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Reuse – Reduce – Recycle: water and wastewater management in swimming pool facilities

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ABSTRACT

The main objective of the study is to analyze the quality of washings resulting from backwashing of filter beds in a selected swimming pool facility from the point of view of their possible discharge into surface waters, their use for utility purposes within the pool facility or their return to the pool water circulation, and thus rationalize water and wastewater management in the swimming pool under consideration. The quality of the washings samples was tested under laboratory conditions in three stages (stage 1 – sedimentation, stage 2 – jar coagulation, stage 3 – ultrafiltration). After each stage, based on physicochemical and bacteriological analysis of washings samples, the degree of their contamination was determined and compared with the conditions to be met when wastewater is discharged into surface waters and with the guidelines of the regulation on the quality of swimming pool water. The discharge of raw washings into surface water is not possible, mainly due to the total suspended solids (TSS) content above 35 mg/L and the free chlorine concentration above 0.2 mg Cl_2/L. As a result of stage 1, TSS decreased by about 67% and free chlorine by about 28%. After stage 2, TSS decreased to 11.7 mg/L and free chlorine to 0.09 mg Cl_2/L. After stage 3, TSS was reduced to 5.3–7.8 mg/L and free chlorine to 0.01–0.03 mg Cl_2/L (depending on the type of membrane). The total number of mesophilic bacteria >100 CFU/1 mL was not found in the supernatant after stages 1, 2 and in the permeate after stage 3. The use of a three-stage washings treatment process makes it possible to use permeate from the washings to replenish losses in the swimming pool water circuit. In laboratory tests, about 65% of the washings volume was recovered for use.

Keywords: Coagulation; Management of rational water and wastewater; Sedimentation; Swimming pool; Ultrafiltration; Washings

1. Introduction

Among the various public buildings, swimming pools require the highest amount of water. Water consumption in the swimming pool facility is the result of the demand for both technological and utility purposes. Consumption for technological purposes is associated with the necessity of rinsing filter beds and replenishing water losses due to water evaporation, splashing and being taken out by bathers [1–3]. Moreover, at least once a year, it is necessary to completely change the water in the pool [4–6].

Utility purposes include the sanitary and hygienic needs of users and the facility's staff, as well as cleaning works. According to the German Institute of Standardization (DIN 19643), the volume of water for only technological purposes should be no less than 30 L/person/d [5]. However, according to the ordinance of the Minister of Infrastructure in Poland on determining the average standards of water

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consumption for an indoor swimming pool, it should be 160 L/person/d [7].

The high cost of water supply and sewage discharge made swimming pools owners interested in the reuse of swimming pool sewage that comes from washing the filter beds. Most often, these washings are discharged to the sewage system. However, modern technologies allow them to be used, and thus to reduce the costs of water supply and sewage discharged from swimming pool facilities [8–10].

The necessity of regular filter backwashing in pool water technological systems generates unproductive water losses. In order to properly wash the filter bed, a water consumption of 4–6 m^3 per 1 m^2 of the bed is required. According to the guidelines, this backwashing should take place every 2–4 d [4–6].

It can be estimated that the monthly water consumption for a typical installation, consisting of two filters with a diameter of 1,800 mm, can be over 450 m^3. Every year, there are over 5,000 m^3 of wastewater discharged usually into the sanitary sewage system. In Poland, there are almost 600 public pools equipped with at least two filters. Therefore, it can be estimated that more than 3 million m^3 of backwash water is not used annually. Assuming an average price for wastewater discharges in large cities, 2.15 EUR/m^3, it is easy to estimate that over 6.45 million EUR per year is spent on the disposal of "pool" washings. In addition, the water used to backwash filtration beds is usually taken from the technological system in which it was previously heated. The temperature of the washings ranges from 25°C to 36°C (average about 28°C). For this reason, its discharge into the sewage system is also a waste of energy used to heat it.

The basic criterion for deciding the profitability, possibility and method of managing the washings in an environmentally safe manner, apart from their volume, is their quality. In addition, one should also take into account the size of the swimming pool facility, its function that is usually associated with its size (aquapark, recreational swimming pool, sports swimming pool, etc.), applied technology of water treatment, type of filters and filter beds, length of filtration cycles, and daily load of bathers [9–12].

Among the possibilities for the management and use of water generated as a result of rinsing filter beds in swimming pool facilities, the following are mentioned most frequently: heat recovery [13], watering the greenery, sprinkling courts and sports fields often located near swimming pools and constituting a complex of sports facilities, discharge to water or ground [14,15], supplying water installation for flushing toilets, and supplementing water losses in a swimming pool circuit [8,10].

Depending on the planned use of the washings, DIN 19645 specifies three types of process water. Type 1 is water that can be used to fill the pool, compensate for circulation water loss, flush filters, and for applications allowed for type 2 and type 3. Type 2 is water used for surface cleaning, flushing toilets, and watering green areas. Type 3 is water for direct discharge to surface water or rainwater drainage. Each type of process water must meet certain quality requirements. For type 1 process water, free chlorine content (≥0.3 mg Cl_2/L), oxidisability value (≤5 mg O_2/L) and turbidity (≤0.2 NTU) were determined. The specifications of the water quality of the type 2 process may differ as the requirements for surface cleaning, toilet flushing, or landscape irrigation may differ. However, type 2 water must be sufficiently sterile and should not be chlorinated if used for irrigation. On the other hand, type 3 process water must be of such quality as to meet the requirements of the local permit for the discharge of wastewater into surface waters. To meet the quality of type 1 process water, a combination of the following processes is required: preliminary filtration (sand filter), ultrafiltration (UF), UV-ray disinfection, reverse osmosis, and chlorination [16].

