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Review

Human and environmental impact of chemical agents used for cleaning, antisepsis, disinfection ad sterilization in healthcare facilities. A semi-qualitative study among medical institutions of Puglia and Basilicata, southern Italy

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Abstract. *Background and Aim:* The widespread use of of chemical agents used for cleaning, antisepsis, disinfection ad sterilization has raised concerns about their potential human and environmental toxicity. As these substances are dispersed in diverse environments, they interact with ecosystems and natural elements, potentially leading to ecological consequences. Moreover, they may pose toxic effects on human health — such as skin irritation, eye damage, or inhalation risks. The careful management of chemical agents in healthcare settings plays a crucial role, embodying the principles of sustainability and responsible healthcare. Our study aims to identify the types of chemical products in use, their chemical compositions, and their potential human and environmental impacts. *Methods:* This semi-qualitative, cross-sectional study focused on the characteristics of chemical products used in healthcare facilities in Puglia and Basilicata, southern Italy. From June to July 2023, we requested the list of these products from the health directorates of major healthcare facilities in the two regions. Two researchers analyzed the available safety data sheet for the extracted products. Stata MP18® was used for statistical analysis. Variables were expressed as frequencies and proportions. The chi-square or the Fisher's exact tests were used to compare categorical variables between groups. A two-sided p-value < 0.05 was considered statistically significant for all tests. *Results:* Four of 7 healthcare facilities inquired gave the documents and the sample is representative for all Puglia and Basilicata healthcare facilities. Among the 72 chemical agents analyzed, a concerning observation emerged. Data on the toxicity related to human exposure were not reported for 35.9% of them. Information on environmental impact and toxicity data was missing for 27.8% of the products. *Conclusions:* The integration of health, safety, and environmental is crucial for the sustainable and high-quality development of human society. The sustainable and responsible use of chemical agents requires a holistic approach that considers both human safety and environmental well-being. Adopting solutions that prioritize public health and environmental sustainability is imperative for a healthier and resilient future. The lack of information on the potential impact of these products raises alarms, especially considering the urgency of addressing global environmental concerns. (www.actabiomedica.it)

Key words: SARS-CoV-2, chemical agents, healthcare facility, management, resources, green hospital, climate change, bio-hazard, toxicity, environment

