Anionic surfactants monitoring in healthcare facilities — a case of Belo Horizonte City, Brazil

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Abstract Surfactants are substances that when in aquatic environments can cause negative impacts. Hospital effluents carry numerous chemicals daily, including surfactants, used in sanitization and disinfection procedures. These chemicals are found in the effluents and reach water bodies due to a lack of proper removal in the wastewater treatment plants. The present study investigated data about wastewater monitored from healthcare facilities located in the city of Belo Horizonte, Brazil, focusing on anionic surfactants. The results showed 72 establishments monitoring this parameter, resulting in a median concentration of 1 mg L^{-1} and 2.49 mg L^{-1} mean value of anionic surfactants, between 2007 and 2019. It is also observed in the correlation between surfactants and oils in all healthcare establishment sizes, except for the medium-sized. Although anionic surfactants are the most used in cleaning product formulations, cationic surfactants still do not have specific legislation in the studied country that dictates a limit for discharge into sewage; consequently, they are not routinely monitored in effluents. However, these compounds are used in the formulation of routine hospital products.

Keywords Hospital effluents · Surfactants · Hospitals · LAS · QAC

Introduction

Daily, hospital effluents convey several chemical substances, often without previous treatment. When they reach the wastewater treatment plants, the removal of many chemicals is not always sufficient, thus, several substances can reach aquatic environments and cause damage to the ecosystem, and human health. Given this context, correctly identifying the most critical substances is a strategy to promote more efficient monitoring of liquid effluents generated by healthcare facilities, thinking about strategies for more effective removals, which contribute to the mitigation of the harmful effects on aquatic environments (Al Aukidy et al., 2014; Niemi et al., 2020; Verlicchi et al., 2010).

Surfactant substances are commonly present in hospital effluents. These substances are known for having a polar and a non-polar part, characteristics that make them able to have an affinity with both oil and water, and form micelles in solution (Bergé et al., 2018; Daltin, 2011; Palmer & Hatley, 2018; Tadros, 2013). Because of their properties, these substances are used in the manufacture of soaps and detergents, products frequently used in hospital activities as sanitizing agents due to their solubilizing capacity and detergent action, conferred by the formation micelles (Daltin, 2011; Tadros,

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2013). Among other classifications, surfactants can be mainly of three types: anionic, cationic, or non-ionic, established by the electric charge on the hydrophilic part of its molecule (Daltin, 2011). Depending on the classification, the action of detergents may vary, for instance, by provoking the solubilization of proteins or modifying the structures and activities of enzymes (Panouillères et al., 2007), which can make their treatment process and removal difficult. Some examples of surfactants used in hospitals around the world are shown in Table 1.

In particular, the quaternary ammonium compounds (QACs) are a family of molecules that belong to the group of cationic surfactants, widely used as active products in the manufacture of disinfectants and softeners, due to their high affinity to negatively charged surfaces (Hora et al., 2020) and antimicrobial action, mainly against gram-negative bacteria and lipid membranes of enveloped viruses (Lasek et al., 2019; Pereira & Tagkopoulos, 2019). Therefore, they are very useful in hospital disinfection activities. Their basic structure can be represented by $(R_4N^+)X^-$, and by changing the R groups, several other compounds were developed, expanding their effectiveness and applicability through the inactivation of energy-producing enzymes, denaturation of proteins, and cell membrane breakdown. In the presence of organic matter, soaps, and anionic surfactants can inactivate QACs (Brasil, 2005; Gerba, 2015).

The products containing QACs are a mix of compounds with alkyl chain sizes ranging from C8 to C18, whereby compounds with C12 and C14 exhibit higher biocidal activity (Pereira & Tagkopoulos, 2019). In 2016, the European Union established regulations on the use of biocides derived from QACs, restringing its use in personal care products such as hand and body antiseptics (EU, 2016).

