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ANALYSIS OF THE EFFECTS OF USING CLASSICAL AND MODIFIED POOL WATER TREATMENT TECHNOLOGIES

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Abstract
Contemporary requirements on the quality of swimming pool water necessitate the improvement of the classical technology of its treatment. It is associated with the need to modernize installations or implement a new technology. The purpose of the analysis is to compare the effects of using classical and modified technologies for the treatment of swimming pool water in sports and recreational pools with similar characteristics. The research was carried out for ten pools, which were divided into two groups – pools with a classical water treatment system and a modified one. The conducted tests showed significant differences in water quality in terms of: pH, redox, permanganate index (COD_{Mn}), total organic carbon (TOC), free chlorine, combined chlorine, chloroform and trihalomethanes (THMs), and no differences in terms of: temperature, turbidity, nitrates and ammonium ion. It was found that the modified swimming pool water treatment technologies made it possible to obtain water of better quality with regard to physical, chemical and bacteriological properties.

Keywords: **Pool water; Classical treatment technology; Modified treatment technology.**

1. INTRODUCTION

There are approx. 760 indoor public swimming pool facilities in Poland, most of which (66%) are regular swimming pools (25 m × 12.5 m), 23% are training and recreation pools (at least 16 m long), 9% are sports-type swimming pools (25 m × 16 m) and 2% are Olympic pools (50 m long) [1]. Many of them, due to very strict requirements, struggle with the problem of maintaining adequate water quality.

The current requirements as to the quality of swimming pool water [2–5] necessitate the improvement of the classic technology of its treatment (Fig. 1). In the majority of cases, it is associated with the need to modernize existing installations or implement a new technology.

The classic technology of treatment and disinfecting swimming pool water, used in many swimming pool facilities, does not allow for the sufficient removal of chemical compounds which are products of chlorine reacting with pollutants introduced into the water by bathers and which often have an adverse effect on their health [6–9]. In order to maintain the proper quality of water in swimming pools, especially in public ones with high bathers loads, the classic technological systems of swimming pool water treatment are now being abandoned in favor of systems using filtration and final disinfection with a chlorine compound supported by ozone [10–12], dosing products with nanosilver [13], irradiation with UV rays [14–17] or ultrafiltration [18, 19]. Including these processes in the technological system of swimming pool water treatment allows to lower the doses of chlorine in the final stage of its disinfection, which in turn reduces the amount of disinfection by-products (DBPs) [9, 12]. Many epidemiological studies have shown that both short-term and long-term exposure of swimmers and bathers to DBPs causes allergic reactions, the development of respiratory and digestive system diseases,

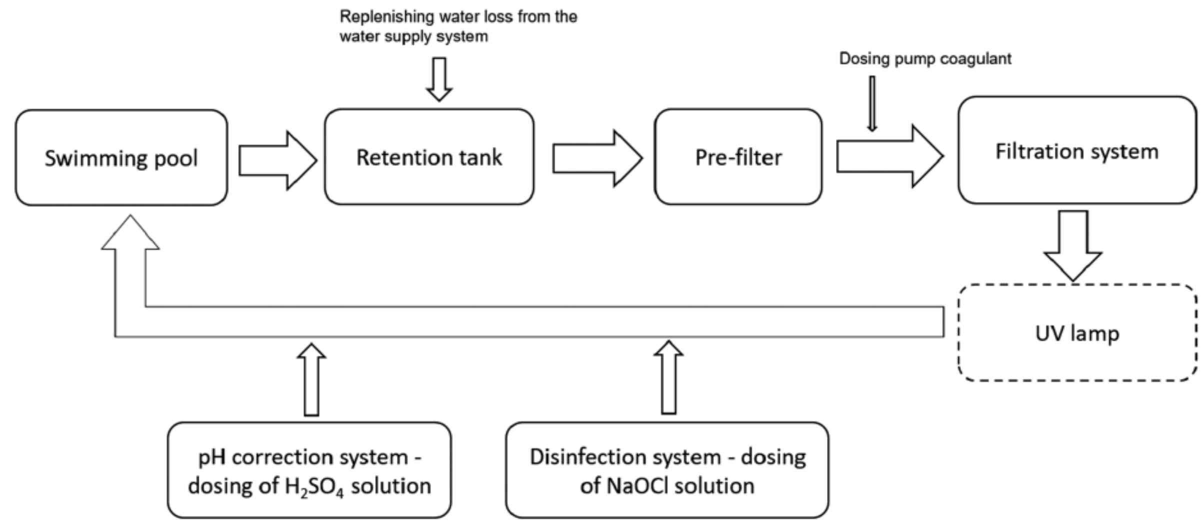


Figure 1.
Classical pool water treatment technology

changes in metabolic profiles, as well as genotoxic and mutagenic changes [20–24].

