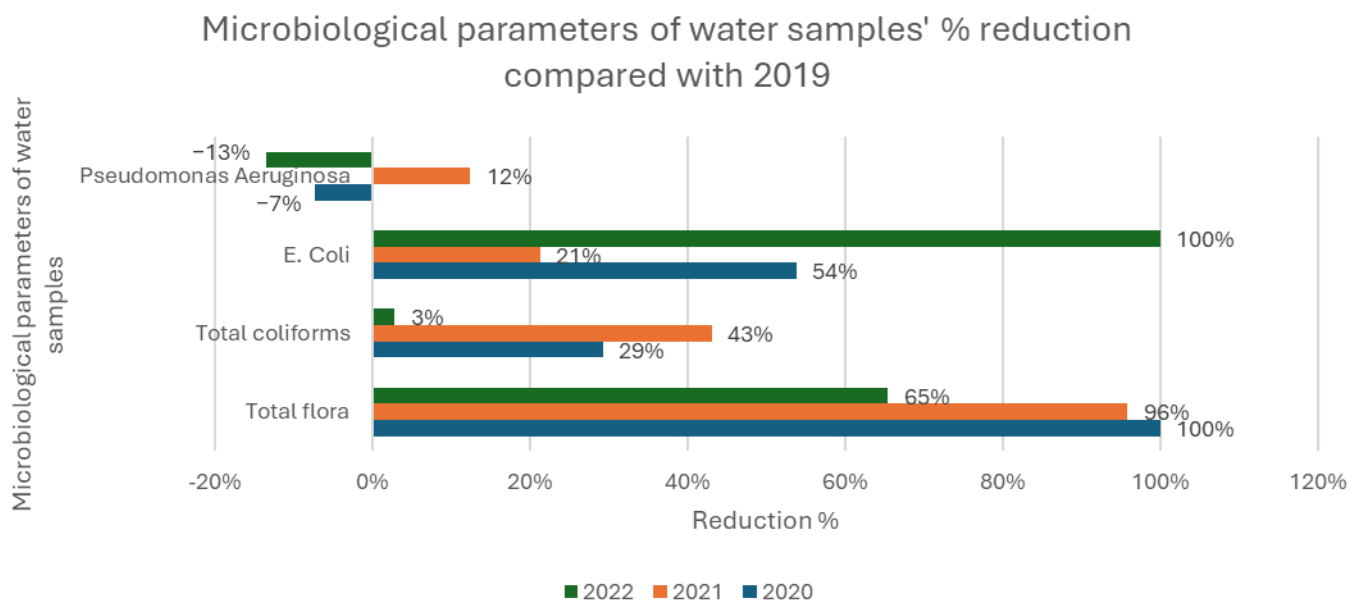


Figure 4. Microbiological parameters of water samples' % reduction compared with 2019 for the years 2020 (blue column), 2021 (orange column), and 2022 (gray column).

According to public health authorities, both chlorination and temperature parameters are critical for assessing the microbiological hygiene of water, regardless of the existence

of extensive pandemic restrictions [40,41]. Based on the analysis of 708 samples, for all operating years, the following statistical indicators were calculated.

The odds ratio for increased temperatures of water inside the pool and the presence of Gram-negative bacteria, namely *P. aeruginosa*, was counted to be 1.5294 with a *p*-value of 0.3293, a 95% CI of 0.6513 to 3.5916, and a *z* statistic of 0.975.

Additionally, the relative risk of non-compliance with chlorination standards of <0.4 mg/L was calculated to be 3.88 for the presence of *P. aeruginosa*, 2.34 for *E. coli*, 11.42 for total microbial flora, and 4.84 for total coliform bacteria. The *p*-values were significant for *P. aeruginosa* ($p < 0.0001$), total microbial flora, and coliform bacteria, but not for *E. coli* (0.26) (Table 3).

Table 3. Residual chlorine and relative risk calculation for the water microbiological parameters of all samples between 2019 and 2022: *E. coli* and *P. aeruginosa*, <1 CFU/100 mL; total microbial flora, <200 CFU/mL; and total coliforms, >15 CFU/100 mL.