The research carried out so far by the authors shows that the washings discharged from the pools cannot be directly discharged into water and soil, mainly due to the exceeded content of suspended solids and the concentration of free chlorine. Sedimentation analyses of washings from many swimming pools showed a good susceptibility of suspensions to settling, allowing for a reduction in the amount of suspensions easily settling by approx. 90%. The possibility of using a coagulant (normally used in swimming pool water treatment) to reduce the content of suspended solids in the washings was also demonstrated, as well as the high efficiency of pressure membrane filtration processes for washings treatment of washings [14,15].

The main goal of this study is to analyse the quality of washings discharged from a selected swimming pool and treated in three successive stages: sedimentation – coagulation (fast mixing + slow mixing + sedimentation) – ultrafiltration (UF). On the basis of the results of this study, the possibility of recycling and reusing filter backwash water was assessed. Consideration was given to the possibility of discharging the washings into surface water or the ground, using them for watering greenery and recycling them to the pool water circulation.

2. Materials and methods

2.1. Tested pool and water treatment system

Thematic research was carried out for washings samples taken from a selected sport swimming pool (SP). The pool analyzed is supplied with water from the municipal water supply, which meets the quality requirements for drinking water [17,18]. The facility has closed circulations of the water treatment system (Fig. 1). The pool is 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 using circulation pumps integrated with prefilters. The remaining pool has a filtration system consisting of pressure filters with multilayer beds. Before the pipeline filters, a coagulant solution is applied. If the pH of the water needs to be adjusted, a sulfuric acid solution is used. The pool water treatment plant has been equipped with automatic systems for dosing reagents and controlling basic water quality parameters (temperature, pH, redox potential, free chlorine, and combined chlorine).

The same length of the filtration cycle was observed during the research. Each filter worked for 3 d before its filter bed was rinsed. Washing of filtration beds is carried out with air (all filtration systems are equipped with air blowers) and water (taken from retention tanks). About 4.5 m^3 of water per 1 m^2 of bed was used for washing. After washing

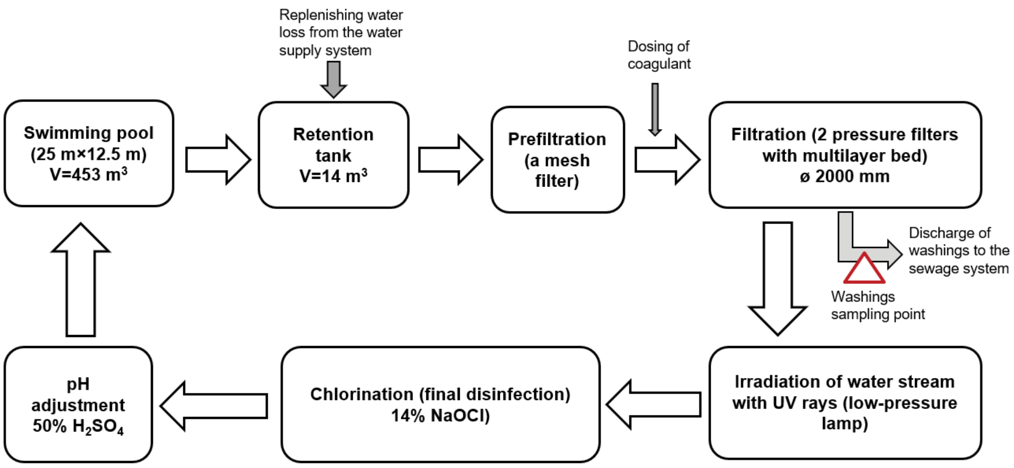


Fig. 1. Water treatment system in the tested swimming pool.

the filter bed, the retention tank was refilled with fresh tap water (approx. 14 m^3). The swimming pool was available to bathers 14 h/d. The process of rinsing the filter beds took place after the swimming pool facility was closed and the washings were discharged to the sanitary sewage system.

The technical parameters of the tested pool and water treatment system are presented in Table 1.

2.2. Sampling and washings treatment stages

2.2.1. Samplings

To obtain an average mixed sample, the washings were collected in batches (approx. 5 L of washings were taken every 1 min) during the process of washing the filter bed with water (for approx. 6 min). The washings were collected through valves installed in the canal that discharged the washings to the sanitary sewer. Three series of measurements were taken at intervals of one week. In each series, a 30 L sample of the washings was collected in a sterile polyethylene container equipped with a stirrer. Washings samples were collected, transported to the laboratory, and analyzed in 1 d. Sampling of the washings was carried out according to the procedure PN-ISO 5667-10:1997 (Water quality – Sampling – Guidelines for sampling wastewater).

2.2.2. Methods of washings treatment

Each series of tests consisted of three stages carried out under laboratory conditions. In stage 1, the washings were subjected to the sedimentation process, then the supernatant water was subjected to the jar coagulation process (stage 2) and in stage 3 to the pressure membrane filtration process (ultrafiltration with the use of polymer UF-PM and ceramic membrane UF-CM), (Fig. 2).

2.2.3. Sedimentation (stage 1)

In stage 1 of the research, the washings were subjected to a 2 h sedimentation process in an Imhoff funnel to remove easily sedimented suspensions.

2.2.4. Coagulation (stage 2)

After the sedimentation process, the decanting water (750 mL) was then subjected to the coagulation process (stage 2) carried out using the jar test method (rapid stirring 200 rpm for 1 min, slow stirring 20 rpm for 20 min, sedimentation for 30 min). Coagulation was conducted in a four-stand laboratory coagulator. A 0.5% solution of aluminum hydroxychloride (a coagulant used in the analysed swimming pool circuit to support the filtration process) was dosed into four samples of water in the following doses: 0.5, 1.0, 2.0, and 4.0 mg Al/L. In all series of measurements, the dose of 1.0 mg Al/L was considered optimal. Stages 1 and 2 were carried out until approximately 20 L of supernatant water was obtained, which was then subjected to the ultrafiltration process (stage 3).