Modernization of water treatment systems in many swimming pool facilities consists in the replacement of filter units (the old, often horizontal filters, filled only with quartz sand, are replaced by highly effective multilayer filters with a layer of anthracite, activated carbon, zeolite), and the use of high-quality chemicals, e.g. coagulants containing a solution of silicic acid, sodium tetrahydroxy-aluminate, pentahydroxy-aluminum chloride, installation of automatic chemical dosing systems, measurement and control of circulating water quality, the use of equipment for cleaning the bottom and walls of swimming pools and the use of modern methods and techniques for disinfecting swimming pool water [25].

In the majority of swimming pool facilities built in the last five years, the installed water purification and disinfection systems allow for comfortable bathing and protection against bacteriological contamination, compounds that may cause allergies, irritation of mucous membranes or that have carcinogenic properties. In older facilities, where the water quality does not meet the requirements specified in the guidelines, this situation can only be changed by the modernization of the swimming pool water treatment system [9, 14, 26].

The main goal of this analysis was to compare the effects of using classic and modified technologies for the treatment and disinfection of swimming pool water in sports and recreational pools with similar technical and functional characteristics.

2. CHARACTERISTICS OF THE STUDIED POOLS – FUNCTIONAL SIMILARITY, TECHNOLOGICAL DIFFERENTIATION

The research was conducted for ten sports and recreational swimming pools (P1, P2, P3, P4, P5, P6, P7, P8, P9 and P10), which were divided into two groups. The first group includes pools with a classic water treatment system (WTS) or a system resembling the classic one. This group has been designated as P classic WTS and includes pools P1, P2, P3, P4, P5 and P6. The second group includes swimming pools with a modified WTS. This group has been designated as P modified WTS and includes pools P7, P8, P9 and P10. The division of pools into groups with the characteristic features of the filtration and/or disinfection process in the water treatment system is presented in Table 1.

In addition, it should be added that in the group of pools with classic WTS, in pools P2 and P6 an additional active carbon filtration layer was used and in pools P4 and P5 chemical disinfection (dosing of NaOCl solution) supplemented with physical disinfection (UV irradiation) was used. Nevertheless, these processes do not significantly modify the WTS, and in the DIN19634 standard of 2012 and the Pool Water Treatment Advisory Group (PWTAG 2017) guidelines, they are recommended for standard use in swimming pool water circuits [3, 4].

All the analyzed pools are supplied with water from the municipal water supply, which meets the quality requirements for drinking water [27, 28]. The pools

Table 1.
Division of pools according to their water treatment system

Swimming pool	Characteristic features of the filtration and/or disinfection process	Division of swimming pools according to the similarity criterion
P1	Classic system (CS)	Group of pools with a classic, or similar to a classic, water treatment system (P classic WTS)
P2	CS + Activated carbon layer in the filter	
P3	CS + Membrane electrolysis for NaOCl production	
P4	CS + Medium pressure UV lamps	
P5	CS + Low pressure UV lamps and membrane electrolysis for NaOCl production	
P6	CS + Zeolite filters with a layer of activated carbon and calcium hypochlorite for disinfection	
P7	Pola® system	Group of pools with a modified water treatment system, in relation to a classic water treatment system (P modified WTS)
P8	Filter bed - diatomaceous earth, SPID WOFIL® ozonation system, medium pressure UV lamp	
P9	DAISY® system, medium pressure UV lamp	
P10	Ozonation of part of the optoZON® stream and membrane electrolysis to generate NaOCl	

Table 2.
Technical parameters of the tested swimming pools

Parameter	The tested swimming pools									
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Dimensions of the pool basin, m	12.5×25	12.5×25	8.5×25	12.5×25	12.5×25	12.5×25	12.5×25	16×25	12.5×25	12.5×25 + 6 places for hydromassage
Depth of the pool basin, m	1.2-1.8	1.1-1.8	1.80	1.6-1.8	1.2-1.8	1.2-1.8	1.2-2.2	1.2-1.8	1.2-1.8	1.2-1.8
Volume of the pool basin, m^3	469.0	453.0	382.5	513.3	562.0	469.0	531.0	601.2	469.0	484.0
Usable area UA, m^2	312.5	312.5	212.5	312.5	312.5	312.5	312.5	400.0	312.5	322.4
Attendance, person/h	22	12	16	12	14	14	12	25	16	18

are equipped with a vertical water flow system with an active overflow, which discharges the displaced water to the retention tanks. Water is pumped from the tanks to the filtration system by means of circulation pumps integrated with pre-filters. In P8 pool, an open vacuum filter with filter elements washed with diatomaceous earth was used. The remaining pools have a filtration system consisting of pressure filters with multilayer beds. A 0.5% solution of hydrolyzed aluminum chloride was dosed into the pipeline supplying water to the filters. The average dose of this coagulant was 0.5–1.0 mL/m^3. The same length of the filtration cycle was observed during the research. Each filter worked for 3 days before its filter bed was rinsed. If the pH of the water needed to be adjusted, a 30% sulfuric acid solution was used in all pools. The pool water treatment plants have been equipped with automatic systems for dosing reagents and controlling basic water quality parameters (temperature, pH, redox potential, free chlorine, combined chlorine, ozone). Each of the pools was available to bathers 16 hours a day.

