


Water loss in swimming pool filter backwashing processes in the Balearic Islands (Spain)

Antonio Doménech-Sánchez ^{a,b,*}, Elena Laso^b and Clara I. Berrocal^b

^a Instituto Universitario de Investigación en Ciencias de la Salud (IUNICS), Universidad de las Islas Baleares, Carretera de Valldemossa km 7.5, 07122 Palma de Mallorca, Spain

^b Saniconsult Ibérica SL, Can Foradí 38 bajos, 07009 Palma de Mallorca, Spain

*Corresponding author. E-mail: adomenech@uib.es

 AD, 0000-0002-7892-8349

ABSTRACT

Swimming pools are a major contributor to water consumption in our community. However, the high water loss associated with filter cleaning is unknown. In this work, we investigate the current procedures for filter backwashing in public swimming pools by questionnaires to owners and managers. Then, we use the collected data to estimate their environmental and economic costs. Besides, we measure several parameters in the field during the process performed in four representative swimming pools. The investigation revealed that the water loss associated with filter cleaning in public swimming pools rises to 5.5 million m³ water per year, which represents an expense of 13.96 million €. Based on our results, the followed protocols were inappropriate in most cases, indicating that even the required water amount would be higher. The most suitable parameters for filter backwashing monitoring were combined chlorine, ammonium, turbidity and chemical oxygen demand (COD). The necessity for specific strategies and legislation for the management of these installations, the treatment of the generated wastewater, as the implementation of different technological solutions to reduce water loss are discussed.

Key words: Backwashing, Filter cleaning, Swimming pool, Water conservation, Water policy, Water losses

HIGHLIGHTS

- Water loss from filter backwashing in our community is huge.
- Current filter backwashing practices are insufficient and should be improved.
- The most suitable parameters for filter backwashing monitoring are combined chlorine, ammonium, turbidity and COD.
- Official parameters and limits for backwashing monitoring are needed.
- Water-saving strategies should include water reuse and technological improvements.

This is an Open Access article distributed under the terms of the Creative Commons Attribution Licence (CC BY 4.0), which permits copying, adaptation and redistribution, provided the original work is properly cited (<http://creativecommons.org/licenses/by/4.0/>).

GRAPHICAL ABSTRACT



INTRODUCTION

Swimming pools are popular facilities for recreational, leisure or sport activities. Besides, aquatic activity is often associated with many health benefits. However, the use of swimming pools associates with outbreaks of diseases caused by microorganisms (World Health Organization, 2005). Some pathogens, including *Legionella* and *Escherichia coli*, are present in pool water (World Health Organization, 2005). Coliform bacteria and pseudomonads are the most frequently isolated microorganisms in pool waters in our community (Doménech-Sánchez *et al.*, 2008). Chemical compounds may also become hazardous. Disinfection by products (DBPs) irritate the mucous membrane when the person is in the pool water and prolonged contact with DBPs may cause various health issues such as asthma, bladder cancer, and atopic dermatitis (Panyakapo *et al.*, 2008; Boucherit *et al.*, 2015; Ciorba *et al.*, 2015). Thus, these facilities must have their own water treatment circuit to maintain the appropriate microbiological and physicochemical levels in the water (Łaskawiec *et al.*, 2019). The water treatment includes disinfection and cleaning of swimming pool water and continuously carries on in these close-loop circuits during the facility's operation. Chlorine is, by far, the most common disinfectant in swimming pools because of its cost-effective properties (Rosende *et al.*, 2020), whereas filtration is used to remove suspended particles. The main water supply to the swimming pools is water mains. It contains organic and inorganic compounds and products derived from the disinfection treatment (DBPs) (Zhang *et al.*, 2017). Although other pollutants may enter the water in different parts of the treatment circuit, the main factors that significantly impact water quality are human pollutants. These organic compounds include, among others, cosmetics products, urine, sweat and saliva introduced by the users of the pool (Carter & Joll, 2017). Filtration, commonly associated with flocculation and coagulation treatments, constitutes one key element of the pool water treatment process. This procedure performs in pressure beds, where the suspended matter in the water is removed by forcing it through the filter (Arendze & Sibiya, 2014). Mono-layer pressure filters with one type of filtration bed (usually sand or gravel with different grain size) constitute the simplest type of filters. This solution is widespread, but research to increase the filtration efficiency resulted in multi-layer filters, whose filter bed consists of two or three layers of various materials. The filling of multi-layer filters is usually gravel, quartz sand, anthracite or activated carbon (Wyczarska-Kokot & Lempart, 2019). The consequent filter clogging after the filtration process causes a pressure loss over time (de Deus *et al.*, 2020). Rinsing is required to remove the contaminants

accumulated during that filtration process and condition the beds for continued efficient operation (Łaskawiec *et al.*, 2017a). The filter is cleaned by expanding and disturbing the filter bed, flushing them with water and/or air stream in the reverse direction to normal flow (Arendze & Sibiyi, 2014). Therefore, this rinsing process is often known as backwashing. The process removes the impurities from the equipment and recovers the appropriate pressure levels (de Deus *et al.*, 2020). The resulting wastewater or backwash water streams characterized by high contents of suspension and dissolved substances, including residues of DBP, coagulants and flocculants, which often impart a toxic character to the backwash water stream (McCormick *et al.*, 2010). The backwashing process must be performed once every 2–3 days to ensure the physicochemical and sanitary standards of basin water. Approximately 4–6 m³ of water for every m² of the filtration bed is required. That generates a high amount of backwash water, which is discharged usually to the sanitary sewer system. The backwashing from swimming pool systems may constitute 20% to even 70% of the total wastewater volume, depending on the size of the swimming pool and the water treatment technology applied (Wyczarska-Kokot & Lempart, 2019).

The interest in the environmental aspects of water use has undoubtedly increased in the last decade. Besides, the European Commission published in 2015 the Circular Economy Strategy, with an action plan that includes a specific mention to this requirement of reuse the water. This need to save water, together with the increase of prices associated with water and sewage, leads to increased research for new solutions in the ambit of water and sewage management by the designers and owners of swimming pools (Wyczarska-Kokot & Lempart, 2019). In this sense, the potential opportunities to reuse backwash water is a stimulating and widely studied subject (Lewis *et al.*, 2015). Different levels of treatment will be required depending on the final use, from toilet flushing to direct reintroduction into the swimming pools. In any case, these treatments must separate to reduce the potential risk of reintroducing contaminants into the principal treatment process. Conventional or traditional water treatment includes sedimentation, coagulation, sand and granular activated carbon filtration. Advanced procedures like membrane filtration (micro-, nano- or ultrafiltration) or ultraviolet irradiation are increasingly used for pool water treatment (Skibinski *et al.*, 2016, 2019). Simple purification processes, including a settling tank with a coagulant chamber and after a tank for intensive aeration, allow the backwash water to introduce into waters or the ground (Wyczarska-Kokot & Lempart, 2018). The simple filtration with granular activated carbon effectively removes free chlorine and DBPs from the water, as demonstrated by Skibinski *et al.* (2019). That enables its use in toilet flushing and other low-level applications. Weiyang *et al.* (2010) used membrane microfiltration with monolith ceramic membranes to treat backwash wastewater, obtaining drinking water standards. In Poland, the treatment of pool water installation washings required a flocculation step previously to the ultrafiltration system to ensure an appropriate outcome (Łaskawiec *et al.*, 2017a). Reißmann *et al.* (2005) used a combination of ultrafiltration and reverse osmosis to enable backwash water reuse within the swimming pool itself (Reißmann *et al.*, 2005). The suitability of membrane processes for the purification of backwash water from washing filtration beds in a swimming pool water system was analysed by Łaskawiec *et al.* (2017b). Their results showed the need for supporting processes aimed at reducing membrane pore blocking and, in the case of ultrafiltration, assuring the safety of the purified stream in terms of the toxicological effect. The advance of wastewater regeneration and reuse does not depend only on technological improvements but also depends on a legal framework that accentuates guidelines so that the reuse does not turn harmful to health.