Introduction

The extensive use of chemical agents has become a hallmark of public health and hygiene efforts, particularly within healthcare facilities. These formulations, designed to eliminate harmful microorganisms and reduce the spread of infections, have played a pivotal role in safeguarding patient well-being (1). Chemical products, while indispensable in healthcare, have a far-reaching impact that extends beyond the confines of medical institutions. They are deployed in schools, public transportation, households, and industrial sectors, contributing to a broader environmental footprint. In particular, the COVID-19 pandemic prompted a coordinated response from local authorities, governments, and public health institutions worldwide aimed at implementing effective preventive measures (2). These measures included a range of non-pharmaceutical interventions such as handwashing, mask-wearing, and social distancing (2). The emphasis on hand hygiene and regular surface decontamination intensified disinfection efforts in healthcare settings, public facilities, communal spaces, and households. Consequently, there was a significant and unprecedented surge in the use of chemical agents globally (3). For instance, Choi K et al. (4) observed increased handwashing frequency and the use of hygiene products like hand antiseptics and soaps in South Korea, comparing the pre- and post-COVID-19 eras. Moreover, a 2020 study documented an exponential rise in the demand of chemical agents to the extent that producers and manufacturers struggled to meet the overwhelming market requirements, particularly during the initial phases of the pandemic (5). The increasing ubiquity of chemical products use, not only in hospitals but also in many other settings, has brought concerns regarding their potential environmental toxicity (1). As these products are disseminated across various environments, they interact with ecosystems and natural elements in intricate ways, potentially engendering unforeseen ecological consequences. Chemical agents' heightened use threatens aquatic ecosystems by directly destroying plants' cell walls, or they can bond with other materials to form harmful compounds (6). Furthermore, the overuse and misuse of these formulations have led to an increase in antimicrobial resistance (7). Residues of chemicals present on surfaces can become airborne, potentially leading to a decline in indoor air quality; this deterioration in air quality can have adverse effects, particularly for individuals with asthma, allergies, or heightened sensitivities (8). Additionally, the entire lifecycle of these products, from production to disposal, raises complex issues regarding chemical composition, environmental persistence, and waste management (9). Nason SL et al. (10) qualitatively identified increasing concentrations of disinfectants in environmental matrices (or environmental compartments), including in sewage sludge, during the early stages of the COVID-19 pandemic, reflecting the heightened usage of chemical disinfectants. The need to balance effective infection control and environmental protection has never been more relevant as the scientific community grapples with these intricacies, there is an imperative to comprehensively examine the environmental toxicity risks linked to the widespread use of chemical agents. Within a "green hospital" framework, the meticulous handling of chemical products in healthcare settings assumes a pivotal role (11). The conscientious management of these in hospital facilities embodies the principles of sustainability and responsible healthcare. This multifaceted approach serves the dual purpose of safeguarding patient and healthcare worker well-being and ensuring the sustainability of the hospital's internal environment and the surrounding ecosystem. It involves implementing sound waste management practices and ensuring that the disposal of used products and related materials adheres to stringent environmental standards. Furthermore, an equally critical facet of this strategy revolves around procuring chemical formulations with the lowest conceivable levels of environmental toxicity. The careful selection of these agents reflects a commitment to minimizing the ecological footprint of healthcare activities. In this context, Green Public Procurement (GPP) is an environmental policy tool aimed at promoting the development of a market for products and services with reduced environmental impact through the lever of public demand. It plays a crucial role in achieving the objectives of vital European strategies, such as those related to resource efficiency and the Circular Economy (12). GPP in the healthcare sector is a strategic approach aimed at reducing environmental impact and promoting sustainability in procuring and managing healthcare supplies and services. GPP in healthcare is a significant step toward creating eco-friendly and environmentally responsible healthcare facilities. GPP practices include selecting suppliers and products that comply with stringent environmental regulations, purchasing low-impact medical devices, optimizing water and energy resources, implementing sustainable waste management, and promoting clinical practices and therapies that reduce environmental impact. These actions contribute to pollution reduction and operational cost savings and enhance overall healthcare quality (13). Although the subject is of considerable contemporary relevance, there is a distinct lack of studies specifically aimed at identifying and assessing the types of chemical agents employed in hospital environments. Noteworthy, however, are observations regarding the application of ozone as an environmentally sustainable disinfectant during the COVID-19 pandemic (14), suggesting promising avenues for eco-friendly sanitation technologies. At the same time, concerns have been raised that the prolonged and excessive use of conventional biocides may contribute to the growing problem of antimicrobial resistance in healthcare settings. This underscores the urgent need to investigate alternative disinfection strategies that are both effective and less detrimental to the environment (15). A recent review highlights the presence of pollutants in hospital wastewater and evaluates their ecotoxicological impact, thereby offering a complementary perspective to the debate. It reinforces the necessity of developing realistic and sustainable environmental management policies for healthcare institutions, including the substitution of hazardous chemical products with less polluting alternatives (16). This semi-qualitative study seeks to address these critical issues by focusing on the characteristics of chemical products employed in healthcare facilities in Puglia and Basilicata, southern Italy. In those regions, the procurement of these formulations for public healthcare facilities is conducted by the local health authorities, covering all hospitals within the provincial area. This procurement process typically involves predefined requirements and price assessments through tendering procedures. However, the environmental impact is expected not to be evaluated during this process.