Anionic compounds are widely used in the formulation of household and industrial detergents (Penteado et al., 2006). According to Steber (2007), they are the most used in cleaning products. Linear alkylbenzene sulfonate (LAS) is one of the families in this group. Like the QACs, LAS also composes the formulation of laundry products (Roberts, 2003). Penteado et al. (2006) showed that the presence of these substances in the environment can be harmful to aquatic life and highlighted problems in water bodies such as the decrease in dissolved oxygen, among others.

The Brazilian Federal Standard, Resolution CONAMA nº 357 of 2005 (Brasil, 2005), establishes the standards for the effluents discharged into water bodies. Among the physicochemical parameters, the surfactants monitored, either for fresh, saline, and brackish waters comprise only those that react with methylene blue, a colorimetric analytical technique that allows the determination of anionic surfactants (Brasil, 2005). CONAMA 357 does not include limits for other surfactant groups, such as cationic

Table 1 Surfactants commonly used in hospital environments around the world

Surfactant	Group/family	Hospital application	Reference
Didecyl dimethyl ammonium chloride (DDAC)	Cationic surfactant/quaternary ammonium compounds (QACs)	Antiseptic for skin Surface maintenance Disinfectant detergent for medical instruments, clothing, and operating room fabrics	Lasek et al. (2019) Zhang et al. (2015)
Chlorhexidine digluconate (CHD)	Cationic surfactant/QACs	Biocide Antiseptic for skin and hand preparation for surgery and obstetrics Disinfectant for surgical instruments	Lasek et al. (2019) Karpiński and Szkaradkiewicz (2015)
Bis(aminopropyl)laurylamine (BAPLA)	Anionic surfactant/tertiary amine	Surface maintenance and cleaning of food area and equipment; Antimicrobial: destroys or inhibits the growth of bacteria, minimizing the spread of disease Can be used to impregnate into fabrics Disinfectant detergent for surfaces	Lasek et al. (2019)

surfactants, which means that they are not monitored. Also, as noted by Palmer and Hatley (2018), the wastewater treatment plants do not yet focus on removing surfactants.

Sampling for the determination of cationic surfactants presents problems related to their strong ability to adsorb. Therefore, to keep the compounds of interest available to be determined, a mixture of LAS in chloroform is added immediately after sampling. The chloroform helps to prevent adsorption onto the glass walls, while the LAS forms stable complexes with the quaternary ammonium compounds, transferring them to the organic phase (Martínez-Carballo et al., 2007).

Even though surfactants of the cationic group are not monitored, they can be found in the compositions of detergents and disinfectants used in healthcare establishments in Brazil (Santa Bárbara et al., 2012). Several authors have mentioned the use of QUACs, and their growth in the disinfectant market over the years, around the world (Hora et al., 2020; Kümmerer et al., 1997; Zion Market Research, 2021), which may imply the increase in the concentration of these compounds in hospital effluents.

With the SARS-CoV-2 (COVID-19) crisis there has been a significant increase in the use of disinfectants, and these are used in homes, commercial areas, industry, and public transportation systems (Hora et al., 2020). In healthcare centers, these have always been used throughout the hospital routine due to the range of different types of cleaning and disinfection, procedures, equipment, surfaces, and clothing. Through the continuous use in hospital activities, these organic compounds reach the effluents, being able to react with other substances.

Given the concern of the presence of surfactants in the environment, this study investigated data about the monitoring of liquid effluents from healthcare facilities located in the city of Belo Horizonte, Brazil, focusing on anionic surfactants. It is further emphasized that some groups of surfactants are not monitored due to the current legislation from Brazil.

Methodology

The monitoring data analyzed cover the period from September 2007 to January 2019. The initial database provided contained 395,586 results related to

physicochemical parameters, monitored in 78 healthcare facilities such as hospitals, clinics, and outpatient clinics. Monitoring of the effluent from each establishment was quarterly and covered years vary for each establishment. All the establishments are located in the city of Belo Horizonte, capital of the State of Minas Gerais, Brazil. The data analyzed in this study were provided by the municipal sanitation company, which, to authorize the receiving of non-domestic effluents, such as healthcare establishments, requires the discharge of the effluent following the conditions and limits of physicochemical parameters and biological characteristics (COPASA, 2018). All physicochemical and biological parameters were analyzed related to surfactant presence, using statistical tools.