The Balearic Islands are a Mediterranean archipelago in Eastern Spain. This location makes them highly predisposed to suffer climatological droughts. The climate associated variability of precipitation includes intra and inter-annual periods frequently leading to water scarcity (Kent *et al.*, 2002). The problem is particularly significant during the summer season. On the other hand, our community constitutes one of the major tourist destinations in Spain and the Mediterranean area (Deyà Tortella & Tirado, 2011). In 2016, 15.4 million tourists visited our islands (IBESTAT, 2020). The high water consumption associated with this touristic pressure, together with the

above-mentioned drought periods, make water scarceness one of the most important socio-environmental issues that our community faces (Hof *et al.*, 2018). Thus, proper water resources management is crucial to ensure water supply. The proliferation of swimming pools for residential and touristic use has increased in our islands in the last few years (Hof *et al.*, 2018). The intensification of water consumption associated with this circumstance is critical and constitutes a challenge for water management in our community. This is revealed in different environmental studies performed in areas with limited water resources. There, swimming pools are flagged as the principal contributor in the urban and tourism sectors (Gober *et al.*, 2016). Altogether, these findings highlight the relevance of swimming pools in water resource analyses and their weight to the demand side of water management in our community. There are some studies of water use in swimming pools. However, in most of them, the analysis failed to assess an important aspect of pool water consumption: they did not account for the cleaning of pool filters (Hof *et al.*, 2018). The novelty of the present work lies in the specific investigation of this critical factor.

The present study investigates the current practices in swimming pool filter backwashing in our community and the water loss associated with these procedures. The scheme of this work includes the initial recompilation of information from different swimming pool facilities and the analysis of these data. Then, the calculation of the associated environmental and economic costs. And finally, a field investigation of the backwashing processes monitoring illustrative water parameters in representative facilities. This quantitative knowledge on the most significant water-consuming factors in the Balearic Islands will help the policymakers to establish appropriate strategies and legislation for the complex water resource management in our community. Different approaches to optimize the processes and save water are also discussed.

METHODS

Compilation of information on the current backwashing procedures for public swimming pool filters in the Balearic Islands

The information on the routine procedures followed in public facilities for the swimming pool backwashing process was compiled by written and oral questionnaires. Based on our current national legislation (Ministerio de Sanidad Servicios Sociales e Igualdad, 2013), public swimming pools include type 1 pools: pools where water-related activity is the main objective, as in the case of public swimming pools, leisure, water parks or spas; and type 2: pools that act as a supplementary service to the main objective, as in the case of hotel pools, tourist accommodation, camping or therapeutic pools in health centres, among others.

First of all, the questionnaires included general aspects of the swimming pools: the size, the indoor or outdoor location, the water heating, the presence of jets, waterfalls and/or air bubblers typical for SPA installations. The second section reported the swimming pool treatment, including information about the type of disinfection system and the filtration bed type. The bed type influences the backwashing quality (Wyczarska-Kokot & Lempart, 2019). Finally, different aspects related to the backwashing process, including the existence of a written protocol, the basis applied to the procedure, the time expended, the size and appropriateness of the used equipment, and the monitoring of the process, were also included.

The study was carried out from April to August 2016. The management and technical departments of installations located in our community were sent the questionnaires and then fulfilled during the visit of our auditors.

Estimation of the amount of wastewater generated during the backwash process and the related economic costs

We estimate the amount of wastewater generated in the backwash processes in the Balearic Islands from the data collected from the surveyed swimming pool facilities. Among them, the two more relevant factors were the working conditions of the pumps and related equipment used for filter backwashing and the total time of the process.

Thus, we calculate the average values for the operating flow (OF) and time (T). Then, we estimate the average volume of backwash water eliminated by one individual swimming pool (ABWi) in a single backwashing process as

$$ABWi (m^3) = \frac{T(\text{min}) \times OF (m^3 h^{-1})}{60} \quad (1)$$

We calculate the total water loss associated with filter backwash in the entire set of public swimming pools in our community by multiplying the above calculated ABWi by the number of public swimming pools in the Balearic Islands, estimated at 2,747 by the Spanish Association of Professionals of the Swimming Pool Sector (ASOFAP).

In the cost evaluation associated with the water loss in the backwashing process, we followed the same approach as in our prior study on the cost-effectiveness of disinfection systems for pool waters (Rosende *et al.*, 2020). Therefore, we considered the value of 2.52 € water m⁻³. This value corresponds to the average price in the Balearic Islands in 2016 excluding local taxes.

Facilities

The present work represents a proof of concept for the evaluation of the backwashing process and the analysis of the associated water loss. Therefore, in this first approach, the model was limited to four swimming pools. To ensure the most representative picture of the current situation, we used the surveyed data from the previous section. These values showed the most frequent characteristics among our community facilities (see the Results section) and stated the basis for the field experiments.

The facilities investigated in this research were selected based on their characteristics regarding their size, indoor/outdoor location, the applied disinfection system, the climatization and the presence of elements frequent in whirlpools and SPAs like jets, waterfalls or air bubblers (Table 1). The filtration beds consisted of sand of different sizes, the most widespread in our facilities (see Results).

Experimental design

The objective of the field experiments was to collect information on the quality and quantity of the backwash water generated during the backwash process. For this purpose, no modifications were introduced in the process during the visits to the facilities to ensure a real picture of the current situation. All the procedures were carried out by the operators responsible for the facilities. Backwash water was sampled directly from the filter eluent. The time used routinely by the technical staff in charge of the swimming pool maintenance, called T, was set as the reference. The sample collected at this time T represents the current backwashing wastewater for the investigated

Table 1 | Characteristics of the swimming pools investigated in this work.