Methods

This is a cross-sectional study that employed a semi-qualitative approach. Between June and July 2023, we requested the formulary of detergents, antiseptics, disinfectants and sterilants used in healthcare facilities from relevant authorities (17). In the public healthcare sector, procurement occurs under regional contractual agreements, resulting in the uniform use of the same products across all public hospitals in the region. Conversely, private healthcare facilities acquire their products through independently conducted tenders. To ensure geographic and institutional representativeness, we contacted the local health authorities (ASLs) of Bari, Barletta-Andria-Trani, Foggia, Lecce, and Taranto in the Apulia region, and Matera in the Basilicata region. The sample comprised institutions delivering both acute and long-term care. Specifically, the request encompassed the formularies adopted by first-level hospitals (e.g., "Vito Fazzi" Hospital of Lecce), second-level hospitals (including the University Teaching Hospital Consortium "Giovanni XXIII" of Bari and the University Teaching Hospital "Policlinico Riuniti" of Foggia), and accredited private institutions, such as the Scientific Institute for Research, Hospitalisation and Healthcare (IRCCS) "Casa Sollievo della Sofferenza" in San Giovanni Rotondo, the National Institute of Gastroenterology (IRCCS) "S. De Bellis" in Castellana Grotte, and IRCCS "Maugeri" of Bari, the latter specialised in long-term care. The Matera Health Authority (ASM Matera) in the Basilicata region was also included. It should be specified that the General-University Hospital Policlinico of Bari is the largest hospital in Puglia, with 1,000 beds, 70 wards, and 7,000 healthcare workers. Therefore, the data from Policlinico of Bari are applicable to all the Local Health Authorities in the Puglia region, as the procurement specifications are centralized at the regional level. The documentation request included the list of products that had won the procurement contract, the formularies used within the hospital facilities, and the technical data sheets of the products listed in the formularies. All commercial names of the chemical agents were extracted from the provided lists, and duplicate products were excluded. Two researchers analyzed the available safety data sheet for the extracted products. The information reported in the safety data sheets was classified using the EC Regulation 1272/2008 (18). This regulation introduced Hazard Statements (H Phrases) on labels, indicating the nature of the hazard of chemicals and mixtures. Each researcher compiled a form available in excel, documenting, for each chemical product, the active ingredient(s), the category of use (cleaning and/or -antisepsis of intact skin, cleaning and/or disinfection of environments and surfaces, cleaning and/or antisepsis of injured skin or mucosae, cleaning, disinfection, and sterilization of medical devices and equipment, and mixed-use), and their human and environmental hazard profile. This evaluation was based on the Green Public Procurement criteria (12), assessing toxicity (carcinogens, mutagens, reproductive hazards), endocrine-disrupting chemicals, neurotoxicity, allergenicity/asthmagenicity, sensitization, skin and eye irritation, persistence, bioaccumulation, and toxicity to aquatic organisms (both acute and chronic). Additional considerations included the recyclability or compostability of packaging, the use of refillable bottles, and disposal methods (hazardous waste vs. regular waste). These variables were expressed as categorical variables, indicating whether the safety data sheet included that specific information and, if so, whether it had that profile or not. Any discrepancies were resolved through consensus between the two researchers. Subsequently, both quantitative and qualitative analyses were performed. In the qualitative analysis, we reviewed the characteristics of the active ingredients of the chemical agents under analysis, with a primary focus on the human and environmental hazard profile as reported in the safety data sheets. The information reported in the aforementioned standardized form was analyzed in the quantitative analysis, and the categorical variables were expressed as frequencies and proportions. The chi-square or the Fisher's exact tests were used to compare categorical variables between groups. A two-sided p-value < 0.05 was considered statistically significant for all tests.

Results

Quantitative analysis

Four of 7 healthcare facilities gave the documents, 1 of second-level hospitals - University Teaching Hospital Consortium "Giovanni XXIII" of Bari- 1 of the accredited private institutions, the Scientific Institute for Research, Hospitalisation and Healthcare (IRCCS) "Casa Sollievo della Sofferenza" in San Giovanni Rotondo (756 beds, annually, it manages an average of 32,551 admissions and 922,655 outpatient procedures), the accredited private institution for long-term care, IRCCS "Maugeri" of Bari (48 beds), and ASM Matera (the combined bed capacity across the facilities amounts to 555 beds). Out of the 72 antiseptics, detergents, disinfectants and sterilants analyzed, a concerning observation emerged as 8 (11.1%) products were characterized by an inappropriate documentation of safety data. Out of these 72chemical products, 19 (26.4%) were utilized for cleaning and/or antisepsis of intact skin, 13 (18.1%) for the cleaning and/or disinfection of environments and surfaces, 4 (5.6%) for cleaning and/or antisepsis of injured skin or mucosae, and 29 (40.3%) for cleaning, disinfection, and sterilization of medical devices and equipment. Seven (9.7%) products fell into a mixed category of use, with 4 being used both for cleaning and/or antisepsis of intact skin and injured skin or mucosae, and 3 for the cleaning and/or disinfection of environments and surfaces, as well as for cleaning, disinfection, and sterilization of medical devices and equipment. The toxicity data concerning human exposure is graphically described in Figure 1, which provides a comprehensive overview of the potential risks associated with the use of these chemical agents on human health. On average, 35.9% (25/72) of the analyzed products did not include or report any information about their potential toxic effects on human health — such as skin irritation, eye damage, inhalation risks, or other safety hazards related to human exposure.