2.2.5. Ultrafiltration (stage 3)

The ultrafiltration process (UF) was carried out in two circuits operating in a cross-flow system using pipe membranes made of different materials (Table 2). The first filtration circuit was made entirely of steel and equipped with a pipe module adjusted to polymer membranes (PM) with an active surface of 240 cm^2, an intermediate tank with a volume of 15 L, a high-pressure pump with a capacity between 0.5 and 3.0 m^3/h (type CRN 3, Grundfos) and a control and measurement apparatus. The second filtration circuit had a structure similar to the first, but this was adjusted to ceramic membranes (CM). This circuit had a low-pressure pump with a capacity between 1.50 and 3.50 m^3/h (type CRN 1, Grundfos). Membrane filtration tests were carried out in the following order: membrane conditioning with deionised water, supernatant water filtration, and an attempt to clean the membranes. The process was carried out under 0.1 MPa transmembrane pressure conditions – ceramic membrane and at 0.2 MPa – polymer membrane. The temperature of the filtered water was kept at a constant level of 20°C ± 2°C. The membranes were cleaned in a three-stage process which consisted of flushing them with deionized water, chemical cleaning

Table 1
Technical parameters of the tested swimming pool and water treatment system

Parameter	Swimming pool (SP) and water treatment system (WTS)
Dimensions of the pool basin	25 m × 12.5 m
Depth of the pool basin	1.1 m – 1.8 m
Volume of the pool basin	453 m^3
Water surface area in the pool	312.5 m^2
Average attendance	12 person/h
Bather loads	26.0 m^2/person (37.8 m^3/person)
Hydraulic system	Vertical (inflow through two DN160 channels located at the bottom of the pool basin)
Volume of the retention tank	14 m^3
Time of one water change in the pool basin	2.4 h
Filtration	Filter type: pressure (closed) Number of filters: 2 Type and height of the filter bed: sand layer (0.7 m) and activated carbon layer (0.5 m) Filter diameter: 2,000 mm Filtration area of one filter: 3.14 m^2 Filtration velocity: 30 m/h Filtration flow: 188.4 m^3/h
pH correction	50% solution of H_2SO_4
Coagulation	0.5% solution of aluminum hydroxychloride (average dose of the coagulant: 0.5–1.0 mL/m^3)
Disinfection	UV irradiation (low-pressure UV lamp, 1.8 kW, 600 J/m^2) and final disinfection (14% solution of NaOCl)

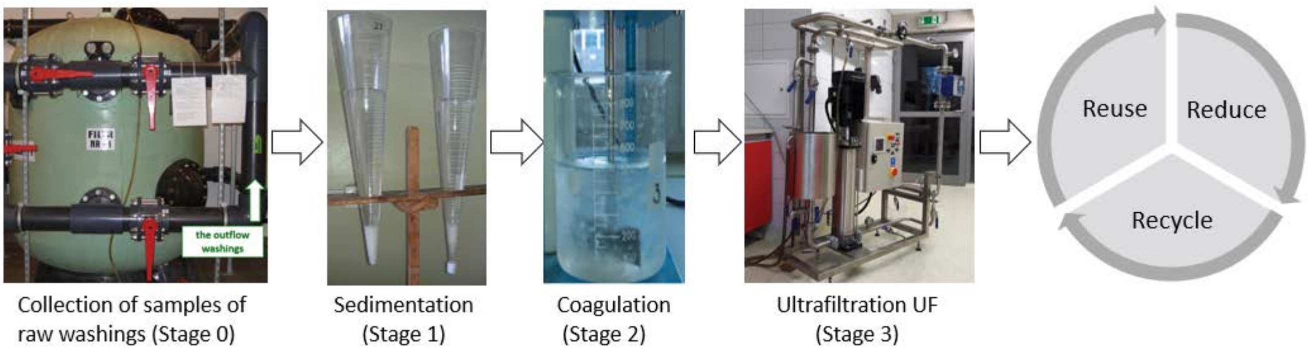


Fig. 2. Washings treatment stages.

Table 2
Characteristics of membranes used in stage 3 of the research

Membrane type	ES625	–
Abbrev.	PM	CM
Manufacturer	PCI Membrane System Inc.	TAMI Industries
Membrane material	Polyethersulfone	TiO_2
Max. temperature (°C)	80	150
Max. pressure (MPa)	1.5	9.0
pH range	1.5–12	0–14
Molecular weight cut-off (g/mol)	25,000	8,000
Membrane area (m^2)	0.024	0.350

with a 0.3% solution of HNO_3 acid and a 1% solution of NaOH hydroxide. The actual washings treatment process, regardless of the type of membrane, was carried out to receive 50% of the feed (the volume of feed was 20 L).

In preliminary tests, it was determined that during the filtration of deionized water, the efficiency of the polymer membrane was five times lower than that of the ceramic membrane. The average volumetric flow of the polymer membrane permeate was 61.2 L/m^2 h, and of the ceramic membrane 273.2 L/m^2 h. During the filtration of deionized water, the permeate flux was stable over time and did not change.

According to the manufacturer's data, a regularly cleaned membrane has a durability of 2 y for a polymer membrane (PM), and 3 or 4 y for a ceramic membrane (CM).