Initially, the data was pre-processed to be organized and to eliminate inconsistencies and insignificant data. The database was rearranged, and since some parameters were monitored several times a day, such as temperature and pH, the median for these parameters was calculated in the rearrangement. Then the parameters whose amount of data was scarce were discarded. Some parameters had very extreme values that indicated the presence of outliers. These extreme values were removed by using the boxplot where the upper limit of the whisker was calculated to be twenty times the interquartile range. A total of 390 values were considered the outliers, which corresponded to 0.5% of the spreadsheet values. After pre-processing, the data matrix showed a total of 28 parameters (total aluminum, benzene, total boron, total cyanides, total copper, hexavalent chromium, total chromium, BOD, COD, ethylbenzene, total phenols, total iron, total fluoride, oils and grease, total mercury, total nickel, ammoniacal nitrogen, pH, total silver, suspended solids, sedimentable solids, surfactants, sulfates, total sulfide, temperature, toluene, xylenes, total zinc) and 2902 lines (days sampled).

All the samples were analyzed in laboratories that follow the Anionic Surfactants methodology as MBAS 5540 C, (APHA, 2012) Standard Methods for the Examination of Water and Wastewater, 22 or 23rd Edition, and have ISO 17025/2017 accreditation.

After pre-processing, the facilities were divided into three groups. The first group of establishments was allocated as large and university hospitals. In the second group are the medium-sized hospitals, maternity, and orthopedic hospitals, and in the third group were allocated the other establishments (small

hospitals — outpatient clinic and health insurance, day hospital, eye surgery, rehabilitation clinics, clinics, blood centers, hemodialysis, reproductive medicine, nephrology, ophthalmology, oncology, otorhinolaryngology, emergency room, radiology, urology, and psychiatric hospital).

A multiple linear regression model was created with the parameter surfactant substances as the dependent variable and the other 27 parameters as independent variables. All the data analyses, including preprocessing, were performed using the R Language and Environment for Scientific Computing (R Core Team, 2020).

Results and discussions

Parameters identified in the monitored hospital effluents

Table 2 presents the descriptive statistics for the surfactant parameter, being analyzed in the substances that react with methylene blue and LAS (ABNT NBR 10,738:1989, SMWW 5540:2017, ASTM D4251-89:2016, ISO 7875-1:1996/COR 1:2003) (ABNT, 1989; ISO, 2003; D12 Committee, 2016; Baird & Bridgewater, 2018) and monitored in the analyzed hospitals. Since the data do not follow a normal distribution, the median is the best estimator of the central position of the data, and the absolute deviation from the median (MAD) as the data dispersion

estimator. The number of establishments that presented effluent measurements was increasing over the years. In 2007, only one establishment monitored its effluents. In 2018, a total of 72 establishments were performing the same monitoring. For the year 2019, there are data only for January, which explains why there are only 31 establishments for the year.

As observed in Table 2, the median value for the monitored hospitals between 2007 and 2019 was 1 mg L⁻¹ while the mean value was 2.49 mg L⁻¹. When comparing with other studies, a hospital in Istanbul, Turkey, with 780 beds, also found anionic surfactants identified in the raw hospital effluent (Top et al., 2020), ranging from 0.26 to 2.08 mg L⁻¹, and with a mean value of 1.96 mg L⁻¹. Another study in French hospitals found lower values of anionic surfactants, median of 0.40 mg L⁻¹, and a high value in urban effluents: 2 mg L⁻¹ (Wiest et al., 2018).