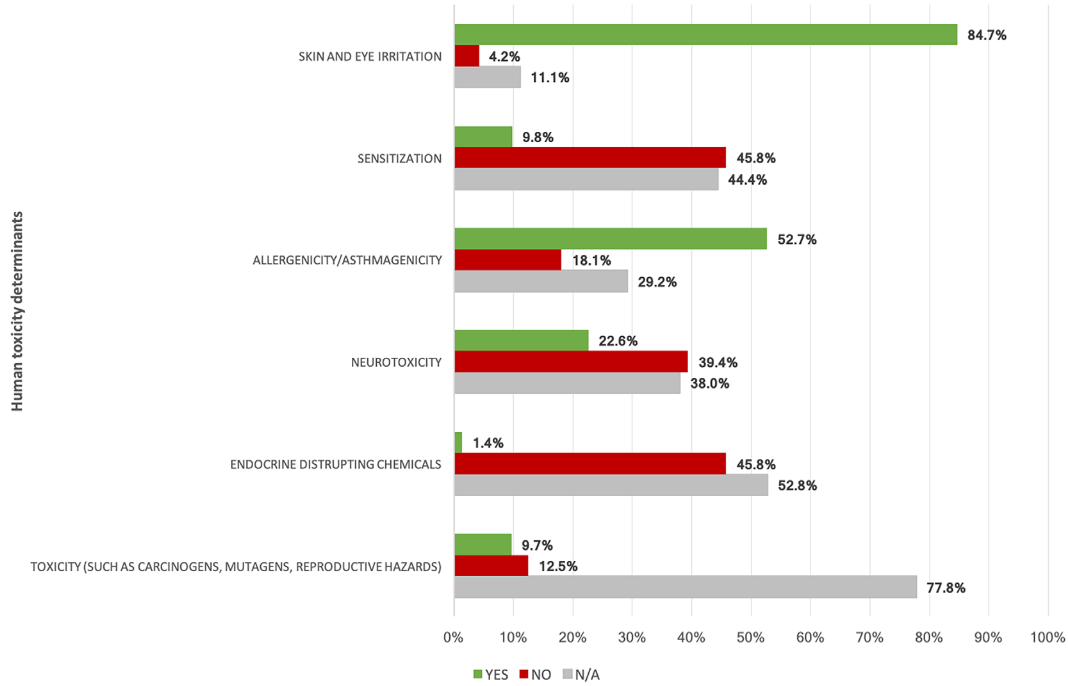

Figure 1. Human toxicity profile of the 72 analyzed chemical products for cleaning, antisepsis, disinfection and sterilization.

The toxicity data concerning human exposure by category of use is described in Table 1.

The environmental impact and toxicity data are detailed in Figure 2, shedding light on the potential consequences of these products on the ecosystem. On average, 27.8% (20/72 -) of the analyzed products did not provide information about their environmental impact such as acute and chronic aquatic toxicity, persistence of bio accumulative and toxic substance, reusability of bottles, waste disposal or recyclable packaging.

The toxicity data concerning environmental exposure by category of use is described in Table 2.

Qualitative analysis

The toxicity characteristics of the active principles of the analyzed products are described in table 3, as reported in their respective safety data sheets. Among the 72 chemical agents analyzed, an average of 31.9% of the products lacked crucial information regarding either their environmental impact (e.g., aquatic toxicity, bioaccumulation, packaging sustainability) and/or their potential toxic effects on human health. This average reflects the overlap between the 35.9% of products lacking environmental data and the 27.8% lacking health-related toxicity data.

Discussion

Our investigation into the toxicity profiles of chemical agents for cleaning, antisepsis, disinfection and sterilization has revealed significant gaps in human and environmental safety information, with an average of a notable 31.9% of products lacking environmental data (35.9%) and/or health-related toxicity data (27.8%) among 72 products analysed. This critical deficiency poses a considerable challenge in comprehensively assessing the risks associated with these widely-used products. This absence of information raises significant questions about the transparency and accountability of these particular products in ensuring user safety. The human toxicity profile is concordant

Table 1. The human toxicity profile of the analyzed detergents, antiseptics, disinfectants and sterilants, by use category.