Swimming pool	Disinfection system	Indoor/ Outdoor	Climatized	SPA ^a	Water volume (m ³)	Water surface (m ²)	Capacity (people)
Pool A	Bromine	Indoor	Yes	Yes	144	60	20
Pool B	Saline electrolysis	Indoor	Yes	No	2,500	1,250	417
Pool C	Sodium hypochlorite	Outdoor	No	No	340	330	164
Pool D	Chlorine isocyanates	Outdoor	No	No	3,000	1,600	800

^aSwimming pool with jets, waterfalls and/or air bubblers.

facility. We collected additional samples at different times during the backwashing for a broader view of the evolution of the water characteristics throughout the washing process. These samples included the first portion of water after turning on the pump, representing the initial conditions of the filter bed, and considered as time 0; and the water when the backwash was halfway through the process, designed as T/2. Moreover, to determine the further evolution of water characteristics if lengthening the procedure, the backwashing was increased half the time routinely used by the operators, then obtaining the T + T/2 samples.

We visited the facilities on three different days to investigate the filter backwashing procedure.

Some parameters were determined *in situ* (see next section), and then samples were transported to the laboratory in refrigeration for the rest of the determinations. Transport lasted less than one hour in all cases.

Physicochemical determinations

To monitor the quality of the backwash water, we selected and measured some physicochemical parameters. Our experiments analysed the levels of pH, conductivity, total dissolved solids (TDS), turbidity, bromine or free and combined chlorine, cyanuric acid, ammonium, chemical oxygen demand (COD) and fats and grease. There is no specific legislation for backwashing monitoring. For this reason, the parameters investigated in the present study were selected, first, from those included in the legislation in force establishing the technical and sanitary criteria for swimming pools in Spain (Ministerio de Sanidad Servicios Sociales e Igualdad, 2013). And second, to include those which may help to monitor specific water contaminants, like ammonium (for human body fluids like urine or sweat), COD (for organic matter) and fats and grease (for sunscreen or cosmetics, among others). Most of them have been previously used for backwash water studies (Wyczarska-Kokot, 2016; Łaskawiec *et al.*, 2017a, 2017b, 2019). The pH levels were analysed *in situ* by the phenol red method using a MD100 photometer (Lovibond®, Germany), following the manufacturer's instructions. The conductivity and TDS levels were analysed in the laboratory with a Crison CM35+ conductivity meter (Crison Instruments S.A., Spain), as indicated by the manufacturer. The turbidity was measured with a 2100N IS turbidimeter (Hach, Spain) following ISO 7027-1:2016 instructions. The Lovibond® portable MD100 instrument was used *in situ* for determining the concentration of disinfectants (free chlorine, combined chlorine and bromine, depending on the disinfection system used) by the colorimetric method described in Rosende *et al.* (2020). The cyanuric acid levels were also determined *in situ* by the turbidity method explained in Rosende *et al.* (2020) when applied to the swimming pool treatment. The ammonium concentration was determined by the indophenol blue method with a Spectroquant® NOVA60 photometer (Merck, Spain), as stated by the manufacturer (APHA/AWWA/WEF, 2005). COD was also determined with the Spectroquant® NOVA60 instrument, in this case by the chromosulphuric oxidation method (APHA/AWWA/WEF, 2005). Finally, the levels of fats and grease were determined by the gravimetric method using n-hexane (APHA/AWWA/WEF, 2005).

RESULTS

Characteristics of the current backwashing procedures for swimming pool filters in the Balearic Islands

The average size of our public swimming pools, estimated from the questionnaires, was 260 m³, in agreement with data from the Spanish Association of Professionals of the Swimming Pool Sector, where the average size for public swimming pools in Spain is 230 m³. Aspects involved in the procedures used during the filter backwashing in the swimming pools located in the Balearic Islands were investigated to know the current situation. The results derived from this study stand in Figure 1. There, the disinfection system column informs on the disinfection system applied to the swimming pool; the written protocol column indicates whether there is a paper copy of the protocol followed by the technical department or not; the own protocol column means that the technical staff developed the protocol themselves; the procedure column shows the basis used for the backwashing process, and the control column

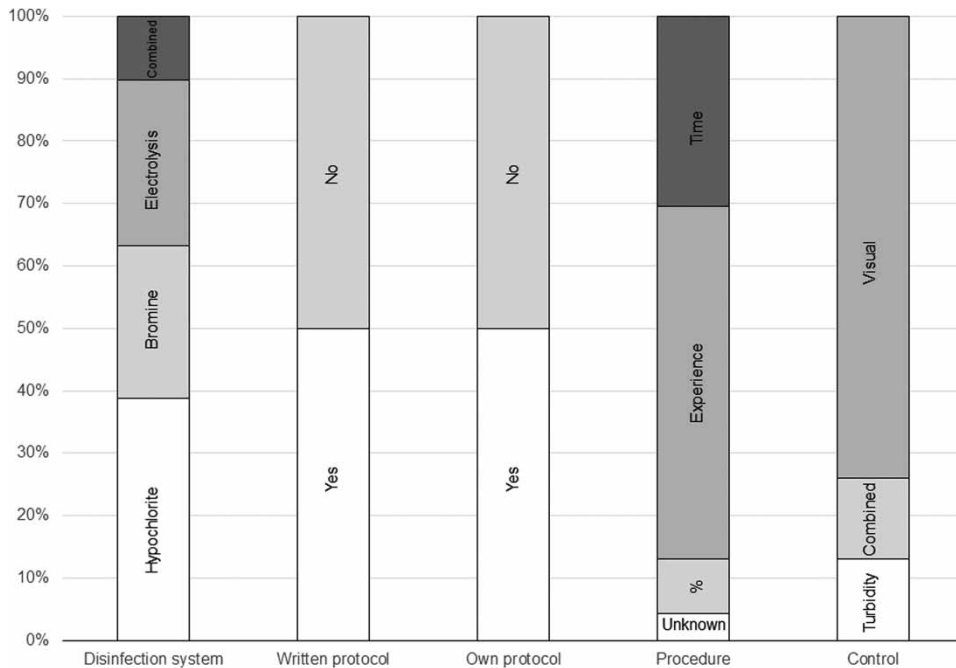


Fig. 1 | Results from the questionnaires on the filter backwashing procedures.

indicates the check performed by the technical staff to finish the process. Our investigation revealed that chlorine was the most frequent active principle in our community pools. Thus, disinfection systems based on the action of chlorine, including sodium hypochlorite, saline electrolysis or combinations among them or with cyanuric acid-stabilized chlorine (chlorine isocyanates), were present in up to 75.5% of the swimming pools surveyed. Chloride dioxide was not used routinely in any of them. As for the filter bed, sand-based pressure filters were present in almost all the surveyed facilities, with very few cases of activated glass filter beds.