The basic technical parameters of the swimming pools and the average attendance are presented in Table 2.

3. MATERIALS AND METHODS

Water quality tests in the selected pools were carried out for 6 weeks. Samples were taken at fixed times (between 9 a.m. and 11 a.m.) twice a week (Mondays and Thursdays) for physicochemical analyses. Once every two weeks (Thursdays), samples were taken for bacteriological analyses. On the scheduled days of sampling from the pools, students from nearby schools took part in swimming lessons. In total, 12 water samples for physicochemical analyses and 3 water samples for bacteriological analyses were collected from each pool.

The main objective of the physicochemical tests was to determine the parameters of water quality, taking into account substances harmful or hazardous to health, such as combined chlorine (chloramines) and trihalomethanes (THMs). The main goal of bacterio-

Table 3.
Median, average and permissible values of physical and chemical parameters of swimming pool water quality

Parameter	P1		P2		P3		P4		P5		P6		P7		P8		P9		P10		Permissible values according to [2]
	P classic WTS												P modified WTS								
	Me	Av	Me	Av	Me	Av	Me	Av	Me	Av	Me	Av	Me	Av	Me	Av	Me	Av	Me	Av	
pH, -	7.2	7.1	7.4	7.4	7.1	7.1	7.3	7.3	7.4	7.4	7.2	7.2	7.1	7.1	7.0	7.0	7.3	7.3	7.1	7.1	6.5-7.6
Redox, mV	731	730	622	645	771	763	724	723	729	730	713	710	711	716	756	739	759	758	749	747	> 750
Temperature, °C	27.9	27.9	28.6	28.6	28.2	28.2	27.7	27.7	27.7	27.7	28.0	28.0	28.1	28.1	27.2	27.1	27.7	27.7	27.9	27.9	26.0-30.0
Turbidity, NTU	0.25	0.27	0.16	0.20	0.28	0.29	0.26	0.26	0.42	0.41	0.18	0.18	0.19	0.20	0.36	0.35	0.13	0.12	0.26	0.26	0.50
Nitrates, mg NO_3^-/L	3.68	3.57	9.90	9.74	3.95	5.08	4.48	5.01	7.12	7.49	8.54	8.78	5.30	5.80	5.15	4.66	2.10	1.88	7.64	8.17	20.00
Ammonium ion, mg NH_4^+/L	0.1	0.10	0.09	0.09	0.22	0.24	0.06	0.05	0.23	0.24	0.11	0.10	0.15	0.16	0.17	0.17	0.10	0.10	0.05	0.05	0.50
Permanganate index, mg O_2/L	2.2	2.4	2.2	2.3	2.0	1.9	4.4	4.5	3.6	3.7	1.9	2.0	1.4	1.4	2.6	2.6	1.8	1.8	2.1	2.1	4.0
TOC, mg C/L	3.65	3.69	3.21	3.28	3.14	3.11	3.34	3.37	3.65	3.68	1.57	1.61	2.29	2.28	3.24	3.39	2.95	2.82	2.95	2.89	4.00
Free chlorine, mg Cl_2/L	0.41	0.41	0.49	0.50	0.41	0.42	0.33	0.33	0.35	0.35	0.43	0.43	0.52	0.51	0.57	0.56	0.54	0.53	0.41	0.40	0.30-0.60
Combined chlorine, mg Cl_2/L	0.29	0.29	0.25	0.22	0.29	0.29	0.20	0.20	0.36	0.36	0.32	0.32	0.16	0.15	0.19	0.21	0.23	0.23	0.19	0.19	0.30
Chloroform, mg/L	0.034	0.033	0.026	0.025	0.025	0.024	0.025	0.024	0.037	0.036	0.030	0.032	0.012	0.011	0.030	0.030	0.018	0.018	0.017	0.016	0.030
THMs, mg/L	0.042	0.042	0.030	0.027	0.031	0.030	0.032	0.033	0.043	0.045	0.040	0.043	0.014	0.013	0.041	0.041	0.020	0.020	0.022	0.021	0.100

Me - Median value
Av - Average value

logical tests was to assess the risk associated with microbial contamination.