	Cleaning and/or antisepsis of intact skin (n=19)	Cleaning and/or disinfection of environments and surfaces (n=13)	Cleaning and/or antisepsis of injured skin or mucosae (n=4)	Cleaning, disinfection, and sterilization of medical devices and equipment (n=29)	Mixed-use (n=7)	Total (n=72)	p-value
Skin and eye irritation							
N/A	4 (21.1%)	0 (0.0%)	0 (0.0%)	2 (6.9%)	2 (28.6%)	8 (11.1%)	0.192
No	0 (0.0%)	2 (15.4%)	0 (0.0%)	1 (3.5%)	0 (0.0%)	3 (4.2%)	
Yes	15 (78.9%)	11 (84.6%)	4 (100.0%)	26 (89.6%)	5 (71.4%)	61 (84.7%)	
Sensitization							
N/A	12 (63.2%)	8 (61.5%)	0 (0.0%)	10 (34.5%)	2 (28.6%)	32 (44.4%)	0.068
No	6 (31.6%)	4 (30.8%)	2 (50.0%)	17 (58.6%)	4 (57.1%)	33 (45.8%)	
Yes	1 (5.3%)	1 (7.7%)	2 (50.0%)	2 (6.9%)	1 (14.3%)	7 (9.7%)	
Allergenicity/asthmagenicity							
N/A	9 (47.4%)	4 (30.8%)	0 (0.0%)	6 (20.7%)	2 (28.6%)	21 (29.2%)	0.558
No	3 (15.8%)	2 (15.4%)	1 (25.0%)	5 (17.2%)	2 (28.6%)	13 (18.1%)	
Yes	7 (36.8%)	7 (53.8%)	3 (75.0%)	18 (62,1%)	3 (42.8%)	38 (52.7%)	
Neurotoxicity							
N/A	7 (36.8%)	6 (50.0%)	2 (50.0%)	10 (34.5%)	2 (28.6%)	27 (38.0%)	0.718
No	5 (26.4%)	4 (33.3%)	2 (50.0%)	14 (48.3%)	3 (42.8%)	28 (39.4%)	
Yes	7 (36.8%)	2 (16.7%)	0 (0.0%)	5 (17.2%)	2 (28.6%)	16 (22.6%)	
Endocrine disrupting chemicals							
N/A	12 (63.2%)	7 (53.9%)	2 (50.0%)	14 (48.3%)	3 (42.8%)	38 (52.8%)	0.696
No	7 (36.8%)	5 (38.5%)	2 (50.0%)	15 (51.7%)	4 (57.1%)	33 (45.8%)	
Yes	0 (0.0%)	1 (7.6%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (1.4%)	
Toxicity *(such as carcinogens, mutagens, reproductive hazards)*							
N/A	16 (84.2%)	7 (53.8%)	4 (100.0%)	25 (86.2%)	4 (57.1%)	56 (77.8%)	0.111
No	1 (5.3%)	3 (23.1%)	0 (0.0%)	2 (6.9%)	3 (42.9%)	9 (12.5%)	
Yes	2 (10.5%)	3 (23.1%)	0 (0.0%)	2 (6.9%)	0 (0.0%)	7 (9.7%)	

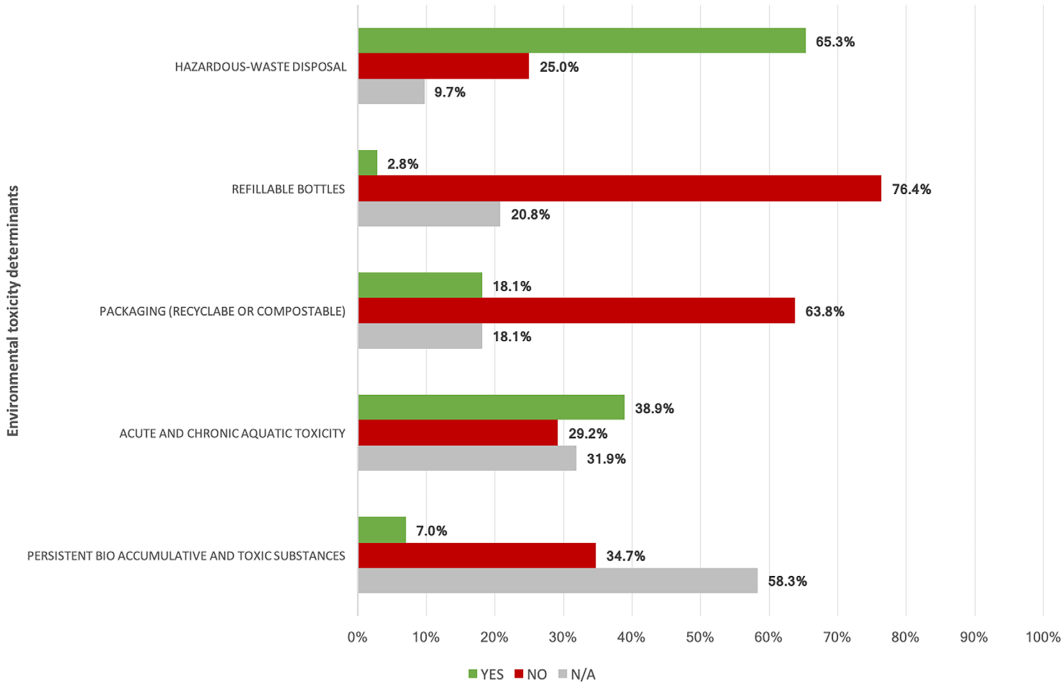

Figure 2. Environmental impact profile of the 72 analyzed chemical products for cleaning, antisepsis, disinfection and sterilization.