The answers to the question asking whether a written filter backwashing protocol was available for the technical staff, showed up that only in half of the swimming pools was this the case. For the elaboration of the protocol, only half of the facilities incorporated external information or recommendations provided by installers, product suppliers or consultants. One of the most critical questions inquired on the foundation of the procedure. In most cases, the protocol based on the experience of the technical staff, and the backwashing lasted what the operator considered appropriate in each case. In other cases, the protocol was based on a fixed time (30%) or in the renovation of a fixed fraction (percentage) of the pool water (8.7% of cases). Curiously, the staff responsible for the swimming pool maintenance did not know the basis of the established protocol in 4.3% of the cases. As for the drive pump and other equipment involved in the process, the staff considered that they were well-dimensioned to the size of the pool in all cases. Finally, the backwashing was controlled visually in most cases. Only in 13% of the swimming pools, the monitoring included turbidity measurement.

Water loss associated with the backwash process and its related economic costs

The calculation of the total amount of water lost in the backwash process was the main objective of our study. This information allows the problem to be quantified and contextualized. Our investigation showed that the pumps and related equipment used for filter backwashing in our community works, on average, at $65 \text{ m}^3 \text{ h}^{-1}$

(OF). The average time (T) for backwash inferred from the questionnaires was 5.1 min (range 1.5 to 15), in accordance with previous studies (Wycarska-Kokot & Lempart, 2019). For one daily backwashing, 5.53 m³ of water are eliminated for each swimming pool (ABWi) every day. That means that, for one individual pool, 2,017 m³ of water associated with the process of filter backwashing loss each year. Since the number of public swimming pools in the Balearic Islands has been estimated at 2,747 by the Spanish Association of Professionals of the Swimming Pool Sector (ASOFAP), the total water loss per year associated with filter backwash amounts to 5.5 million m³.

The environmental costs of water loss are evident, but the economic impact also has to be assessed. For this purpose, the value of 2.52 € water m⁻³, corresponding to the average price in the Balearic Islands in 2016 excluding local taxes, was considered (see Methods). Thus, for an individual swimming pool in our community, the costs associated with water loss in the backwashing process is 13.92 € per day and 5,082 € per year. We considered the total of public swimming pools and the cost increase to 38,247 € per day and 13.96 million € per year.

Monitorization of the filter backwashing process

The evolution of the selected parameters mentioned above during the filter backwashing process was monitored in the four selected swimming pools. The use of most of these parameters in other works (Wycarska-Kokot, 2016; Łaskawiec *et al.*, 2017a, 2017b, 2019) demonstrates their suitability for these type of investigations. The average time for backwash inferred from the questionnaires was 5.1 min (range 1.5 to 15), in accordance with previous studies (Wycarska-Kokot & Lempart, 2019). The values for time and filtered volumes corresponding to the field experiments in the different swimming pools are in Table 2. The standard time T for backwash was five minutes in two of the selected swimming pools, whereas the time was shorter and only lasted three minutes in the two remaining pools. The times for sampling calculated as explained in the Methods section.

The values obtained in the three independent experiments for the four swimming pools is shown in Figures 2–6. The dotted grey lines with circles correspond to experiment 1 values; the dashed lines with triangles show values for experiment 2, and solid black lines with squares indicate the experiment 3 values. Levels of pH barely changed during the process, ranging between 7.5 and 8.1 in all cases, with similar patterns in the four pools (Figure 2).

The diluted and suspended solids present in the backwash water were determined by measuring the conductivity, TDS and turbidity (Figure 3). Opposite to what happened with the pH, the conductivity and TDS values differ among the different swimming pools. Besides, the levels of these parameters in the elution water were higher in swimming pools B and D. This aspect is attributed to pool B using a saline electrolysis system (as indicated in Table 1). Brackish water from a nearby well partially fills the pool D to save water. Independently of the

Table 2 | Times and filtered volumes applied during the filter backwashing process for each swimming pool.

	Pool A	Pool B	Pool C	Pool D
Standard time T (min) ^a	5	3	3	5
Time T/2 (s)	150	90	90	150
Time T (s)	300	180	180	300
Time T+T/2 (s)	450	270	270	450
Filtered volume T/2 (m ³ /‰ ^b)	3/2.1	5.9/0.2	5/1.5	6/0.2
Filtered volume T (m ³ /‰ ^b)	6/4.2	11.7/0.5	9.9/2.9	12/0.4
Filtered volume T+T/2 (m ³ /‰ ^b)	9/6.3	17.6/0.7	14.9/4.4	18/0.6

^aTime spent on routine pool maintenance for the filter backwashing process. ^bPercentage of filtered water for the stated time with respect to the total water volume of the swimming pool.

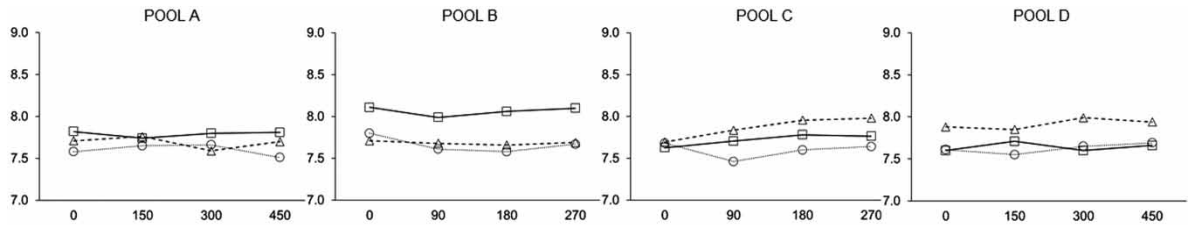


Fig. 2 | Evolution of the pH levels throughout the filter backwashing process in swimming pools. The abscissa axis indicates the time in seconds.