Selecting variables to be used in the multiple linear regression model, twenty regression models were initially created using random sampling of 50% of the data. For each model, separated sampling was done. Of the 27 independent variables used in the models, only the variables Chromium VI, Chromium, COD, Phenols, and Sulfides were significant in all the models created in this step and were selected as variables for the final regression model. The final regression model was created using 67% of the randomly sampled data. The remaining 33% were used for model validation. Table 3 summarizes the coefficients of the final regression model.

Table 2 Descriptive statistics of surfactant measurements (mg L⁻¹) over the years

Years	Health care facilities	Samples	Mean	SD	Median	MAD	Min	Max	IQR
2007	1	2	1.50	0.83	1.50	0.87	0.918	2.09	0.58
2008	6	18	1.63	0.93	1.54	0.93	0.24	3.26	1.16
2009	20	118	3.05	9.4	1.38	0.97	0.08	80.21	1.28
2010	29	140	2.02	2.6	1.28	1.2	0.0	17.80	1.79
2011	50	258	7.42	65	1.14	0.93	0.0	829.38	1.50
2012	54	292	2.04	2.1	1.50	1.5	0.0	18.10	2.31
2013	54	301	2.07	3.6	1.18	1.4	0.0	45.40	2.11
2014	56	307	1.99	3.7	1.10	1.1	0.0	44.00	2.05
2015	63	335	1.68	2.8	0.997	1.1	0.0	31.00	1.51
2016	66	342	1.81	2.7	0.938	1.2	0.0002	22.40	1.97
2017	71	380	2.71	6.0	0.738	0.94	0.0	49.20	1.81
2018	72	378	1.52	2.7	0.500	0.59	0.0	22.75	1.36
2019	31	31	1.05	1.4	0.680	0.76	0.0	6.96	0.96
All	78	2852	2.49	19.8	1.00	1.1	0	829.38	1.84

SD standard deviation, MAD median absolute deviation, Min minimum value, Max maximum value, IQR interquartile range

Table 3 Coefficients of the final regression model

	Estimate	Std. dev	Error	p value*
(Intercept)	0.790	0.12	6.8	1.08×10^{-11}
Chrome VI	10.1	1.4	7.4	1.47×10^{-13}
Chromium	-6.16	1.4	-4.4	1.33×10^{-5}
COD	0.00251	0.00022	12	$< 2.00 \times 10^{-16}$
Phenols	-0.635	0.22	-2.9	0.00399
Sulfide	0.991	0.13	7.5	7.18×10^{-14}

Std. dev. standard deviation

*significant values when $p < 0.05$

The regression model had an adjusted R^2 of 0.1446. The standard error of the model residuals was 2.879, which corresponds to a coefficient of variation of 1.48. For the validation data, the R^2 was 0.1418, and the standard error of the residuals was 2.786, which are similar values to the values obtained for the regression model, which showed the validity of the model.

In the final regression model, positive correlations were found for the variables Chromium VI, COD, and Sulfides, as presented in Table 2, suggesting a high value of these parameters associated with high value of surfactants. Considering negative correlations, Chromium and Phenols, the lower these parameters, the higher the value of the surfactants. The presence of surfactants in effluents could lead to an increase in COD values, and the positive correlation presented in Table 2 confirmed this hypothesis. In the presence of surfactants, the phenol could be solubilized in the micelles, and cations ($M2+$ and $M3+$) promoted the capture of these micelles, corroborating the negative correlation. These cations are present in the hospital wastewaters (Cavalcante et al, 2018; Sultana, et al., 2021). Sulfites can be formed in the degradation of bacteria.