2.3. Index parameters and methods of analysis

To evaluate the quality of the washings quality (in stage 0) and the supernatant water in subsequent, successive processes (stage 1, stage 2, and stage 3) of research, the basic parameters were analysed as indicators of the degree of pollution for both sewage and swimming pool water. Based on previous experience, the authors concluded that the common index parameters are [15,19]:

- pH as an indicator of correct disinfection and coagulation process,
- temperature as an adjustable indicator depending on the function of the pool and influencing the efficiency of the processes of coagulation, disinfection and water pH correction,
- turbidity as an indicator of aesthetic and usable water quality and effectiveness of the coagulation process,
- total suspended solids (TSS) and chemical oxygen demand (COD) as indicators of the filtration process and the possibility of washings management,
- total organic carbon (TOC) as an indicator of the total content of organic substances in the water, used in the quantitative assessment of anthropological pollutants introduced into the swimming pool water,
- free chlorine and combined chlorine as indicators of the antiseptic effect of the disinfectant,
- chlorides and nitrates as indicators of insufficient replenishment of the swimming pool circuit with fresh tap water,
- aluminium as an efficiency index of water coagulation and filtration process,
- total number of mesophilic bacteria as an indicator of the risk of contamination of swimming pool water with pathogenic bacteria and improperly occurring treatment processes.

The pH of water and the temperature were measured with the potentiometric method (sensION meter + MM150 DL, Hach®, Loveland, CO, USA). Concentrations of free and combined chlorine were determined with a colorimetric method (portable Pocket Colorimeter II DeviceTM, Hach®, Loveland, CO, USA). The measurement of chlorides, nitrates, aluminium concentration, chemical oxygen demand value and the amount of total suspended solids were carried out with the photometric method in cuvette tests (DR 3900 VIS spectrophotometer with RFID technology, Hach®, Loveland, CO, USA). To determine the turbidity of samples, a nephelometric method was used (TN 100 turbidity meter, Eutech®, Singapore). Total organic carbon was measured using a TOC-L series analyzer by catalytic oxidation combustion at 680°C (Shimadzu). The total number of mesophilic bacteria (in 36°C ± 2°C and 44 ± 4 h) was determined by an external accredited laboratory according to ISO methods.

The statistical analysis of the research results was based on the Microsoft Excel data analysis package. Each sample was analysed three times, and 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.

After each stage of the test, based on physicochemical and bacteriological analysis of washings samples, the degree of their contamination was determined and compared with the ordinance guidelines on substances harmful to the aquatic environment and the conditions to be met when discharge of wastewater into surface waters or soil [20], with the guidelines of the regulation on swimming pool water quality [5,21,22] and with the guidelines of the regulation on drinking water [17,18]. The permissible values of the parameters tested in drinking water, swimming pool water, and wastewater discharged into surface water or soil are summarized in Table 3.

3. Results and discussion

The results of the analyses after three measurement series for raw washings and those subjected to subsequent treatment stages are presented in Table 4.

Based on the results of the analyses, after each stage of the research, it was assessed whether the washings are suitable (1) for discharge into surface water or soil (Reduce), (2) for watering green areas, washing surfaces, or flushing toilets (Reuse), (3) for supplying the swimming pool water circulation (Recycle).

It was clearly stated that raw washings and washings after the sedimentation process (stage 1) cannot be used for the purposes mentioned above, mainly due to the content of suspended solids above 35 mg/L (on average 146.3 mg/L in raw washings and 48.0 mg/L in supernatant) and the content of free chlorine above 0.2 mg Cl_2/L (average 0.28 mg Cl_2/L in raw washings and 0.2 mg Cl_2/L in supernatant).

In the analysed washings, stage 2 of treatment (coagulation) allowed to reduce the number of suspended solids to an average of 11.7 mg/L and free chlorine to an average of 0.09 mg Cl_2/L and to consider the use of supernatant to water greenery, wash the surface or flush the toilets. On the other hand, the values of the analysed permeate quality parameters obtained in stage 3 correspond to the values for the water supplying the swimming pools and thus allow for further research and activities aimed at the use of permeates for this purpose.

The specified parameters characterizing the quality of washings, supernatants (after stages 1 and 2) and permeates (after stage 3) should be assessed comprehensively, taking

Table 3
Permissible values of the tested parameters in drinking water, swimming pool water, and wastewater discharged into surface water or soil

Parameter	Drinking water [17,18]	Swimming pool water [5,21,22]	Wastewater discharged into water or soil [20]
pH (–)	6.5–9.5	6.5–7.6	6.5–9.0
Temperature (°C)	–	26–30	35
Turbidity (NTU)	1.00	0.50	–
TSS (mg/L)	–	–	35
COD (mg O_2/L)	–	–	125
TOC (mg C/L)	5.00	4.00	30
Free chlorine (mg Cl_2/L)	0.3	0.3–0.6	0.2
Combined chlorine (mg Cl_2/L)	0.50	0.30	–
Chlorides (mg Cl^-/L)	250	–	1,000
Nitrates (mg NO_3^-/L)	50	20	30
Aluminium (mg Al/L)	0.20	0.20	3
Total number of mesophilic bacteria (in 36°C ± 2°C and 44 ± 4 h)	200[a]	100	–

[a]Total number of bacteria (in 22°C).

into account the possibility of their interaction. Nevertheless, due to changes in the values of selected parameters during the subsequent stages of the research (Figs. 3 and 4), they allow the evaluation of the effectiveness of the applied washings treatment methods.

3.1. pH

As a result of the treatment processes, the pH of washings decreased from an average of 7.8–7.3 (Fig. 3a). The pH of raw washings, supernatants after sedimentation and coagulation, and permeates after UF were within the range that allowed their discharge to the natural environment, use for cleaning surfaces, flushing toilets, watering greenery, and/or supplying the swimming pool circuit.