Table 2. Environmental impact profile of the analyzed detergents, antiseptics, disinfectants and sterilants-by category of use.

	Cleaning and/or antisepsis of intact skin (n=19)	Cleaning and/or disinfection of environments and surfaces (n=13)	Cleaning and/or antisepsis of injured skin or mucosae (n=4)	Cleansing disinfection, and sterilization of medical devices and equipment (n=29)	Mixed-use (n=7)	Total (n=72)	p-value
Hazardous-waste disposal							
N/A	12 (63.2%)	9 (69.2%)	4 (100.0%)	19 (65.5%)	3 (42.8%)	47 (65.3%)	0.532
No	3 (15.8%)	0 (0.0%)	0 (0.0%)	2 (6.9%)	2 (28.6%)	7 (9.7%)	
Yes	4 (21.0%)	4 (30.8%)	0 (0.0%)	8 (27.6%)	2 (28.6%)	18 (25.0%)	
Refillable bottles							
N/A	5 (26.3%)	0 (0.0%)	0 (0.0%)	5 (17.2%)	5 (71.4%)	15 (20.8%)	0.003
No	14 (73.7%)	11 (84.6%)	4 (100.0%)	24 (82.8%)	2(28.6%)	55 (76.4%)	
Yes	0 (0.0%)	2 (15.4%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	2 (2.8%)	
Packaging (recyclable or compostable)							
N/A	4 (21.1%)	1 (7.7%)	0 (0.0%)	5 (17.2%)	3 (42.8%)	13 (18.1%)	0.601
No	13 (68.4%)	9 (69.2%)	4 (100.0%)	17 (58.6%)	3 (42.8%)	46 (63.8%)	
Yes	2 (10.5%)	3 (23.1%)	0 (0.0%)	7 (24.2%)	1 (14.4%)	13 (18.1%)	

Table 2 *(Continued)*

	Cleaning and/or antisepsis of intact skin (n=19)	Cleaning and/ or disinfection of environments and surfaces (n=13)	Cleaning and/or antisepsis of injured skin or mucosae (n=4)	Cleansing disinfection, and sterilization of medical devices and equipment (n=29)	Mixed-use (n=7)	Total (n=72)	p-value
Acute and chronic aquatic toxicity							
N/A	7 (36.8%)	3 (23.1%)	0 (0.0%)	10 (34.5%)	3 (42.8%)	23 (31.9%)	0.251
No	3 (15.8%)	6 (46.2%)	3 (75.0%)	6 (20.7%)	3 (42.8%)	21 (29.2%)	
Yes	9 (47.4%)	4 (30.7%)	1 (25.0%)	13 (44.8%)	1 (14.4%)	28 (38.9%)	
Persistent bio-accumulative and toxic substances							
N/A	12 (63.2%)	8 (61.5%)	1 (25.0%)	19 (65.5%)	2 (28.6%)	42 (58.3%)	0.355
No	6 (31.6%)	4 (30.8%)	3 (75.0%)	7 (24.1%)	5 (71.4%)	25 (34.7%)	
Yes	1 (5.2%)	1 (7.7%)	0 (0.0%)	3 (10.3%)	0 (0.0%)	5 (7.0%)	

Table 3. Toxicity characteristics of the active principles of the analyzed chemical products for cleaning, antisepsis, disinfection and sterilization.