Surfactant concentrations identified in the literature

The effluents generated in hospital laundries present different characteristics from the others, due to the high volume of water and great complexity, such as the presence of different classes of surfactants and detergents, besides the high microbial and viral load, pharmaceuticals and common parameters in all the effluents (Kern et al., 2015; Lutterbeck, Colares, et al., 2020; Lutterbeck, Machado, et al., 2020; Zotesso et al.,

2017). Table 4 presented the surfactant concentrations of studies conducted in countries such as France, Switzerland, and Turkey. In the survey conducted by Lutterbeck, Machado, et al. (2020), Lutterbeck, Colares, et al. (2020), treatment processes and toxicity of influents and effluents from the laundry of a 180-bed hospital, which generates 150 m^3 of effluent daily, were evaluated. Of this volume, 33% is produced in the hospital laundry. The mass balance of the laundry products used in each step of the process was performed, obtaining the following values for consumption of 6.3 m^3 of water: nonyl-phenol ethoxylate: $43.7 \text{ } \mu\text{g L}^{-1}$; sodium hydroxide: $220 \text{ } \mu\text{g L}^{-1}$; hydrogen peroxide: $190 \text{ } \mu\text{g L}^{-1}$; quaternary de ammonium compounds: $63.5 \text{ } \mu\text{g L}^{-1}$; and sodium bisulfite: $31 \text{ } \mu\text{g L}^{-1}$. The acute ecotoxicity tests, with *Daphnia magna*, revealed, for the raw effluent, extreme toxicity ($\text{EC}_{50} 24.5\%$). After undergoing effluent treatments, a 100% EC_{50} was obtained, indicating non-toxicity (Lutterbeck, Colares, et al., 2020; Lutterbeck, Machado, et al., 2020). In 2015, Kern and collaborators also analyzed the laundry effluent from the same hospital and identified the following surfactants: lauryl ethoxylate, benzoic acid, n-(4-aminophenyl)-n-methylacetamide, 2-(diethylamino)-n-(2,6-dimethylphenyl)-acetamide, and methyl-m-(1-methylbutyl) phenyl ester, by gas chromatography.

In the study of Lasek et al. (2019), effluents from a French university hospital, whose water consumption corresponds to 482 L/bed , were analyzed through the collection of samples carried out in campaigns between the years 2016 and 2017. The authors observed the concentrations of three substances that have detergent-disinfectant actions, the CHD, DDAC, and BAPLA, in 3 isolated collection points, as well as at the point of confluence between all the effluents. The concentrations in mg L^{-1} observed for the sampling campaigns are expressed in Table 4. In the research by Kovalova et al. (2012), the authors analyzed the effluent from a Swiss hospital to evaluate the removal of micropollutants and disinfectants.

In a Brazilian research, Kern (2015) quantified 2.22 mg L^{-1} of anionic surfactants in the raw water generated in the laundry of the hospital studied. Souza (2018) also studied the final effluent of a hospital, with 840 beds, before being released into the wastewater collection system, finding 4.96 mg L^{-1} of anionic surfactants. When comparing these data with