	Statistics	<i>Pseudomonas aeruginosa</i>	<i>E. coli</i>	Total microbial flora	Total coliform bacteria
Residual chlorine <0.4 mg/L and relative risk	Relative risk	3.88	2.34	11.42	4.84
	95% CI	2.7611 to 5.463	0.5182 to 10.5919	5.4611 to 23.8849	2.9132 to 8.0538
	<i>z</i> statistic	7.793	1.106	6.470	1.106
	Significance level	$p < 0.0001$	0.26	$p < 0.0001$	$p < 0.0001$
	NNT (harm)	2.83	51.470	4.974	4.373
	95% CI	3.845 (harm) to 2.249 (harm)	8.848 (harm) to ∞ to 70.432 (benefit)	6.529 (harm) to 4.017 (harm)	6.306 (harm) to 3.348 (harm)

Finally, linear regression analysis was conducted to record the relation of *P. aeruginosa* with non-conformities in the residual chlorine level < 0.4 mg/L. Breusch–Pagan test results indicated that the null hypothesis for homoscedasticity can be supported at the $\alpha = 0.05$ significance level ($p = 0.10$). The linear correlation coefficients indicated a positive association between poor chlorination (<0.4 mg/L) and the unacceptable occurrence of *P. aeruginosa* ($r^2 = 0.05$, $p < 0.0001$) (Table 4).

Table 4. Results of the *P. aeruginosa* linear regression analysis with presence of non-conformities in the residual chlorine level < 0.4 mg/L.

Variable	Coefficient	95% Confidence	Limits	F-Test	<i>p</i> -Value
Residual chlorine < 0.4 mg/L	14.916	10.015	19.817	35.70	0.000000
High presence of <i>Pseudomonas aer.</i>	3.01	1.659	0.735	17.81	0.000028
Correlation coefficient r^2	0.05				
Analysis	Coefficient	<i>p</i> -value			
Pearson's correlation analysis	0.22	<0.0001			
Spearman's correlation analysis	0.28	<0.0001			

4. Discussion

In March 2020, acknowledging the necessity to strengthen global resources to combat the pandemic, numerous states consulted the WHO to urge the establishment of a global repository for intellectual property pertaining to technology for the detection, prevention, control, and treatment of COVID-19 [42]. According to the US CDC, there is no existing evidence suggesting that the SARS-CoV-2 virus can be transmitted to individuals via water in swimming pools, hot tubs, splash pads, or through freshwater or marine environments, including lakes, rivers, ponds, and seas. Proper water disinfection using chlorine or bromine should effectively inactivate the virus in pools, hot tubs, and splash pads. Operators and managers of public pools, hot tubs, splash pads, or freshwater must adhere to federal, state, local, tribal, or territorial directives and collaborate with local health authorities [43].

Numerous nations have instituted more stringent rules and devised supplementary ways to curtail the transmission of COVID-19 in recreational aquatic settings. The Greek Tourism Ministry has required the enforcement of health procedures in all hotels across the country to guarantee their safe reopening and operation following the initial wave of the COVID-19 epidemic. The design, construction, and maintenance of swimming pools incorporated preventative measures to reduce disease spread and ensure user comfort. During pool operation, disinfection and filtration of the water is essential for eliminating microorganisms and removing impurities, respectively [22]. Chlorine- or bromine-based disinfectants are utilized in many swimming pools to inhibit microbial growth. Nonetheless, chlorination is the predominant procedure employed [23]. Consequently, checking for free chlorine and sustaining appropriate chlorine levels in swimming pools is a critical safety measure.