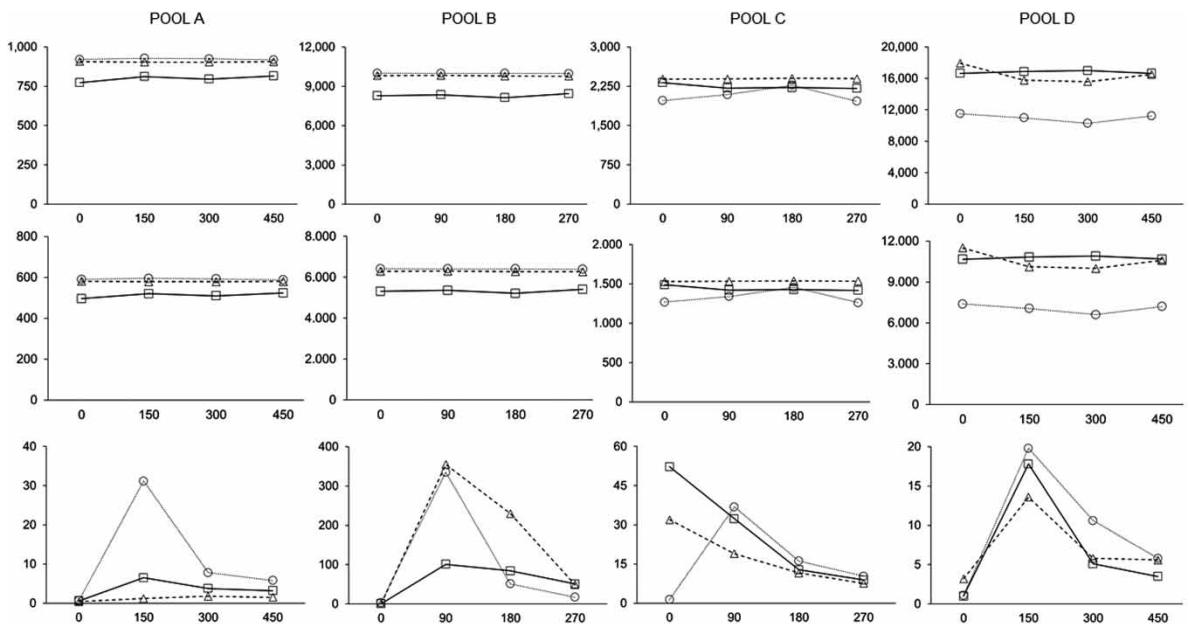


Fig. 3 | Evolution of the conductivity (upper panel, $\mu\text{S cm}^{-1}$), TDS (middle panel, mg L^{-1}) and turbidity (lower panel, NFU) in water samples throughout the filter backwashing process in swimming pools. The abscissa axis indicates the time in seconds.

initial conductivity and TDS levels, figures remained constant during the process. In contrast, the turbidity levels decreased during the process in all cases.

The progress of disinfectant values in the backwashing process were monitored as well. Bromine detected in pool A or free chlorine in swimming pools B, C and D. The obtained profiles did not show a similar pattern, not even when the same disinfectant was compared (pools B, C and D). Differences also detected among the three independent experiments. As an example, in pool C the disinfectant increased in the first experiment; dropped initially down and then increased in the second, and remained relatively stable in the third. Another parameter where reduction detected throughout the backwashing process was the combined chlorine. Thus, in pools B, C and D the final levels were below the initial ones, independently of the concentration at time 0. Pool A used bromine and, therefore, combined chlorine not detected in any case. The last parameter selected from the legislation was cyanuric acid. This compound was only present in pools C and D, and no reduction detected in any experiment. If any change, a slight increase may infer from the pool D experiments.

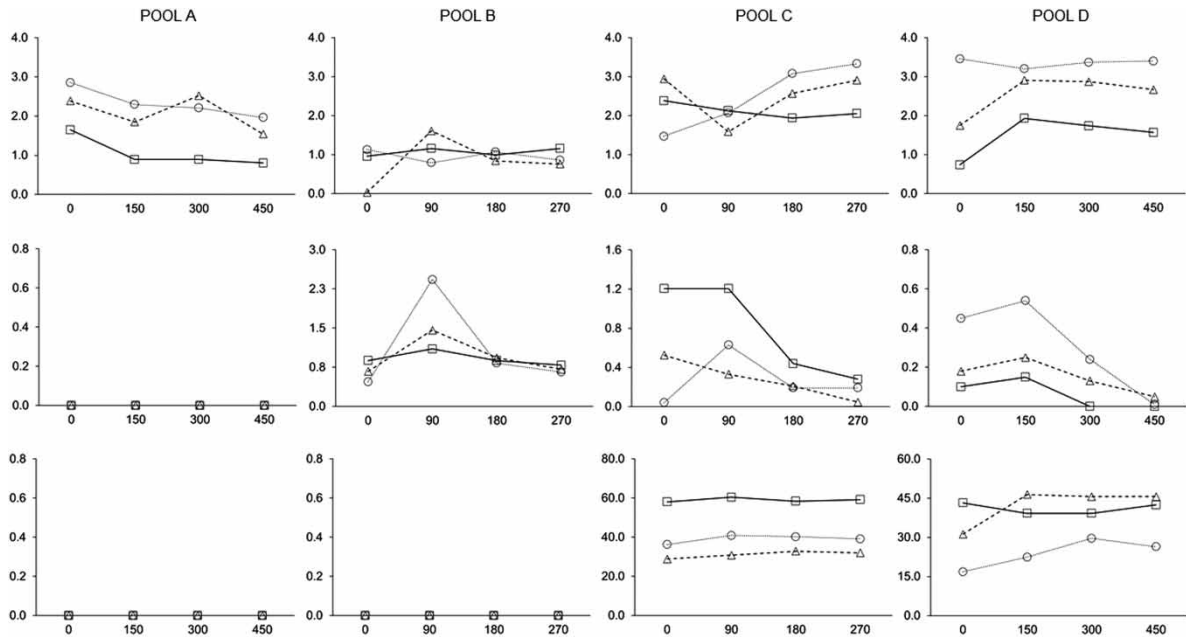


Fig. 4 | Evolution of compounds related to the disinfection treatment in water samples throughout the filter backwashing process in swimming pools. The upper panel shows the values for bromine (pool A) or free chlorine (pools B–D). The middle panel shows the combined chlorine levels. The lower panel shows the values for the cyanuric acid. Units are mg L^{-1} in all cases. The abscissa axis indicates the time in seconds.

Anthropogenic contaminants like sweat, urea or saliva investigated through the evolution of ammonium concentration. This compound was only detected in pools B and C, decreasing to undetectable levels at the end of the process in both cases (Figure 5). However, the concentration of fats and grease, most derived from cosmetics and/or sun blockers, showed irregular patterns. As observed in Figure 5, the values of these compounds randomly increase or decrease throughout the backwash process.

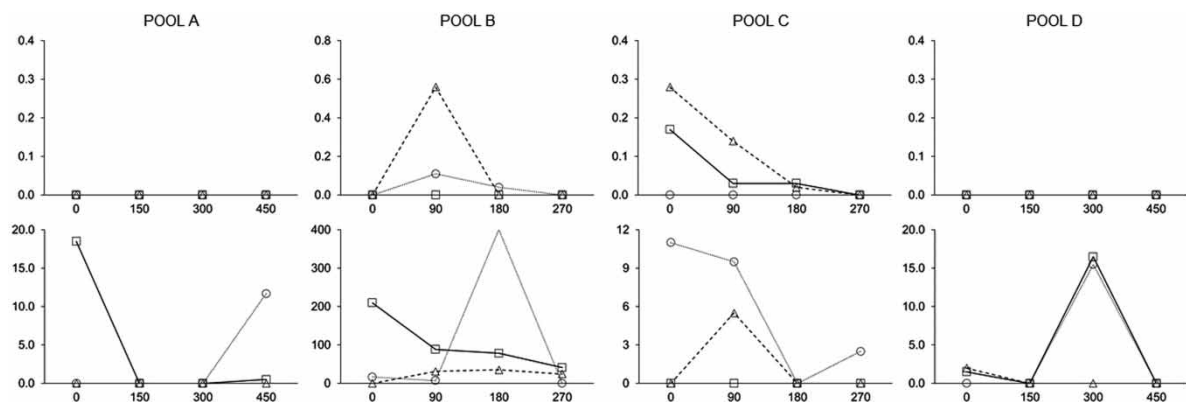


Fig. 5 | Evolution of human-derived contaminants as ammonium (upper panel, mg L^{-1}) and fats and grease (lower panel, mg L^{-1}) in water samples throughout the filter backwashing process in swimming pools. The abscissa axis indicates the time in seconds.