Table 4 Concentrations of surfactants detected in hospital effluents

Surfactants	Place sampled	Concentration (mg L ⁻¹)	Source
DDAC	Oncology, laundry, cardiology, geriatrics, pulmonology, main pharmacy	1.52–3.25	Lasek et al. (2019)
	The main building of the hospital: medical clinic, operating rooms, endoscopy, and intensive care units	0.93–2.33	
CHD	Oncology, Laundry, cardiology, geriatrics, pulmonology, main pharmacy	0.027–0.056	
	The main building of the hospital: medical clinic, operating rooms, endoscopy, and intensive care units	0.031–0.097	
BAPLA	Oncology, Laundry, cardiology, geriatrics, pulmonology, the main pharmacy	0.031–0.097	
	The main building of the hospital: medical clinic, operating rooms, endoscopy, and intensive care units	0.018–0.093	
Anionic	Median concentrations for the sampling campaigns conducted from 2013 to 2015	0.4	Wiest et al. (2018)
Cationic		1.1	
Nonionic		4.9	
Anionic	Raw hospital wastewater	4.55×10^{-4}	Buelow et al. (2020)
	Treated hospital effluent	3.57×10^{-5}	
Cationic	Raw hospital wastewater	5.51×10^{-4}	
	Treated hospital effluent	1.28×10^{-4}	
Nonionic	Raw hospital wastewater	6.27×10^{-3}	
	Treated hospital effluent	3.155×10^{-5}	
Anionic	Average sample in 24 h	< 0.01	Boillot et al. (2008)
Cationic		5.0	
Glutaraldehyde		0.0021	
Nonionic		2.9	Perrodin et al. (2013)
Anionic, upstream and downstream of hospital effluent discharge from February to May 2011	Arve River	< 0.10	
	Hospital effluent	< 0.05	
Cationic, upstream and downstream of hospital effluent discharge from February to May 2011	Arve River	< 0.4	
	Hospital effluent	< 0.4 e 1	
Nonionic, upstream and downstream of hospital effluent discharge from February to May 2011	Arve River	< 2	
	Hospital effluent	16.8 e 17.9	
Nonionic	Raw hospital effluent	4.24 a 19.95	
	Effluent after HWW	< 0.01	Perrodin et al. (2016)
Anionic	Raw hospital effluent	< 0.05 a 0.24	
	Effluent after HWW	< 0.05	
Cationic	Raw hospital effluent	< 0.4	
	Effluent after HWW	< 0.4	Kovalova et al. (2012)
QAC BAC C12-18	-	0.049	
BAC C12	-	0.034	
DDAC-C10	-	0.102	

Table 4 (continued)

Surfactants	Place sampled	Concentration (mg L ⁻¹)	Source
Anionic	Average	1.96	Top et al. (2020)

our study, Belo Horizonte hospitals showed median values were significantly lower.

In the study of raw hospital effluents in France, Wiest et al. (2018) found 0.4 of anionic surfactants, with a maximum value of 9.6 mg L⁻¹. Hospital effluent samples in Turkey indicated a range of 0.26 to 10.8 mg L⁻¹ of anionic surfactants (Top et al., 2020). Perrodin et al. (2016), also in France, identified non-ionic substances in the raw effluents about 17 mg L⁻¹, and good removal efficiency after wastewater treatment system was implemented.

Through the statistical analyses developed, correlations were observed between the surfactants and other physicochemical parameters found in the monitored effluents of small, medium-sized, and large healthcare establishments (Table 5), in which the highest correlations observed originated in the effluents from the large establishments. The correlation of surfactants with oils was observed in all healthcare establishment sizes, except for the medium-sized. The oils may originate from the effluents from the kitchen of the healthcare establishment's facilities. The correlation of surfactants with this parameter may be linked to their solubility in lipids, characterized by the hydrophobic part present in the structure of these organic compounds (Nakama, 2017).

The current Brazilian legislation that dictates the conditions and standards for effluent discharge includes only the limits for anionic surfactants. The “Deliberação Normativa Conjunta” COPAM/CERH-MG n° 01, of May 5th, 2008 (Minas Gerais, 2008),

legislation in force in the State of Minas Gerais, Brazil, establishes the conditions and standards for effluent discharge into surface waters. For the organic parameters, which include surfactants that react with methylene blue, the limit set for discharge, except for public treatment systems, is 2.0 mg L⁻¹ of LAS (Minas Gerais, 2008). Regarding the quality standards for surface water, both in the state and federal legislation, CONAMA 357/2005, the maximum value to be maintained is 0.5 mg L⁻¹ of LAS. The “Companhia de Saneamento do Estado de Minas Gerais — COPASA” defines the limits for the discharge of non-domestic effluents into the public collecting system, through Technical Standard T.187/6, in which the expected concentration allowed for surfactant substances is 5 mg L⁻¹ (Copasa et al., 2018).