Active Principle	Toxicity Characteristics
1-Propanamino,3-Amino-N-(Carboxymethyl)-N,N-Dimethyl,N-C8-18acyl Derivatives	In a mixture, it serves as a disinfectant hand soap, causing severe eye damage and proving harmful to aquatic organisms with long-lasting effects
2-Phenoxyethanol	It is included in a mixture as an instrument disinfection product, it is harmful if swallowed and causes severe eye irritation
Alkyl Ether of Carboxylic Acid	It is used in mixtures as a disinfectant and cleaning agent for surgical instruments, endoscopes, laboratory accessories, and anesthesia. It is irritating to the skin and eyes but non-toxic
Benzalkonium Chloride	It is used for cleaning and antisepsis of injured skin, antisepsis of the hands, delimitation, and preparation of the operating field. Possible intolerance and frequent applications may cause skin irritation and dryness. It should not be used for prolonged treatment, and contact with the eyes should be avoided
Boric Acid	It is used for disinfecting medical-surgical devices. It can be harmful if inhaled, irritating the respiratory tract and skin, and dangerous if swallowed, leading to eye irritation. It is partially soluble in water, and there is no toxicity and bioaccumulation data for aquatic organisms
Butane/Propane	It is used as an instrument lubricant, it may cause irritation through inhalation, skin, and eye contact. It may also lead to allergic reactions. It is not classified as carcinogenic, not considered environmentally hazardous, and is not bioaccumulative
Cetrimide	It is used for cleansing and disinfection of injured skin, external cleansing and antisepsis in obstetrics, gynecology, urology, and disinfection of intact skin. It is non-toxic topically, causes slight skin irritation, and is not classified as dangerous for the environment
Citric Acid	It is used in a mixture with other active ingredients as a liquid detergent, descaler, and disinfectant. It is highly irritating to the eyes and can cause allergic reactions. It is toxic to aquatic organisms, with no data on persistence and biodegradability

Active Principle	Toxicity Characteristics
Didecylammonium Chlorate	Detergent and disinfectant mixed with other active ingredients for medical-surgical devices, decontaminating and cleaning solution for invasive medical devices and electro-medical equipment. It is harmful if swallowed and corrosive to the skin, causing severe skin burns and serious eye damage. It is very toxic to aquatic organisms and has long-lasting effects
Dodecan-1-Ol-Ethoxylate	It is used in a mixture as a skin and mucous membrane antiseptic, causing acute oral toxicity and eye irritation. It is toxic to aquatic organisms with long-lasting effects
Ethanol 96%	It is a highly flammable liquid used as a disinfectant, and inhalation may lead to respiratory tract irritation. Splashes or contact with eyes may lead to eye irritation. It is not classified as environmentally hazardous
Ethyl Alcohol Cyclohexane	It is used as a sanitizer, it is a flammable liquid that irritates the eyes and may cause drowsiness or dizziness. It is very toxic to aquatic organisms and has long-lasting effects
Ethoxylated Fatty Alcohol	Detergent for medical-surgical devices causing skin irritation. It is hazardous to the aquatic environment in the short term and biodegradable
Gioneutacetic Acid	A liquid substance used for instrument disinfection in hospital settings. It is a flammable, corrosive liquid that can cause severe eye damage and skin irritation. There are no available data on carcinogenicity, reproductive toxicity, mutagenicity, or teratogenicity. It is toxic for fish and biodegradable
Glacial Acetic Acid	It is used as a solvent and agent for analysis. This highly flammable liquid and vapor can cause severe skin burns and eye damage. It should not enter drains due to the risk of explosion. It is highly biodegradable
Glucoprotamin	It is used in a mixture as an instrument disinfection product, it is harmful if swallowed or inhaled and skin corrosive. It causes severe eye damage and is hazardous to the aquatic environment in the short term.
Glutaral	It is used in mixtures as a disinfectant for instruments, cleaning of surgical instruments, endoscopes, laboratory accessories, and anesthesia. It has acute oral and inhalation toxicity, is corrosive to the skin, may damage the eyes, and may cause allergic symptoms or breathing difficulties. It is very toxic to aquatic organisms and has long-lasting effects
Hydrogen Peroxide	It is used as a skin disinfectant and instrument disinfectant mixture. It is an oxidizing liquid harmful if inhaled or swallowed, causing severe skin burns and serious eye injuries. It may irritate the respiratory tract and is readily biodegradable
Isopropanol Chlorhexidine Digluconate	It is used in solution with other active ingredients for disinfection, it causes severe eye injuries and is very toxic to aquatic organisms with long-lasting effects
Isopropyl Alcohol	It is used in a mixture with other active ingredients as a hand disinfectant, antisepsis for intact and injured skin, and surface disinfectant. It is a flammable liquid, irritating to the eyes, and may cause drowsiness or dizziness. There is no evidence of mutagenicity, carcinogenicity, and reproductive toxicity, and it is biodegradable
L-(+)Lactic Acid	It is included in a hand disinfectant soap mixture, it causes severe irritation to the eyes and skin
Laurylpropylenediamine	It is used in a mixture as an instrument disinfectant, it is orally toxic, corrosive to the skin, and causes severe eye damage. Prolonged exposure can lead to organ damage. It is very toxic to aquatic organisms with both acute and chronic effects

Table 2 (*Continued*)