3.2. Temperature

The decrease in the temperature decrease of the analysed waters (on average from 20.6°C to 17.9°C) was due to the time needed to transport raw samples to the laboratory and carry out the next stages of treatment (Fig. 3b). In the case of using permeate as water to make up for losses in the swimming pool circuit, the lower the temperature decrease, the greater the savings in heating the water to the temperature required for a sports swimming pool, that is, up to 26°C–30°C.

3.3. Total suspended solids and turbidity

The parameters closely related to each other and decisive for the possibility of managing the washings are the content of total suspended solids (TSS) and the value of turbidity. Although sedimentation resulted in a 67.2% reduction in TSS and a 43.9% reduction in turbidity, the use of supernatant after this treatment stage was not possible due to the amount of TSS above 35 mg/L. After stage 2, the amount of TSS in the supernatant was on average 11.7 mg/L (Fig. 3d), and the turbidity was 4.24 NTU (Fig. 3c), which allows it to be used for washing or discharge into water or soil. On the other hand, the UF process, with the use of a ceramic and polymer membrane, achieved a reduction in TSS of 96.4% and 94.7%, respectively, resulting in a permeate turbidity of 0.21 NTU and 0.18 NTU, respectively, which in turn makes it possible to recirculate it to the swimming pool supply installation.

3.4. Chemical oxygen demand

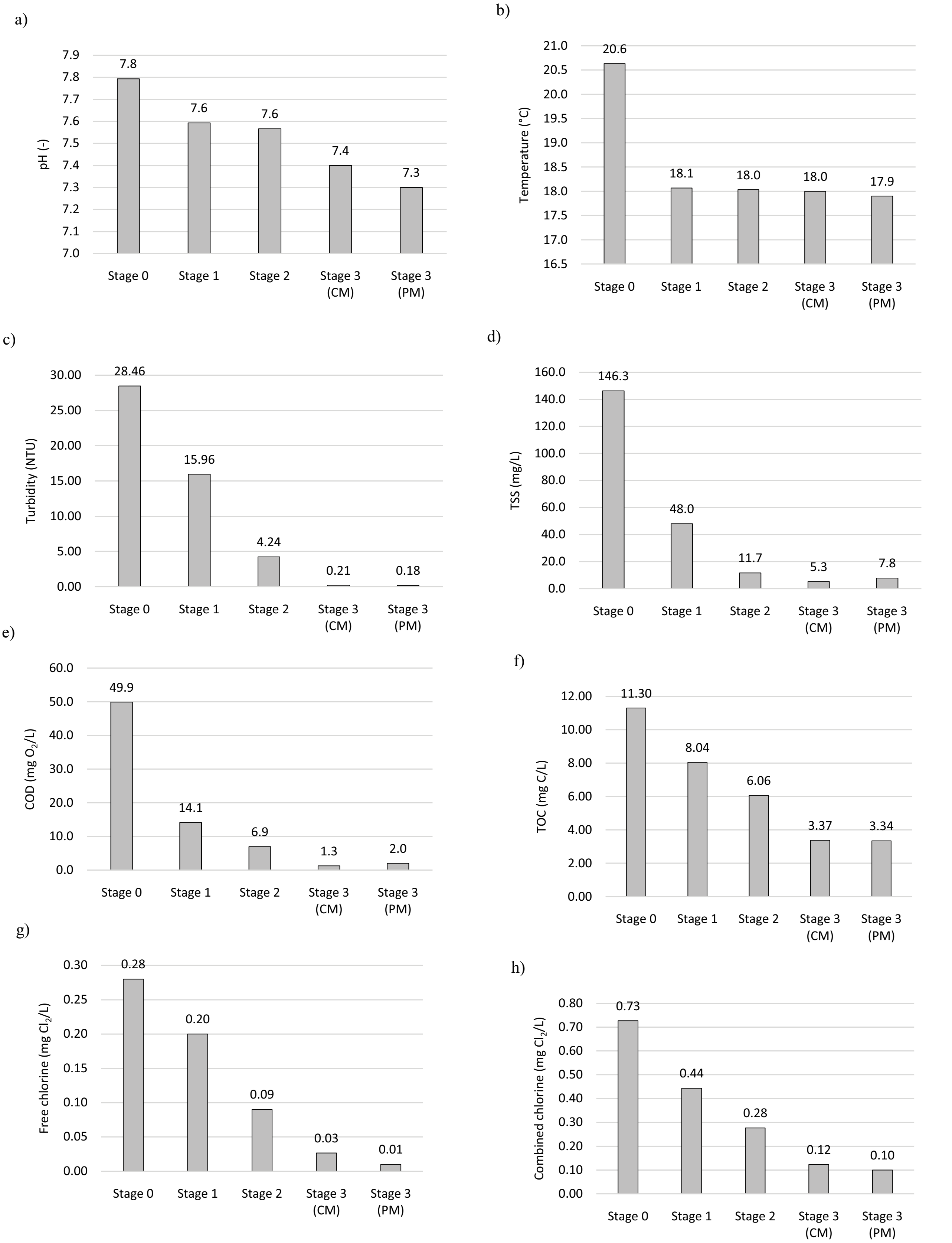
The chemical oxygen demand (COD) value as a parameter for quantifying the amount of oxidizable pollutants found in surface water or wastewater in the washings samples tested did not exceed the limit value for sewage discharged into water or soil (125 mg O_2/L). Its values between stage 1 and stage 3 ranged from 43.8 mg O_2/L to 0.82 mg O_2/L (Fig. 3e), and the successive reduction of the amount of TSS significantly reduced the COD value.