Cationic and non-ionic surfactants do not yet have specific legislation for effluent discharge into sewage, consequently into surface waters (Brasil, 2005; de Sousa et al., 2012; Jesus et al., 2013; Lasek et al., 2019). They have been detected in influent and effluent as well as in sludge samples from wastewater treatment plants. The WWTPs partially remove the QACs, and thus these compounds reach the environment. The action of microorganisms presents in the water body and natural photodegradation is slow, leading to an increase of these compounds in both waters and sediments (Pati & Arnold, 2020). The attenuation mechanisms of these compounds in aquatic environments are slow photolysis and biodegradation, in addition to sorption on suspended materials, which

Table 5 Correlations observed between anionic surfactants with other parameters monitored in small to large-sized healthcare establishment effluents

Grouping/ parameter	Aluminum	Ammonium	Boron	BOD	COD	Phenols	Nickel	Sulfide	Oils
All	-	-	-	-	-	-	-	-	***
Large	**	***	*	-	***	***	***	***	***
Medium	-	-	-	-	-	-	-	-	-
Small	-	-	-	**	**	-	-	-	***

BOD biological oxygen demand, *COD* chemical oxygen demand

***: 0.0001 (*p*-value); **: 0.001 (*p*-value); *: 0.01 (*p*-value)

can sediment (EPA, 2006), causing persistence. They are also found adsorbed on sludge from aerobic and anaerobic processes. A total of 167 mg kg⁻¹ of total QACs were found in sewage sludge in Guangzhou, China (Li et al., 2014). The sludge from 52 WWTPs scattered across China was analyzed, seeking to identify the presence of adsorbed QACs. In the analyses of alkyl trimethyl ammonium, benzyl alkyl dimethyl ethyl ammonium, and dialkyl dimethyl ammonium homologues by LC MS/MS, the concentration range data found were 0.38–294 µg g⁻¹, 0.94–191 µg g⁻¹, and 0.64–343 µg g⁻¹, respectively (Ruan et al., 2014). Chlorhexidine digluconate (CHD) showed toxicity in aquatic organisms, the lowest toxicity being to algae *Pseudokirchneriella subcapitata* (41.3 µg L⁻¹, EC50, 24 h) and to *Vibrio fischeri* 3675.2 µg L⁻¹, EC50 after 5 min assay (Jesus et al., 2013).

Available analytical methodologies to identify and quantify different surfactants

The analytical methodologies for the determination of surfactants in environmental samples have grown over the years in the world, but their implementation in the control of their release into the environment is still slow. This can be attributed to the process and the investments in equipment and standards for certification. The great diversity of compounds and metabolites can contribute to the complexity of this problem.

For environmental samples, anionic surfactants have well-established methods, such as the spectrophotometric method, which determines the active substances that react with methylene blue, the compounds derived from LAS, which was used to determine surfactants in the samples of this study. For the determination of non-ionic surfactants in environmental samples, the cobalt thiocyanate reacting substances method (SMWW 5540:2018), and the method using Dragendorff reagent (ISO 7875–2:1984) (ISO, 1984) have been used. Regarding cationic surfactants, instrumental analytical methodologies have been used, such as HPLC, LC MS, LC MS/MS, with higher costs involved in the acquisition of equipment and supplies. Moreover, analytical standards are required in addition to the metabolites formed, which are not always available for purchase. It also involves the pre-treatment of liquid and solid samples, from the collection and preservation until the solid phase

extraction, its recovery, and the validation of the methodology (Paijens et al., 2020).

Physicochemical characteristic of healthcare establishment effluents and their contribution to the discharge of surfactants in the sewage system and related impacts

The effluents from the laundry of the Regional University Hospital of Maringá, in the state of Paraná (Brazil) showed 130 mg L⁻¹ and 240 mg L⁻¹ of BOD and COD, respectively. Products are used in the different stages of the process, being basically cationic surfactants (Furtado et al., 2020). In that study, the effects of cytotoxicity were investigated with *Allium cepa* L., with the effluents from each step of the process, and after treatment by a physicochemical process, and this one, associated with UV/H₂O₂ processes. That effluent showed to be cytotoxic by inhibiting the cell division of *Allium cepa* L. (Furtado et al., 2020). When investigating the efficiency of hospital effluent treatment using UV photocatalysis and ozonation, Souza et al. (2018) were able to remove surfactants from the effluent generated by an 840-bed hospital in Porto Alegre, Brazil. The initial concentration of anionic surfactants was at 4.96 mg L⁻¹, reduced to 4.25 mg L⁻¹ after the coagulation process, and after the application of O₃/UV treatment, they found 0.218 mg L⁻¹ and a reduction of total organic carbon by 54.7% (Souza et al., 2018).