The primary source of recreational water contamination, and consequently the most significant public health concern, is from microorganisms present in polluted feces and vomit. The quality of pool water is influenced by various elements, including water pollution levels, the number of bathers and their behavior, and the ventilation system (for enclosed pools), as well as the temperature of both water and air, and the water circulation system. The outcomes of physicochemical analyses of pool water-quality parameters, conducted by health inspection authorities, are regarded as supplementary to the evaluation of contamination level [27]. The results of microbiological analyses and the evaluation of the facility's sanitary state are essential. Prior to the onset of the pandemic, more strict criteria were established for water treatment and the maintenance of quality in swimming pools [25]. Water must be filtered and disinfected, conforming to the physical, chemical, and microbiological standards established by Greek legislation. The current legislation stipulates the necessary monitoring frequencies for physicochemical and microbiological indicators, as well as the protocols for closing and maintaining the tank in instances of non-compliance [26].

Disinfectants introduced into water must eliminate or deactivate bacteria while preserving the integrity of swimmers' skin, eyes, and mucous membranes. Chlorine is frequently utilized because of its economical nature, ease of application, and safety. Cleaning and disinfection protocols must be complemented by stringent hygiene and conduct regulations for bathers, together with a cap on the number of bathers permitted [10].

Chlorine was employed by the operators of the examined swimming pools as the primary disinfection strategy. Elevated residual chlorine levels, mandated by health guidelines, significantly impacted the microbial cleanliness of the analyzed swimming pool water. More specifically, water samples tested with incompatible free chlorine levels, water temperatures above 25 °C, and pH values over 7.8 were found, likewise, to have levels of bacteria beyond regulatory limitations, as indicated in similar studies [24–26].

In this study, the physicochemical characteristics of water samples for the operating years 2020, 2021, and 2022 in swimming pools, which correspond to the COVID-19 era, are compared to the reference year 2019, which describes the pre-COVID-19 status.

First, the non-conformities in residual chlorine levels less than 0.4 mg/L for the mentioned years are presented (Figure 1). A vast reduction of 67% and 58% in non-conformities in 2020 and 2021, respectively, was reported, which is attributed to the elevated precautionary measures to combat COVID-19. In our previous study, we showed a 79% reduction in non-conformities between 2019 and 2020 [33]. On the other hand, the increase in non-conformities in 2022 suggests the inability of operators to manage and retain strict protocols over time, which led to restoring chlorine levels to previous statuses. Concerning chlorine as a disinfectant in swimming pool water, a study by Mellou et al. [18], utilized a questionnaire to assess adherence to more strict health protocols in hotel swimming pools during the COVID-19 pandemic. The study revealed that 70% of the facilities met the regulatory standard for free chlorine in pool water (1–3 mg/L).

In 2019, despite the legislative requirement for residual chlorine being 0.4 to 0.7 mg/L, many hotels applied 0.4 to 3 mg/L, in line with global guidelines. In this study, for non-

compliances below 1, 2, and 3 mg/L, a similar behavior is observed for all years during the COVID-19 period (Table 1). As the amount of residual chlorine increased from 1 to 2 to 3 mg/L, the non-compliances also increased from 17.57% to 53.38% to 74.32% for 2020, from 16.9% to 47.89% to 69.95% for 2021, and from 19.35% to 44.52% to 70.32% for 2022, respectively. This is attributed to the fact that strict chlorination at 1–3 mg/L is costly and non-viable for the operators even though a high compliance is reported by them [18].

As was evident in the research of Mellou et al., almost half of the respondents considered that full implementation of new regulations was not feasible (59%). Of them, 128 (38%) reported increased cost as the main reason for the lack of compliance, and 205 (62%) felt the requirements were unrealistic. Furthermore, the study indicated a need for better support and resources to facilitate compliance, as many participants expressed a desire for clearer guidelines and assistance from regulatory bodies [18].