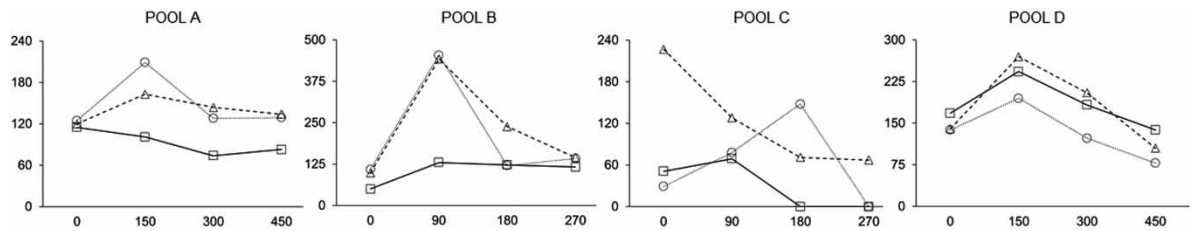


Fig. 6 | Evolution of COD (mg L^{-1}) in water samples throughout the filter backwashing process in swimming pools. The abscissa axis indicates the time in seconds.

Finally, the organic matter levels in backwashing water were also measured. The parameter selected in this case was the COD, and our results demonstrate that the organic load decrease in the wastewater generated in the procedures followed by the four pools tested.

DISCUSSION

Water is a scarce resource in our community. Climate change, the increase of tourist and periods of drought have increased the problems related to this issue in the last decades. Swimming pools are a factor affecting water consumption, and their number has significantly augmented in recent years. Some factors related to water loss, like evaporation, have been previously investigated in the Balearic Islands (Hof *et al.*, 2018). However, the water loss related to swimming pools filters backwashing, although constitute from 20% to even 70% of the total wastewater volume (Hazell *et al.*, 2006; Wyczarska-Kokot & Lempart, 2019), remains unknown. For this, we have investigated the process of filter backwashing in public swimming pools located in our community. Our estimation reveals a yearly water loss of $2,017 \text{ m}^3$ per swimming pool, in agreement with the $1,500\text{--}2,200 \text{ m}^3$ estimated in Łaskawiec *et al.* (2017a), but lower than the over $5,000 \text{ m}^3$ of (Wyczarska-Kokot & Lempart, 2018), both in Poland. Besides, when we consider all the public swimming pools in the Balearic Islands, the water loss increased up to 5.5 million m^3 . Hof *et al.* (2018) estimated a total evaporative water loss of 4.8 million m^3 per year when 62,599 swimming pools (including touristic and residential) in the Balearic Islands were analysed. That means that, for one individual swimming pool, the water loss associated with filter backwashing is 2.62×10^7 times higher than that associated with evaporation. As for the costs associated with water loss in the backwashing process, we calculated a value of 13.92 € per day and 5,082 € per year and swimming pool. To compare, the cost of the total pool water consumption in a single swimming pool analysed in the United Kingdom accounted for 6,116 £ (Lewis *et al.*, 2015). We consider the total of public swimming pools in our community, then the cost increase to 38,247 € per day and 13.96 million € per year. Backwashing processes entails high water and energy consumption (Wyczarska-Kokot, 2016). One limitation of our investigation is that energy related costs were not considered.

To date, all this high amount of water is discharged directly into the sanitary sewage system as wastewater. That entails the problem of overloading the treatment plants and the additional costs related to the treatment. Direct drainage of the washings into waters or soil is a possible solution to these problems. However, our results indicate that the quality of backwash water does not meet the admissible values for introducing sewage into waters or to the soil (Ministerio de Obras Públicas Transportes y Medio Ambiente, 1996). Water discharge from pool installations must not be managed directly due to total suspended solids exceeding 35 mg L^{-1} (Figure 3) and the content of free chlorine exceeding $0.2 \text{ mg Cl}_2 \text{ L}^{-1}$ (Figure 4) in all cases. Besides, the COD levels were higher than the legal limit of $125 \text{ mg O}_2 \text{ L}^{-1}$ at least once in each pool (Figure 6). Therefore, backwash water must be treated before discharging it to a watercourse. Simple purification processes, including sedimentation with coagulant followed by intensive aeration, allow the backwash water to be introduced into waters or the ground (Wyczarska-Kokot & Lempart, 2018, 2019). The reuse of the backwashing water is a better option. Their use for irrigating green areas,

sprinkling grounds and tennis courts (very often located near a swimming pool), as well as flushing toilets is an easy solution that allows to dramatically reduce the environmental and economic costs (Wyczarska-Kokot, 2016). For instance, just filtering through granular activated carbon removes efficiently free chlorine and DBPs from the water, enabling its use in toilet flushing and other low-level applications (Skibinski *et al.*, 2019). Advance membrane filtration technology, including micro-, ultra- and nanofiltration, offers better outcomes when applied to backwashing waters. As an illustrative example, nanofiltration allowed their toxic properties removal. Ultrafiltration offers an appropriate outcome when combined with flocculation (Łaskawiec *et al.*, 2017a, 2017b). The optimal option is to reintroduce the treated water back to the swimming pool. That can be reached, for instance, by using a combination of ultrafiltration and reverse osmosis, as demonstrated by Reißmann *et al.* (2005). Their study showed that significant water savings could achieve through this methodology.

The improvement of the filter backwashing process constitutes a complementary strategy to the treatments mentioned above. In this case, we aim to reduce the amount of generated wastewater and improve the wastewater quality to decrease the necessity of treatment. This improvement is associated with technological improvements. A recent study of the backwash process in sand filters showed that filter beds composed of coarse sand particles and low filter bed heights produced lower increases in the pressure loss with increasing backwash surface velocity (Christensen *et al.*, 2018). The study highlighted the need of evaluating the filter design, the particle size and the height of the filter layer. These results are particularly applicable in our country since based on ASOFAP data, 94.2% of public swimming pools use sand-filter technology. Alternative technologies to sand filtration may therefore be economically attractive if similar or better removal efficiencies can be achieved. Various alternatives already exist, including precoat filtration technologies, membrane filtration and drum filtration (Christensen *et al.*, 2018). The use of precoated filters improves the backwash process as their use reduces 33.3% of the water loss in practice (Christensen *et al.*, 2018). Membrane filtration has previously been used to treat swimming pool water. The use of ceramic microfiltration (Skibinski *et al.*, 2016) and ultrafiltration (Barbot & Moulin, 2008) are examples. The installation of ultrafine filtration systems also reduces water consumption and allows centres to backwash their pools more efficiently. They are relatively cost-effective to install and cause minimal disruption to centre facilities to install and maintain. Besides, the installation of these systems results in a reduction in the time taken to backwash the pool, less regular backwashing and higher water quality (Hazell *et al.*, 2006). Besides the filtration technology, additional factors may be improved. For instance, the way the filter matrix is rinsed. Different systems include high-pressure water washing, mixed water-air system, or even the substitution of water by compressed air, and should also be evaluated as water use reducing factors. Also, a new aspect related to these systems arises from our fats and grease results. Our data indicate that these hydrophobic compounds do not continuously eliminate, but they liberate from the filter like lumps. Besides, they may persist on the filter as films or avoid the correct separation of filter particles, complicating the optimal matrix washing. Based on this, here we propose that protocols should include emulsifiers and dispersants to liberate those compounds from the filter. The action of such compounds will improve the effectiveness of filter rinsing and probably reduce the amount of water needed. The investigation of these improving alternatives requires the monitoring of the process in all cases.