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 water sample for the final analyses was a mixed sample, i.e. collected in at least three characteristic points of the pool basin.

The analysed physicochemical parameters were: nitrates and ammonium ion (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), total organic carbon – TOC (catalytic oxidation combustion method at 680°C, TOC-L series analyser, Shimadzu, Japan), permanganate index (titration method, kit for titration oxidation analysis in acid medium) and turbidity (nephelometric method, TN-100 turbidimeter, Eutech®, Singapore). All measurements/analyses were conducted in triplicate.

The analysed bacteriological parameters were colony forming units (CFU) of *Escherichia coli* and *Pseudomonas aeruginosa* (membrane filtration method), and the total number of microorganisms at 36±2°C after 48 h (horizontal method using agar medium). Bacteriological tests were performed by an accredited laboratory.

The description of the water quality parameters in the tested pools and the determination of the relationships between them were carried out using the Microsoft Excel spreadsheet and Statistica software by StatSoft. The main goal of the statistical analysis was to assess the significance of differences between water quality in the studied swimming pools and to research the reasons for their occurrence. The significance level $\alpha = 0.05$ was adopted for the calculations. The occurrence of statistically significant differences between the studied parameters was found when the test probability p was lower than the adopt-

Table 4.
Pool water treatment effects

Parameter	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
pH, -	+	+	+	+	+	+	+	+	+	+
Redox, mV	-	-	+	-	-	-	-	+	+	+
Temperature, °C	+	+	+	+	+	+	+	+	+	+
Turbidity, NTU	+	+	+	+	+	+	+	+	+	+
Nitrates, mg NO_3^-/L	+	+	+	+	+	+	+	+	+	+
Ammonium ion, mg NH_4^+/L	+	+	+	+	+	+	+	+	+	+
Permanganate index, mg O_2/L	+	+	+	-	+	+	+	+	+	+
TOC, mg C/L	+	+	+	+	+	+	+	+	+	+
Free chlorine, mg Cl_2/L	+	+	+	+	+	+	+	+	+	+
Combined chlorine, mg Cl_2/L	+	+	+	+	-	-	+	+	+	+
Chloroform, mg/L	-	+	+	+	-	-	+	-	+	+
THMs, mg/L	+	+	+	+	+	+	+	+	+	+
Sum "+"	10	11	12	10	9	9	11	11	12	11
Sum "-"	2	1	0	2	3	3	1	1	0	1
"+" means the fulfillment of the water treatment effect within the given parameter										
"-" means failure to the water treatment effect within the given parameter										

ed level of significance ($p < \alpha$). Finally, the significant differences ($p < 0.05$) of the parameters were evaluated through a non-parametric Mann-Whitney test.

The comparison of the obtained results with the permissible levels of water pollution in the group of pools P classic WTS (P1 – P6) and the group of pools P modified WTS (P7 – P10) made it possible to assess the differences between the quality parameters of the studied basin waters treated with the use of classic and modified technologies and the legitimacy of their application.

Initial data analysis (comparison of distributions and assessment of their similarity) indicated the necessity to use non-parametric tests for the evaluation of the test results. As the distribution of data was not normal (Kolmogorov-Smirnov test and Shapiro-Wilk test), the median values were presented in order to compare the parameters of the pool water quality. The average values are also presented in Table 3 as a measure supplementing the analysis of the test results.

4. RESULTS AND DISCUSSION

4.1. Physical and chemical parameters

The values of the median (Me), the average (Av) and the permissible values according to Decree of the Health Minister on the requirements for water in swimming pools in Poland [2] of physical and chemical parameters determining water quality in the analyzed pools are presented in Table 3.

In order to generally determine the fulfillment of the treatment result in terms of a given water quality parameter, the table of swimming pool water treatment effects was prepared (Table 4). In this measure, the median value was also used as the determinant of the effect, referring it to the permissible values according to the requirements for water in swimming pools [2].

On the basis of the analysis of the treatment effects, it was found that the main problem was to obtain, in most of the pool waters, the required redox potential (> 750 mV), in P4 permanganate index (< 4 mg O_2/L), in P5 and P6 the concentration of combined chlorine (< 0.3 mg Cl_2/L) and in P1, P5, P6 and P8 chloroform concentrations (< 0.03 mg/L). Thus, the systems in the P5 and P6 pools turned out to be the least effective treatment systems

The pH values of the water from all the pool basins were within the range of the recommended values, i.e. from pH = 6.5 to pH = 7.6. The median value of the pH indicator ranged from pH = 7.0 (in P8) to pH = 7.4 (in P2 and P5). Due to the fact that the pH of the pool water in all pools was automatically regulated by control and dosing stations, the range of the determined pH values was small, from only 0.1 in P6 and 0.2 in P4, P9 and P10 to 0.7 in P8.