Surfactants and their degradation products have been found in several concentrations in effluents, treated sludge, surface water, solids, sediments, among others, offering risks to the environment (Olkowska et al., 2014; Ying, 2006). In Brazil, detergents can still contain phosphorus in their composition, a nutrient that contributes to the eutrophication phenomenon. Von Sperling (2014) explains that up to 50% of the phosphorus found in domestic sewage may originate from detergents (Von Sperling, 2014). According to Panouillères and collaborators (2007), detergents and disinfectants are among the main substances that cause toxicity to aquatic species. The toxic effects to the biotic community have been discussed in the literature and differ according to the organism and the concentration to which it is exposed.

Wang et al. (2015) studied the effects caused by anionic, cationic, and non-ionic surfactants on embryos

and larval stage of zebrafish. The authors identified results as delayed embryo development and changes in larval locomotion activities. Lechuga et al. (2016) reported the toxicity of surfactants on *Daphnia magna*, luminescent bacteria, *Vibrio fischeri*, and freshwater and saltwater microalgae. The results show that *Vibrio fischeri* exhibited the highest sensitivity to the surfactants tested, although the other organisms were also affected to a lesser extent. Boillot and Perrodin (2008) showed the combination of glutaraldehyde with surfactants (anionic, cationic, and nonionic), both used in hospital routines, and their toxic effects related to the mobility of *Daphnia magna*. Other authors have studied the toxic effects of surfactants and combinations with these compounds, to *Daphnia magna* (Emmanuel et al., 2005; Hodges et al., 2006; Lechuga et al., 2016). Nałecz-Jawecki et al. (2003) analyzed the toxicity of QACs on *Vibrio fischeri*, ciliated protozoa, and *Artemia franciscana*. The authors concluded that these compounds showed toxicity to all organisms tested.

Finally, as presented by Lutterbeck, Machado and colleagues (2020), hospital laundry wastewater can pose negative impacts to human and environmental health, and this topic is rarely discussed in the scientific literature, when discussing the treatment of these effluents. Also, treatment alternatives did not show a complete solution to the toxic effects of this effluent. In this context, concepts as cleaner production and zero waste are important to reduce the quantity of surfactants in the wastewater and, consequently, reducing the toxicity of effluents generated by healthcare facilities. Changing the process with the same hygiene security procedure represents an opportunity in this context.

Conclusions

Hospital effluents have a different composition than domestic effluents. The use of the municipal sewer system to release hospital effluents can result in interactions between compounds present in the two types of effluents, which can lead to undesired reactions, such as the bioavailability of the compounds modifying the final toxicity. This study showed an increase in healthcare establishment number monitoring anionic surfactants in their effluents. Although anionic surfactants are the most used in

cleaning product formulations, cationic surfactants are also found in daily hospital routine products. In Brazil, the current legislation for effluent discharge standards does not mention this group of surfactants, which may have biocidal properties.

Due to the number of compounds used in the hospital routines, monitoring must be sufficient to ensure that hazardous substances do not reach and harm the environment. Therefore, the importance of monitoring surfactants in hospital effluents is highlighted, since the presence of these compounds and their degradation products, carried daily in their effluents, eventually reach water bodies, and may impact organisms and the environment. The management of daily products to guarantee the zero waste of surfactants and maintaining the hygiene quality is an important perspective to consider in hospital decisions.

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Declarations

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