3.5. Total organic carbon

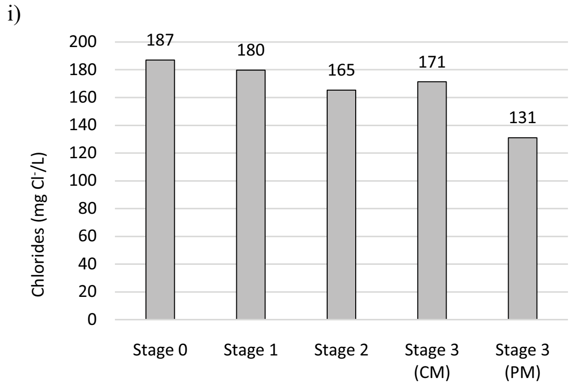
The value of total organic carbon (TOC), as an indicator of contamination of swimming pool water with organic compounds, depending primarily on the load of bathers and a number of technological parameters related to the operation of the swimming pool water treatment plant, corresponded to the requirements for swimming pool water (TOC 4 mg C/L) after applying UF. Both the use of UF-CM and UF-PM allowed to reduce the TOC value to an average of 3.37 and 3.34 mg C/L (Fig. 3f).

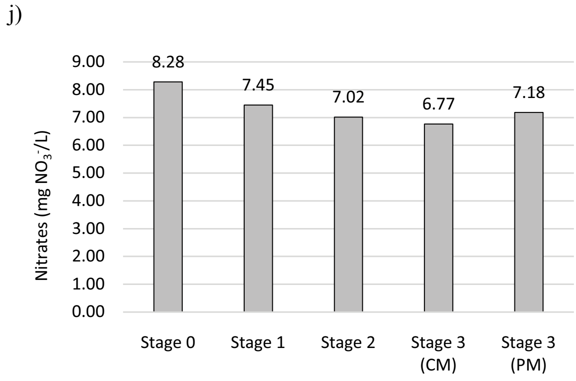
3.6. Combined chlorine

The parameter related to the TOC content is combined chlorine, the concentration of which should not exceed


a)
pH (-)
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
7.1
7.0
7.8
7.6
7.6
7.4
7.3
Stage 0
Stage 1
Stage 2
Stage 3 (CM)
Stage 3 (PM)
b)
Temperature (°C)
21.0
20.5
20.0
19.5
19.0
18.5
18.0
17.5
17.0
16.5
20.6
18.1
18.0
18.0
17.9
Stage 0
Stage 1
Stage 2
Stage 3 (CM)
Stage 3 (PM)
c)
Turbidity (NTU)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
28.46
15.96
4.24
0.21
0.18
Stage 0
Stage 1
Stage 2
Stage 3 (CM)
Stage 3 (PM)
d)
TSS (mg/L)
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
146.3
48.0
11.7
5.3
7.8
Stage 0
Stage 1
Stage 2
Stage 3 (CM)
Stage 3 (PM)
e)
COD (mg O_2/L)
60.0
50.0
40.0
30.0
20.0
10.0
0.0
49.9
14.1
6.9
1.3
2.0
Stage 0
Stage 1
Stage 2
Stage 3 (CM)
Stage 3 (PM)
f)
TOC (mg C/L)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
11.30
8.04
6.06
3.37
3.34
Stage 0
Stage 1
Stage 2
Stage 3 (CM)
Stage 3 (PM)
g)
Free chlorine (mg Cl_2/L)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.28
0.20
0.09
0.03
0.01
Stage 0
Stage 1
Stage 2
Stage 3 (CM)
Stage 3 (PM)
h)
Combined chlorine (mg Cl_2/L)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.73
0.44
0.28
0.12
0.10
Stage 0
Stage 1
Stage 2
Stage 3 (CM)
Stage 3 (PM)

(Continued)





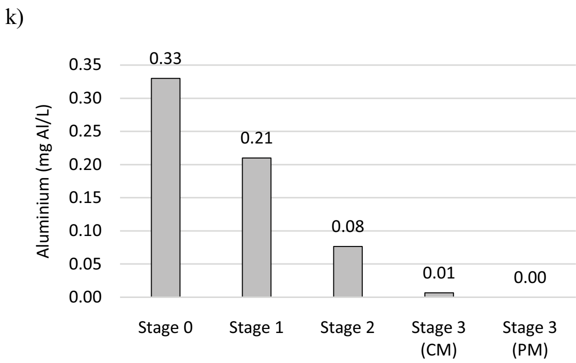


Fig. 3. Average values of washings quality parameters in subsequent stages of treatment: (a) pH, (b) temperature, (c) turbidity, (d) TSS, (e) COD, (f) TOC, (g) free chlorine, (h) combined chlorine, (i) chlorides, (j) nitrates, and (k) aluminium.

0.3 mg Cl_2/L in the swimming pool water. This level of combined chlorine content was obtained after stage 2 of the research (Fig. 3h).

3.7. Free chlorine

Due to protection of swimming pool water against recontamination, the free chlorine content remains within the limits of 0.3–0.6 mg Cl_2/L. In turn, in the case of discharged wastewater into the environment, due to the sensitivity of plant and animal organisms to the content of oxidizing compounds, it is required that the concentration of free chlorine must not exceed 0.2 mg Cl_2/L. In the analysed washings treatment system, a decrease in free chlorine concentration resulted mainly from the duration of the subsequent test stages and the mixing of the samples in the coagulation process. Within approximately 6 h (from the beginning of stage 1 to the end of stage 3), the free chlorine concentration decreased by approx. 90% (after UF-CM) and approx. 95% (after UF-PM), resulting in a trace free chlorine concentration in the permeates of 0.03 and 0.01 mg Cl_2/L, respectively. If it is decided to use the permeate to feed the swimming pool circuit, it would be necessary to dose a chlorine compound to the feed stream as a protection against the growth of pathogenic microorganisms. In the case of discharge of the analysed supernatant into watercourses, only stage 1 of treatment (2-h sedimentation) was sufficient to reduce the concentration of free chlorine to the required level (Fig. 3g).