The redox potential is of particular importance during the disinfection of swimming pool water. The higher this potential, the greater the ability to oxidize contaminants, including microbial contaminants. Redox potential values in the tested pools should not be less than 750 mV. Such values (although not determined in all water samples) were obtained in only one pool with a classic treatment system (P3) and in tree pools with a modified water treatment system (P8, P9 and P10). The largest range of redox values was observed in P2, with the classic system, and in P8, with the modified system, which amounted to 568–788 mV and 625–837 mV, respectively. The median redox potential values ranged from 622 mV in P2 to 771 mV in P3.

The water temperature in swimming pools should be between 27°C and 28°C [2–5]. In the tested pools the water was heated in heat exchangers and was regulated automatically by means of temperature sensors. The median temperature values ranged from 27.2°C in P8 to 28.6°C in P2.

The turbidity of the swimming pool water, assuming accurate and regular measurements are performed, is a very good indicator of the degree of contamination of the water by suspended and dispersed organic and inorganic matter, informing about the efficiency of the filtration process. In all the collected water samples, the turbidity did not exceed the permissible value, i.e. 0.5 NTU [2, 3]. The lowest values of water turbidity, and the smallest dispersion, were found in P6 and P9 pools.

The permissible content of nitrates in swimming pool water is 20 mg NO_3^-/L, but this value is understood as the difference between the nitrate content in the swimming pool water and in the supplementary (tap) water [2, 3]. If this value is exceeded, it is necessary to refresh the pool water circuit with tap water. The increase in the concentration of nitrates observed during the filtration cycle or the bathing season proves the degradation of the pool water quality, the need for careful analysis and taking preventive measures [25]. In all the pools, during the 6-week test cycle, an increase in the concentration of nitrates was observed - the highest in P3 pool (from 2.40 mg NO_3^-/L on the first test day to 13.3 mg NO_3^-/L on the last test day) and in P6 pool (from 4.10 mg NO_3^-/L on the first test day to 16.40 mg NO_3^-/L on the last test day).

An important, although unregulated (in Poland) parameter of swimming pool water quality is the ammonium ion. Its content in water characterizes the degree of contamination with fresh organic matter (sweat, urine), affects the amount and type of chloramines produced, and the effects of the oxidation process (including disinfection). According to DIN 19643, the ammonium ion content should not exceed 0.5 mg NH_4^+/L. The lowest concentrations of ammonium ion were found in P2 (0.01 – 0.14 mg NH_4^+/L), P4 (0.01–0.10 mg NH_4^+/L) and P10 (0.02–0.10 mg NH_4^+/L), and the largest one in P3 (0.15–0.47 mg NH_4^+/L) and P5 (0.15–0.35 mg NH_4^+/L).

The value of the permanganate index (COD_{Mn}), understood as the difference between the value of the permanganate index in the swimming pool water and in the water supplementing the swimming pool circuit, should not exceed 4 mg O_2/L [2, 3]. Only in P4 (in all water samples) and in P5 (in 4 water samples) the permanganate index exceeded the limit value. The lowest values of the permanganate index were found in P7 (1.3–1.7 mg O_2/L).

TOC is a more accurate indicator of the degree of contamination of swimming pool water with organic matter (compared to the permanganate index). The lowest TOC concentrations were found in water samples from P6 (1.28–1.96 mg C/L), and the highest in P5 (2.78–4.56 mg C/L).

Free chlorine content in sports-type swimming pools should be from 0.3 to 0.6 mg Cl_2/L [2, 3]. Except for 4 water samples (1 from P3, 2 from P7 and 1 from P8), the recommended range was not exceeded. The concentration of free chlorine in the swimming pool water was continuously regulated in all the studied facilities by means of a dosing and control station. The analysis of the results shows that the applied two-stage disinfection in P4 (sodium hypochlorite supported by medium-pressure UV lamps) and in P5 (disinfection with electrolytic sodium hypochlorite supported by low-pressure UV lamps) and the dosing of active catalytic oxidant ACO® used in P9, irradiating water with UV rays and dosing of sodium hypochlorite influenced the stability of free chlorine concentrations in swimming pool water.