Next, the pH values must be sustained between 7.2 and 7.8 for chlorine disinfectants [44]. Global public health organizations indicate that a pH value level below 7.2 may lead to ocular discomfort due to increased chloramine production, rapid depletion of chlorine, erosion of exposed cement, and metal corrosion. A pH value greater than 7.6 may diminish the efficacy of chlorine disinfection, elevate chlorine demand, cause ocular irritation, lead to skin desiccation, result in murky water, and promote scale accumulation [5,45]. The research conducted by Masoud et al. [46] revealed that most swimming pools failed to adhere to the established pH value requirements. In the present study, the comparison of the pH values during COVID-19 and pre-COVID-19 revealed a 69% reduction in non-conformities in the year 2020 with the strictest protocols. Even though 2021 and 2022 were expected to be years with similar levels of reduction in non-conformities, a negligible reduction of 1% for 2021 and 3% for 2022 was observed (Figure 2). This suggests a relaxation of the preventative measures which resulted also in pH values out of the acceptable limits.

Similarly, according to the national legislation, it is imperative that the water temperature must remain below 25 °C. Maintaining the appropriate water temperature in a swimming pool is crucial for optimizing the performance, comfort, and safety of swimmers [47]. Nonetheless, in a Mediterranean country such as Greece, with elevated temperatures in the summer touristic season, this limit regulation poses a problem since most swimming pools are outdoors and exposed to sunlight and, thus, hot temperatures. The latter also affects the quantity of free chlorine, deactivating the disinfection process. Herein, a vast issue is observed for the samples measured during COVID-19 since the number of non-conformities in the water temperature values is increased from 2020 to 2022 (Figure 3) up to two times (from 26 in 2019 to 51 in 2022), which is related to the relaxation of the strict protocols over time, leading to a total degradation of the operating rules and non-regulation of the basic physicochemical parameters.

Overall, the evaluation of the physicochemical parameters measured for the years 2019 to 2022 shows that tourist operators followed the guidelines and strict protocols primarily during the first year of the pandemic, which led to very characteristic compliance for 2020 across all parameters. However, after two years and the implementation of strict measures, the operators were excluded from this management, reaching a point of complete non-compliance and disregard for operational rules that could create public health problems. Next, we will see how non-compliance with simple rules regarding chlorination, pH adjustment, and temperature affects the development of harmful microorganisms and public health.

The microbiological quality of swimming pools is crucial for preventing waterborne diseases and ensuring swimmer safety. Various studies highlight the importance of monitoring microbial contaminants, including fecal coliforms, staphylococci, *Legionella pneumophila*, and *P. aeruginosa*, which can indicate health risks associated with swimming activities [3,48–53]. While the focus on microbial quality is vital, it is also important to consider the potential for over-regulation, which may lead to unnecessary closures of facilities, impacting public health and recreation. Balancing safety with accessibility remains a challenge in pool management.

The microbiological hygiene of swimming pools was even more important during the pandemic, and achieving it was more difficult due to the technical problems caused by the country's long period of lockdown. The long-term closure or underperformance of the pools led to water stagnation and inadequate chlorination disinfection.

In this study, a compliance with *E. coli*, total coliforms, and total microbial flora microbiological parameters is observed during the years, which is attributed to the strict protocols, high chlorination of water, increased water circularity, and, finally, the lower capacity of swimmers per m². This comes in agreement with our previous study, in which the comparison of 2019 and 2020 showed a significant reduction in these parameters [33]. Overall, despite the relaxed measures and irregularities from the operators in terms of keeping the physicochemical standards within limits during the pandemic, *E. coli*, total coliforms, and total microbial flora remained under acceptable limits. This is also attributed to the high sensitivity of pathogens to chlorine disinfection.

On the contrary, in 2021, a reduction was recorded in the isolation of *P. aeruginosa*; nonetheless, in the years 2020 and 2022, the presence increased to higher values compared to 2019. This indicates that the regulation of *P. aeruginosa* is more challenging than other microbiological parameters, which validates the assertions and directives of international public health agencies and the scientific community.