3.8. Chlorides and nitrates

In the process of swimming pool water treatment, attention should also be paid to dissolved contaminants (nitrates, chlorides), which in the case of insufficient replenishment (refreshment) of the swimming pool water cycle with tap water, can become concentrated and, depending on their type, cause a health hazard to bathers or corrosion of the swimming pool installation [23–25]. The analysis carried out included the content of chlorides and nitrates as indicators of the "aging" of swimming pool water. During the tests, the chloride content ranged between 194 mg Cl^-/L (1st series in stage 1) and 131 mg Cl^-/L (3rd series in stage 3 of UF-PM) and decreased by 8% (after UF-CM) and 28% (after UF-PM), (Fig. 3i). During the tests, the nitrates content ranged between 9.21 mg NO_3^-/L (3rd series in stage 1) and 5.88 mg NO_3^-/L (1st series in stage 3 of UF-PM) and decreased by 18% (after UF-CM) and 22% (after UF-PM), (Fig. 3j). In the case of a decision to use permeate as a feed to the swimming pool circuit, it will be necessary to monitor the concentrations of chlorides and nitrates and, if their allowable concentrations are exceeded, to replace some of the circulating water with tap water or to use additional treatment processes removing chlorides and nitrates.

3.9. Aluminium

The use of the coagulation process in the swimming pool water or the sewage treatment system requires the

Table 4
Values of raw washings parameters and after three series of tests and in subsequent stages of treatment

Parameter	Raw washings			After sedimentation in supernatant			After coagulation in supernatant			After UF-CM (ultrafiltration with ceramic membrane) in permeate			After UF-PM (ultrafiltration with polymer membrane) in permeate		
	Stage 0			Stage 1			Stage 2			Stage 3 (CM)			Stage 3 (PM)		
No of series	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
pH (–)	7.7	7.9	7.8	7.6	7.5	7.6	7.5	7.6	7.6	7.5	7.4	7.4	7.4	7.4	7.3
Temperature (°C)	22.4	20.4	19.1	18.4	18.6	17.2	18.4	18.5	17.2	18.2	18.4	17.4	18.2	18.4	17.2
Turbidity (NTU)	30.82	26.44	28.12	18.17	13.21	16.49	5.01	4.12	3.58	0.24	0.18	0.21	0.22	0.15	0.18
TSS (mg/L)	156.0	138.0	145.0	64.0	42.0	38.0	12.0	10.0	13.0	6.0	4.0	6.0	8.7	6.6	7.8
COD (mg O_2/L)	48.80	57.00	43.80	14.50	15.70	12.20	7.67	8.12	5.04	1.35	1.61	0.82	3.32	2.14	2.03
TOC (mg C/L)	12.17	10.25	11.49	8.41	7.53	8.19	6.83	5.14	6.21	3.84	2.87	3.41	3.89	3.72	3.34
Free chlorine (mg Cl_2/L)	0.28	0.32	0.24	0.22	0.18	0.20	0.09	0.08	0.10	0.03	0.02	0.03	0.02	0.01	0.01
Combined chlorine (mg Cl_2/L)	0.82	0.62	0.74	0.50	0.41	0.42	0.25	0.26	0.32	0.14	0.11	0.12	0.11	0.10	0.10
Chlorides (mg Cl^-/L)	194	178	189	187	174	178	176	158	162	174	171	169	136	137	131
Nitrates (mg NO_3^-/L)	7.54	8.10	9.21	6.81	7.11	8.42	6.12	7.05	7.88	5.94	6.87	7.49	5.88	6.21	7.18
Aluminium (mg Al/L)	0.34	0.42	0.23	0.21	0.26	0.16	0.09	0.06	0.08	0.02	0.00	0.00	0.02	0.00	0.00
Total number of mesophilic bacteria in 36°C ± 2°C and 44 ± 4 h (CFU/1 mL)	500	620	560	82	96	86	16	32	24	2	5	4	2	4	4

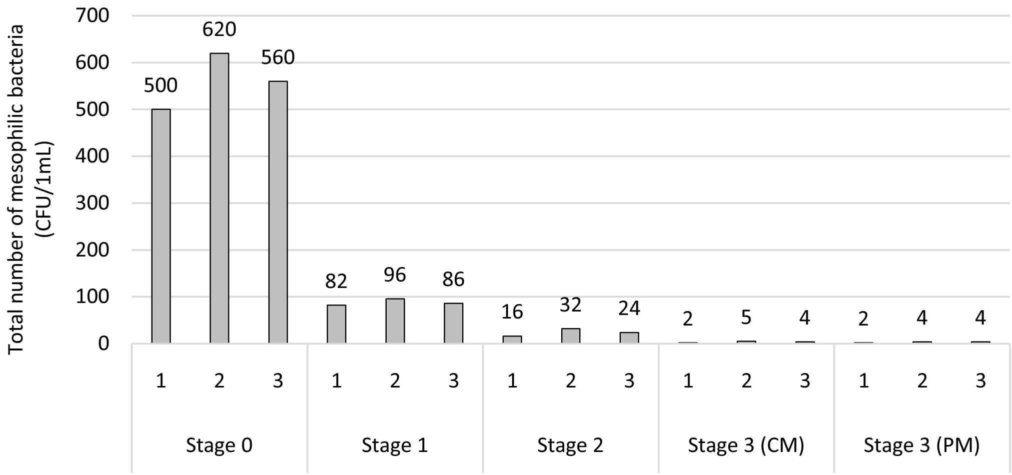


Fig. 4. Total number of mesophilic bacteria in series and stages of research.