Due to the proven adverse effect of disinfection by-products on the health of swimmers, it is recommended to control the content of combine chlorine in pool water (at least once a day) and the content of

THMs and chloroform (once a quarter). In all guidelines concerning the quality of swimming pool water, the permissible values of DBPs mentioned are precisely defined, with the recommendation that they should be as low as possible (combined chlorine ≤ 0.3 mg Cl_2/L, THMs ≤ 0.1 mg/L, chloroform ≤ 0.03 mg/L), [2, 3, 5]. In the tested pools, the permissible concentration of combined chlorine was exceeded in P1, P3, P5, P6 and P8. The permissible concentration of chloroform was exceeded in P1, P2, P3, P5, P6 and P8. However, the permissible THMs concentration was not exceeded. The permissible content of combined chlorine and chloroform was exceeded periodically, most often during the high load of bathers. As it results from research on the content of DPBs in swimming pool waters, it is chloroform that is the dominant component of THMs, and its content primarily determines the content of organic matter introduced by bathers into the pool water and parameters associated with pool operations, i.e. water temperature, water renewal and disinfection method [25, 29, 30].

Lower levels of combined chlorine, chloroform and THMs were observed in P7, P9 and P10 with a modified water treatment system and in P4. However, they were larger in P8 and other pools with a classic water treatment technology (P1, P2, P3, P5 and P6). The lowest levels of THMs and chloroform were determined in the pool equipped with the Pola® system (P7), and the highest in the pool with a classic water treatment technology (P1).

The tests carried out in the group of swimming pools with classic and modified water treatment systems showed statistically significant differences ($p < \alpha$) in water quality in terms of: pH (Fig. 2a), redox potential (Fig. 2b), permanganate index (Fig. 2g), TOC (Fig. 2h), free chlorine (Fig. 2i), combined chlorine (Fig. 2j), chloroform (Fig. 2k) and THMs (Fig. 2l), and no statistically significant differences ($p < \alpha$) in the scope of: temperature (Fig. 2c), turbidity (Fig. 2d), nitrates (Fig. 2e) and ammonium ion (Fig. 2f).

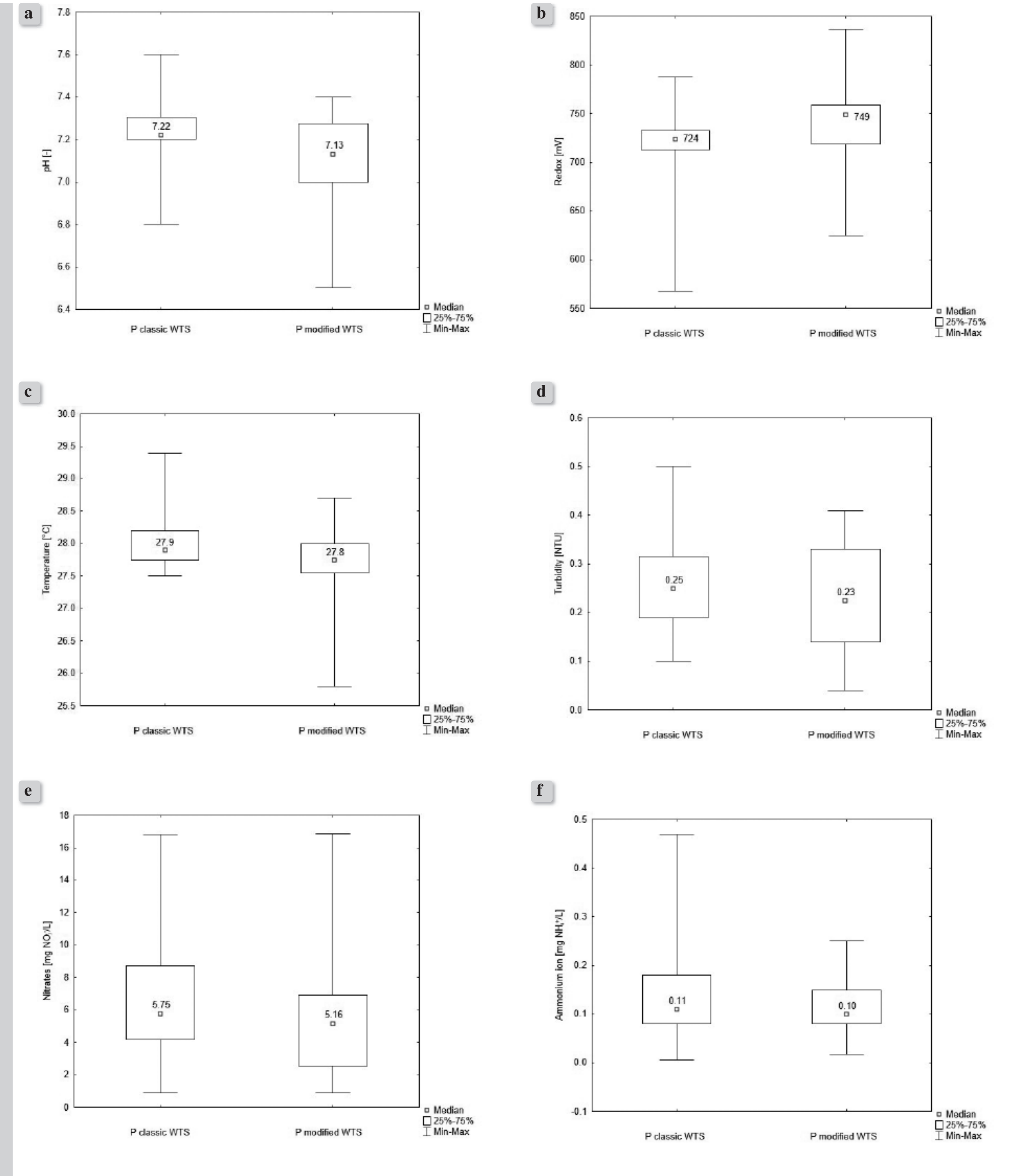
The occurrence of statistically significant differences between the analyzed parameters in the group of pools with classic (P classic WTS) and modified water treatment systems (P modified WTS) was found when the test probability was lower than the adopted level of significance ($p < \alpha$; $\alpha = 0.05$). The calculated through a non-parametric Mann-Whitney test p values are summarized in Table 5.