With regard to total flora, the reduction in non-compliances for the years 2020 and 2021 is significantly higher than in 2022, which is in agreement with the discussion of the irregularities in parameters and incompliance of operators with protocols throughout that year. Accordingly, the evaluation of the reduction in non-conformities in total coliforms showed a medium reduction throughout 2020 and 2021 and a negligible reduction in 2022. In contrast with this trend, *E. coli* conformities were high in 2020 and 2021 and even higher in 2022, showing a higher reduction in 2022. It has been shown that *E. coli* is a highly sensitive parameter in disinfection procedures, and thus, similar studies suggest the usage of other indicators such as free chlorine, pH, and total coliforms for the determination of the hygiene of recreational water [53].

Finally, the current investigation identified the abnormal prevalence rates of the pathogenic bacterium *P. aeruginosa* in the reference years 2020, 2021, and 2022, in accordance with other studies [19,54,55].

In particular, the statistical analysis revealed that the odds ratio for increased temperatures of water inside the pool was correlated with the presence of *P. aeruginosa*. Similarly, the relative risk for the presence of the microorganisms tested, related to low chlorination of <0.4 mg/L, was greater than 1.

The linear regression analysis showed a positive association with the unacceptable occurrence of *P. aeruginosa* in water samples. The bacterium is found in aquatic environments and exhibits resistance to chemical disinfectants, including chlorine. Infection from the pathogen may result in bursitis, otitis externa, keratitis, urinary tract infections, and gastrointestinal infections via exposure to the skin, ears, eyes, urinary system, lungs, and intestines. Seventy-nine percent of ear infections in swimmers are ascribed to *P. aeruginosa*, with symptoms including ear pain and hearing loss [56,57]. An assessment of waterborne infections in the USA from 1999 to 2008 indicated that *P. aeruginosa* was the second most prevalent waterborne pathogen, following *Cryptosporidium*.

5. Conclusions

The present study examined how the strict sanitary protocols imposed by the COVID-19 pandemic on Greece's hotels affected the operation of swimming pools over a three-year period, compared to the pre-pandemic era. The introduction of vaccines and effective treatments, along with the disproportionate costs associated with their implementation, gradually led pool operators to stop fully implementing hygiene protocols. Therefore, the study demonstrates that public health measures, despite their lengthy implementation times and strictness, must be realistic, grounded in the theory of multiple barriers, and simultaneously effective. The study experimentally confirmed the findings of our previous

paper, which suggested that hotel managers attributed their non-implementation to high costs and inadequately trained staff.

Although research has been conducted on microbiological hygiene indicators in recreational waters such as public or private swimming pools, Greece's legislation framework is antiquated and neglects critical metrics like *P. aeruginosa*, which substantially affect swimmers' health. All studies indicate substantial surpluses in this domain. This out-of-date framework raises worries over the safety standards enforced in these facilities, potentially exposing swimmers' health. Thus, there is an immediate necessity for legislation change to integrate modern microbiological indicators and enhance public health protection [6,58,59].

The limitations of the current study included the fact that we could not test the same focal points during the study period. We also could not collect the samples at the same time of the day. Moreover, we did not test for any other chemical agents that may have been affected by the implementation of, for example, higher chlorine levels, such as higher corrosion of metal pipes leading to higher turbidity or other chemical agents that may have been released into circulation such as iron. We also did not test for the effect of the new measures against the presence of amoebae that frequently host some opportunistic pathogens. We also have not commented on any of the financial effects of the application of more strict measures, since the conservation of cold water temperatures at low levels is expensive, especially in environments such as that of Crete.

As a preventative measure, public health authorities must provide a risk assessment tool, according to WHO-recommended water safety plans, to significantly improve the quick and efficient management of emerging public health concerns and issues related to recreational waters (e.g., *Legionella* spp., *P. aeruginosa*, *Cryptosporidium*, *Staphylococcus aureus*, *Vibrio* spp., and other infections) [60–64].

Certainly in the coming years, the decreased amount of rain in regions, including Crete, will lead to a decreased amount of water available for consumption, and the dropping of the aquifer will certainly lead to a decreased quantity of water and depletion; testing just a few microbiological parameters will not be enough. The introduction of other microbiological parameters, testing for the presence of amoeba, and the testing of chemical agents/metals other than just chlorine and pH will be necessary.

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