control of the concentration of the remaining coagulate in the outflow from the treatment plant [26]. In the case analysed, it consisted of the previously determined optimal dose of 0.5% solution of aluminium hydroxychloride and the control of aluminium concentration after each stage of the research. In the raw washings, the aluminium content averaged 0.33 mg Al/L and was significantly reduced in subsequent stages (after stage 1 – 36%, after stage 2 – 77%, after stage 3 – 98%) to traces of 0.02 mg Al/L (Fig. 3k).

It is worth mentioning that post-coagulation sludge with high aluminium content could be recycled or reused [27].

3.10. Total number of mesophilic bacteria

The supernatant discharged to the environment, used for utility purposes, or the permeate recycled to swimming pool circuits must also meet the criteria of bacteriological purity. For the initial assessment of the sanitary condition of the analysed washings, the number of mesophilic microorganisms was determined. The raw washings showed significantly higher numbers of colony-forming units (CFU) than is allowed in pool water (in subsequent series: 500; 620 and 560 CFU/1 mL), after sedimentation – within the limits of the permissible values in the swimming pool water (82; 96 and 86 CFU/1 mL), after coagulation – within the permissible values in the water supplied to the basin, after completion of the treatment process (16; 32 and 24 CFU/1 mL) and after the UF process from 2 to 5 CFU/1 mL (Fig. 4).

3.11. Volume and cost balance of the washings

In the tested swimming pool, 14.13 m^3 of water was used for one washing. In one year, 192 washings are performed, so 2,713 m^3 of washings are produced (Fig. 5). The annual cost of washings discharged to the sewage system in 2021 was 5,822 EUR. In laboratory tests, about 65% of the washings volume was recovered for use. Therefore, the cost of discharged washings can be expected to be about 65% lower, amounting to approximately 2,042 EUR/y.

3.12. Efficiency of the membranes

During membrane filtration, the change in membrane performance is also assessed. The washings' filtration caused a reduction in the volumetric permeate flux in the case of both polymer and ceramic membranes. The reduction in performance of the polymer membrane was 43%, and that of the ceramic membrane was 39%, which was determined compared to the performance determined for deionized water. However, cleaning the membranes proved to be very effective. This process restored the initial efficiency of the membranes to 96% of the initial flux for the polymer membrane and 98% for the ceramic membrane, respectively.

4. Conclusions

The presented results of research for a selected swimming pool facility may be helpful in making decisions on the management of washings discharged from swimming pool facilities and in selecting unit processes (e.g., sedimentation, coagulation, and ultrafiltration that are analysed in this study) for their treatment. It should be remembered that the washings discharged from different swimming pools may differ in degree of contamination, and the type and amount of contamination will depend on the size of the swimming pool facility, its functions, the load on the bathers, or the water treatment and disinfection technology used. The decision on how to manage the washings should be made individually for each swimming pool and preceded by an extended analysis of the physicochemical and bacteriological parameters listed in the applicable legal documents in this regard and in the region where the swimming pool is located. The activities mentioned above should be supplemented by an analysis of investment and operating costs, taking into account pro-ecological activities in the field of water resources protection.

Based on the analysis performed, it was found that three-stage treatment of washings from the tested swimming pool filter installation could result in:

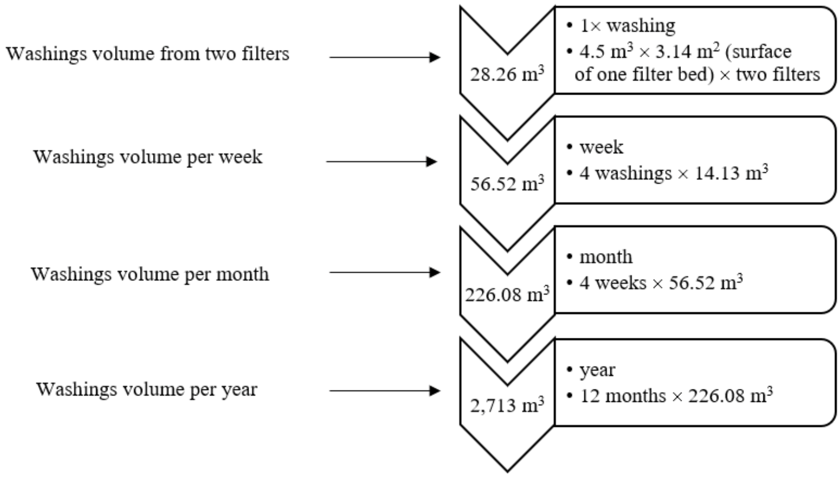


Fig. 5. The volume of washings from the tested filtration system in various time intervals.

- a reduction in the volume of washings discharged to the sewage system by at least 65% and thus a reduction in charges for discharged wastewater,
- the use of supernatant water or permeate for utility purposes on the premises of the considered pool and in accordance with the principle of sustainable development, thus reducing the demand for tap water,
- discharge of supernatant water to a watercourse, provided that a permit required by the Water Law Act for such an operation is obtained,
- the use of permeate as a feed supplementing losses in the swimming pool water cycle, provided that the concentrations of dissolved pollutants (including nitrates, chlorides, TOC and combined chlorine) are monitored.

Author contributions

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

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Data availability

The data sets 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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