4.2. Bacteriological parameters

Bacteriological analyses carried out in the water from the tested pools (P1 – P10) did not show the presence of CFU of bacteria above the values specified in the regulations in this field. Throughout the research period, the presence of *Escherichia coli* and *Pseudomonas aeruginosa* was not found. The total number of mesophilic bacteria in the water from the studied pools did not exceed the permissible value of 100 CFU/mL. Only in three water samples from the group of pools with a classic water treatment system the total number of microorganisms was over 10 CFU/mL, in P1 (15 CFU/mL), in P2 (16 CFU/mL) and in P6 (12 CFU/mL). In the group of pools with a modified water treatment system, the total number of mesophilic bacteria did not exceed 3 CFU/mL.

Table 5.
The test probability *p* for the assessment of the significance of differences between the parameters of water quality in the group of pools with classic and modified water treatment systems

Parameter	*p*
pH, -	0.00141
Redox, mV	0.00155
Temperature, °C	0.20732
Turbidity, NTU	0.12660
Nitrates, mg NO_3^-/L	0.06663
Ammonium ion, mg NH_4^+/L	0.44908
Permanganate index, mg O_2/L	0.00002
TOC, mg C/L	0.00004
Free chlorine, mg Cl_2/L	0.00000
Combined chlorine, mg Cl_2/L	0.00000
Chloroform, mg/L	0.00000
THMs, mg/L	0.00000


a
pH [-]
7.8
7.6
7.4
7.2
7.0
6.8
6.6
6.4
7.22
7.13
P classic WTS
P modified WTS
Median
25%-75%
Min-Max
b
Redox [mV]
850
800
750
700
650
600
550
724
749
P classic WTS
P modified WTS
Median
25%-75%
Min-Max
c
Temperature [°C]
30.0
29.5
29.0
28.5
28.0
27.5
27.0
26.5
26.0
25.5
27.9
27.8
P classic WTS
P modified WTS
Median
25%-75%
Min-Max
d
Turbidity [NTU]
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.25
0.23
P classic WTS
P modified WTS
Median
25%-75%
Min-Max
e
Nitrates [mg NO3/L]
18
16
14
12
10
8
6
4
2
0
5.75
5.16
P classic WTS
P modified WTS
Median
25%-75%
Min-Max
f
Ammonium Ion [mg NH4+/L]
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0.11
0.10
P classic WTS
P modified WTS
Median
25%-75%
Min-Max