The objective of filter backwashing is to ensure a correct filtration of the pool water, thus avoiding chemical and biological compound levels that may be hazardous for the users. The limits to backwash discharge in the water or ground have been elaborated on above. However, there is no legislation indicating what levels the backwash water must meet for considering a backwash as correct. It does not even inform which parameters are used to monitor the procedure. For these reasons, we selected several parameters and investigated their evolution throughout the process (Figures 2–6) to establish the suitability of the practices. The levels of most of them are regulated by our legislation (Ministerio de Sanidad Servicios Sociales e Igualdad, 2013) for water quality in the pool basin and used as reference: pH 7.2–8; Turbidity ≤ 5 NFU; Free chlorine 0.5–2 mg L⁻¹; Combined chlorine ≤ 0.6 ; Bromine 2–5 mg L⁻¹; and Cyanuric acid ≤ 75 mg L⁻¹. Based on this data, the only filter backwashing practice which may

be considered as appropriate was that for swimming pool A. The turbidity values for the rest of the pools remained higher than the 5 NFU level after the corresponding backwash time. In the pool B case, the combined chlorine also persisted over the 0.6 level. Detectable changes must be present throughout the analysis to establish the appropriateness of a parameter for monitoring the process. From this premise, and based on our results, the most suitable parameters for filter backwashing monitoring are combined chlorine, ammonium, turbidity and COD. In the design of this research, we were hopeful that the current wash times would be shortened. That would immediately reduce the amount of water loss. Unfortunately, the situation is the opposite: in most cases, the backwashing time was not enough. This situation implies that, with the current procedures, the time must increase. Therefore, the amount of water loss will be even higher. We highlight that, in most cases, the process relates to a fixed quantity of time or water volume (see [Figure 1](#)). However, the backwashing should adapt to the particular situation of the pool at that moment, like parameter levels in the basin pool, quantity of swimmers or last change of filter matrix, to mention a few. The only way to ensure optimal backwashing is the monitoring of the process testing with the appropriate equipment. That was the case in less than 30% of our pools ([Figure 1](#)).

Policymakers must act immediately to reduce this main environmental and economic problem. They should know exactly how much water is lost through these practices. Our study is a valuable starting point, but it should be able to be followed over time. Here we propose to take advantage of the system currently in use called SILOE. This health information system collects data on the characteristics of swimming pools in Spain and the quality of their water, but no information on backwashing. The inclusion of the backwash water generated would be helpful, both for the authorities and the swimming pool managers. The former should encourage the implementation of new technologies with subsidies or similar actions. The data obtained will facilitate decision-making to the latter when investing in more efficient systems. These actions must include both the improvement of the backwashing process and the treatment of the water generated. As stated above, the best option will be the introduction of the treated water into the swimming pool. However, current legislation prohibits the treated water use in swimming pools ([Presidencia de Gobierno, 2007](#)). We propose that, based on scientific evidence, the reuse into the swimming pool should be allowed. That would be following the Circular Economy Strategy of the European Union. The government should also elaborate guides and legislation on water-saving strategies associated with filter backwashing, including water reuse and updates with technological improvements. These guides should also include the parameters and levels for monitoring correct backwashing. Finally, research in this field should be encouraged. In this sense, a scientific swimming pool installation will be available in 2022 thanks to the collaboration between the autonomous government and the University of the Balearic Islands. This facility aims to incentivize research in health, treatments, materials and other issues related to the swimming pools.

CONCLUSIONS

The purpose of this study was to investigate the water loss in filter backwashing in public swimming pools in the Balearic Islands and determine the suitability of current practices. The possible improvement of the process to reduce the associated water loss was the main interest. Our data indicate that the environmental and economic costs of the water loss associated with this practice are very high. Besides, the current filter backwashing practices in our community are insufficient. Therefore, technological advances and alternative or additional processes must be incorporated to improve them. The most suitable parameters for filter backwashing monitoring in these studies are combined chlorine, ammonium, turbidity and COD. Treatment of the generated wastewater by traditional (i.e., sedimentation, coagulation, granular activated carbon filtration) and/or advanced technologies (i.e., membrane filtration) should also be encouraged. All the parties involved in water management must work together for solutions to improve the process. Those include authorities, responsible for the installations, suppliers and consultants.

Policymakers should act at different levels. First, backwash water information must be regularly collected, for instance, through the SILOE system. Second, elaboration of guides on the backwashing process with parameters

and levels determining what a correct backwash is. Third, they should encourage the implementation of new technologies with subsidies or similar actions. Fourth, wastewater treatment should also recommend and support. In this sense, the reuse of treated water in a swimming pool should be allowed based on scientific evidence. And finally, more research in this field is needed.

FUNDING

This research was funded by the Cluster of the Chemical Industry of the Balearic Islands (CliQIB), project ‘PILOTO 1 – RENOVACIÓN’.

ACKNOWLEDGEMENTS

The authors want to acknowledge the staff of installations visited in this investigation for their collaboration. J.M. Matas and J. Puig are also acknowledged for the critical review of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES

- APHA/AWWA/WEF (2005). *Standard Methods for the Examination of Water and Wastewater*, 21st edn. American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC, USA.
- Arendze, S. & Sibiya, M. (2014). *Filter backwash water treatment options*. *Journal of Water Reuse and Desalination* 4(2), 85–91.
- Barbot, E. & Moulin, P. (2008). *Swimming pool water treatment by ultrafiltration-adsorption process*. *Journal of Membrane Science* 314(1–2), 50–57.
- Boucherit, A., Moulay, S., Ghernaout, D., Ibraheem, A., Ghernaout, A. -G., Naceur, M., Messaoudene, N., Aichouni, M., Mahjoubi, A. & Elboughdiri, N. (2015). *New trends in disinfection By-Products formation upon water treatment*. *Journal of Research & Developments in Chemistry* 2015, 1–27.
- Carter, R. A. A. & Joll, C. A. (2017). *Occurrence and formation of disinfection by-products in the swimming pool environment: a critical review*. *Journal of Environmental Sciences (China)* 58, 19–50.
- Christensen, M. L., Klausen, M. M. & Christensen, P. V. (2018). *Test of precoat filtration technology for treatment of swimming pool water*. *Water Science and Technology* 77(3), 748–758.
- Ciorba, D., Tataru, A., Avram, A., Almasi, A. & Moldovan, M. (2015). *Influence of environmental chloroform concentrations on biophysics skin parameters*. *Farmacia* 63(2), 313–317.
- de Deus, F. P., Mesquita, M., Salcedo Ramirez, J. C., Testezlaf, R. & de Almeida, R. C. (2020). *Hydraulic characterisation of the backwash process in sand filters used in micro irrigation*. *Biosystems Engineering* 192, 188–198.
- Deyà Tortella, B. & Tirado, D. (2011). *Hotel water consumption at a seasonal mass tourist destination. The case of the island of Mallorca*. *Journal of Environmental Management* 92(10), 2568–2579.
- Doménech-Sánchez, A., Olea, F. & Berrocal, C. I. (2008). *Infecciones relacionadas con las aguas de recreo (Infections related to recreational waters)*. *Enfermedades Infecciosas y Microbiología Clínica* 26(SUPPL. 13), 32–37.
- Gober, P., Quay, R. & Larson, K. L. (2016). *Outdoor water Use as an adaptation problem: insights from north American cities*. *Water Resources Management* 30, 899–912.
- Hazell, F., Nimmo, L. & Leaversuch, P. (2006). *Best Practice Profile for Public Swimming Pools – Maximising Reclamation and Reuse*. Perth, Western Australia. https://www.water.wa.gov.au/__data/assets/pdf_file/0017/4229/82406.pdf (accessed 22 February 2021).

- Hof, A., Morán-Tejeda, E., Lorenzo-Lacruz, J. & Blázquez-Salom, M. (2018). Swimming pool evaporative water loss and water Use in the balearic islands (Spain). *Water* 10(12), 1883.
- IBESTAT (2020). *Economics-Tourism- Flow of Tourists (FRONTUR)*. <https://www.caib.es/ibestat/estadistiques/economia/turisme/fluxe-turistes-frontur/043d7774-cd6c-4363-929a-703aaa0cb9e0> (accessed 22 February 2021).
- Kent, M., Newnham, R. & Essex, S. (2002). Tourism and sustainable water supply in Mallorca: a geographical analysis. *Applied Geography* 22(4), 351–374.
- Laskawiec, E., Dudziak, M. & Wyczarska-Kokot, J. (2017a). Treatment of pool water installation washings in a flocculation/ ultrafiltration integrated system. *Journal of Ecological Engineering* 18(5), 96–103.
- Laskawiec, E., Madej, M., Dudziak, M. & Wyczarska-Kokot, J. (2017b). The use of membrane techniques in swimming pool water treatment. *Journal of Ecological Engineering* 18(4), 130–136.
- Laskawiec, E., Dudziak, M. & Wyczarska-Kokot, J. (2019). Evaluation of the effect of body fluid analogs on the parameters of nanofiltration during the purification of swimming pool water. *SN Applied Sciences* 1(6), 1–13.
- Lewis, L., Chew, J., Woodley, I., Colbourne, J. & Pond, K. (2015). Modifications for water management guidance based on an assessment of swimming pool water consumption of an operational facility in the UK. *Water Science and Technology: Water Supply* 15(5), 965–973.
- McCormick, N. J., Porter, M. & Walsh, M. E. (2010). Disinfection by-products in filter backwash water: implications to water quality in recycle designs. *Water Research* 44(15), 4581–4589.
- Ministerio de Obras Públicas Transportes y Medio Ambiente. (1996). Real Decreto 509/1996, de 15 de marzo, de desarrollo del Real Decreto-ley 11/1995, de 28 de diciembre, por el que se establecen las normas aplicables al tratamiento de las aguas residuales urbanas. *Boletín Oficial del Estado* 77, 12038–12041.
- Ministerio de Sanidad Servicios Sociales e Igualdad (2013). Real Decreto 742/2013, de 27 de septiembre, por el que se establecen los criterios técnico- sanitarios de las piscinas. *Boletín Oficial del Estado* 244(1), 83123–83135.
- Panyakapo, M., Soontornchai, S. & Paopuree, P. (2008). Cancer risk assessment from exposure to trihalomethanes in tap water and swimming pool water. *Journal of Environmental Sciences* 20(3), 372–378.
- Presidencia de Gobierno. (2007). Real Decreto 1620/2007, de 7 de diciembre, por el que se establece el régimen jurídico de la reutilización de las aguas depuradas. *Boletín Oficial del Estado* 294, 1–22.
- Reißmann, F. G., Schulze, E. & Albrecht, V. (2005). Application of a combined UF/RO system for the reuse of filter backwash water from treated swimming pool water. *Desalination* 178(1–3 SPEC. ISS.), 41–49.
- Rosende, M., Miró, M., Salinas, A., Palerm, A., Laso, E., Frau, J., Puig, J., Matas, J. M. & Doménech-Sánchez, A. (2020). Cost-Effectiveness analysis of chlorine-based and alternative disinfection systems for pool waters. *Journal of Environmental Engineering* 146(1), 04019094.
- Skibinski, B., Müller, P. & Uhl, W. (2016). Rejection of submicron sized particles from swimming pool water by a monolithic SiC microfiltration membrane: relevance of steric and electrostatic interactions. *Journal of Membrane Science* 499, 92–104.
- Skibinski, B., Uhlig, S., Müller, P., Slavik, I. & Uhl, W. (2019). Impact of different combinations of water treatment processes on the concentration of disinfection byproducts and their precursors in swimming pool water. *Environmental Science and Technology* 53(14), 8115–8126.
- Weiyang, L., Yuasa, A., Bingzhi, D., Huiping, D. & Naiyun, G. (2010). Study on backwash wastewater from rapid sand-filter by monolith ceramic membrane. *Desalination* 250(2), 712–715.
- World Health Organization (2005). *Water Recreation and Disease*. World Health Organization, London.
- Wyczarska-Kokot, J. (2016). The study of possibilities for reuse of washings from swimming pool circulation systems. *Ecological Chemistry and Engineering S* 23(3), 447–459.
- Wyczarska-Kokot, J. & Lempart, A. (2018). The reuse of washings from pool filtration plants after the use of simple purification processes. *Architecture, Civil Engineering, Environment* 11(3), 163–170.
- Wyczarska-Kokot, J. & Lempart, A. (2019). The influence of the filtration Bed type in the pool water treatment system on washings quality. *Ecological Chemistry and Engineering S* 26(3), 535–545.
- Zhang, Y., Chu, W., Yao, D. & Yin, D. (2017). Control of aliphatic halogenated DBP precursors with multiple drinking water treatment processes: formation potential and integrated toxicity. *Journal of Environmental Sciences (China)* 58, 322–330.

First received 30 October 2020; accepted in revised form 31 August 2021. Available online 14 September 2021