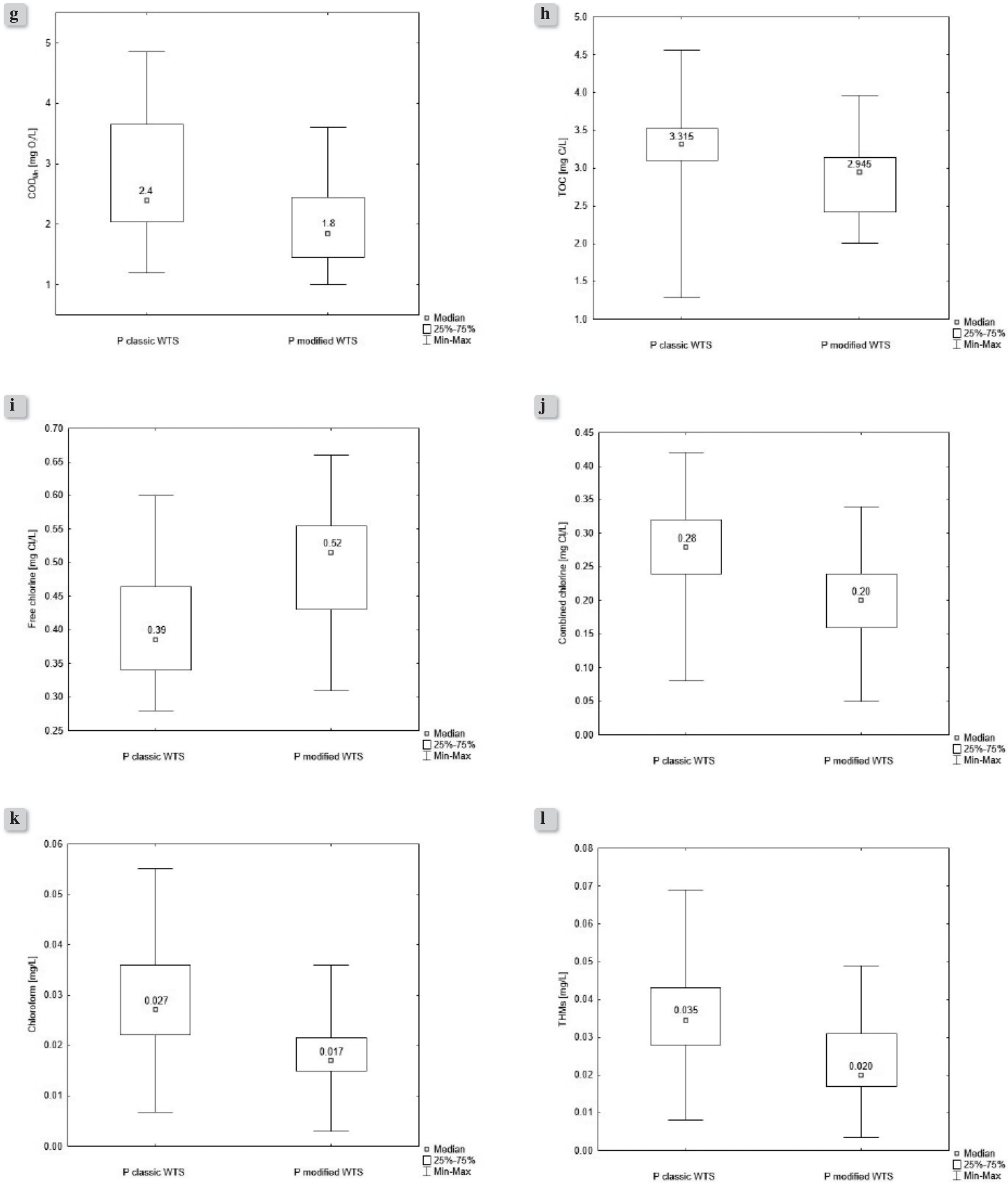


Figure 2.
Comparison of pool water quality parameters in a group of pools with a classic and modified water treatment system: a) pH, b) Redox, c) Temperature, d) Turbidity, e) Nitrates, f) Ammonium ion, g) COD$_{Mn}$, h) TOC, i) Free chlorine, j) Combined chlorine, k) Chloroform, l) THMs

5. CONCLUSIONS

Based on the analysis of the treatment effects, it was found that the least effective treatment systems were those used in P5 and P6 pools, i.e. systems based on the classic solution of the swimming pool water treatment system. It should be emphasized, however, that the quality of swimming pool water is very much influenced by the intensity and method of swimming pool use. In both P5 and P6, the number of swimming lessons for primary school children, conducted as part of physical education program, was greater than in the other pools. Pro-health education, constant reminding of the rules of hygiene, can significantly improve the quality of swimming pool water.

The control and continuous regulation of water pH, free chlorine concentration and water temperature used in swimming pool facilities allow to obtain the required level of these parameters regardless of the load of the pool and the technology used.

Tests carried out for a group of pools with a classic (P classic WTS) and a modified (P modified WTS) water treatment system have shown that the use of the latter allows for obtaining water of better quality in terms of both physiochemical and bacteriological properties.

The use of additional reagents (PolaClear®, PolaOxyd®, APF®, ACO®), new types of filter beds (PolaCarb®, AFM®), water ozonation (SPIDWOFIL®) and at least two-stage disinfection resulted in better water quality in the group of pools with a modified water treatment system.

From the bacteriological point of view, the water quality in all analyzed pools did not raise any objections, and the two-stage disinfection in P4, P5, P9 and P10 and the three-stage disinfection in P8 were effective protection against secondary water contamination.

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