Active Principle	Toxicity Characteristics
Methyl Ketone	A surface cleaner that is a flammable liquid irritates the eyes and may cause drowsiness or dizziness
N-Hexane	It is utilized as a solvent in the laboratory, N-HEXANE is a flammable liquid that causes corrosion and skin irritation. It can be lethal if swallowed and enters the respiratory tract. Suspected of harming fertility, it can induce narcotic effects and drowsiness. It is toxic to aquatic organisms with long-lasting effects
P-Teramylphenol-O-Phenylphenol-O-Benzyl-P-Chlorophenol	A concentrated aqueous disinfectant solution based on phenolic derivatives, it is non-sensitizing, non-carcinogenic, non-mutagenic, and non-teratogenic. It is irritating to the eyes and skin and harmful to aquatic organisms
Pentasodium Diethylenetriaminopentacetate	It is used in decontaminating and cleaning solutions for medical devices and electro-medical equipment, it is suspected of harming the unborn child. It is harmful if inhaled and causes severe eye irritation
Peracetic Acid	It is used in a mixture with other active ingredients for disinfecting and sterilizing endoscopes, medical devices, and instruments. It is a flammable, corrosive liquid with acute toxicity (Category 4) and may irritate the respiratory tract. It poses short- and long-term hazards to the aquatic environment
Phosphoric Acid	It is used for cleaning medical-surgical instruments. Corrosive to metals and skin, causing severe skin burns and eye damage. There is no data on toxicity, and it can be disposed of through the sewer
Poly(Oxy-1,2-Ethanediyl)-Alpha-Tridecyl Omega-Hidaxy, Branched	In a mixture, it is a decontaminating and cleaning solution for medical devices and electro-medical equipment. It is harmful if swallowed and may damage the eyes. It is rapidly biodegradable
Polyglycol Ether of Fatty Acid	It is utilized in a mixture as an instrument disinfectant, it poses acute oral toxicity and causes severe eye damage
Polyhexamethylene Biguanide Hydrochloride	It is used for cleansing and disinfection in a mixture with other active ingredients. It is a solution for irrigation of wounds, rinsing, and moisturizing acute and chronic skin wounds. If swallowed, it may cause allergic skin reactions and severe eye damage. It is very toxic to aquatic organisms and has long-lasting effects
Povidone-Iodine	Antisepsis of intact and injured skin, delimitation of the operating field. It may cause nose and throat irritation, skin contact irritation with prolonged exposure, and severe eye irritation. It has no carcinogenic, teratogenic, or mutagenic effects and is readily biodegradable
Propane-1-Ol	It is included in a mixture as an instrument disinfectant, this flammable liquid causes eye damage and may induce drowsiness or dizziness
Propan-2-OI	In a mixture, it serves as a gel for hand and skin disinfection and for disinfecting surgical instruments, endoscopes, and laboratory and anesthesia accessories. It is a flammable liquid that irritates the eyes and may cause drowsiness or dizziness. It is readily biodegradable
Propyl Alcohol	It is used in a mixture as a hand disinfectant. It is a flammable liquid, irritating to the eyes, and may cause drowsiness or dizziness. There is no evidence of mutagenicity, carcinogenicity, and reproductive toxicity, and it is biodegradable
Sodium Alkyl Ether Sulphate	Disinfectant for surgical hand disinfection and hand hygiene inwards at risk of infection. In a mixture, it is a high-level disinfectant for medical devices, causing skin and severe eye irritation. It has chronic toxicity to aquatic organisms

Active Principle	Toxicity Characteristics
Sodium Dichloroisocyanurate Dihydrate	It is used in a mixture as a disinfectant for medical and surgical devices. The tablet consists essentially of the substance and has all the hazard characteristics. It is harmful if swallowed, irritating by inhalation and in contact with the eyes, and highly toxic to aquatic organisms with the possibility of long-lasting effects
Sodium Hypochlorite	It is used for the disinfection of medical devices, internal circuits of hemodialysis machines, fruit and vegetables, baby objects, and intact skin. Concentrated solutions may irritate the skin and eyes, with no expected bioaccumulation capacity
Sodium Tetraborate Decahydrate	It is used in a mixture as a disinfectant solution for topical use, it causes severe eye irritation, posing no danger to humans or the environment

with the evidence reported in the literature; indeed, a 2022 review identified during the COVID-19 pandemic that irritant effects on the respiratory system, the skin, and the eyes were the most common adverse reaction of antiseptics and disinfectants (19). A 2021 study found that 70.9% of 175 nurses experienced hand dermatitis. The study revealed a significant increase in handwashing, hand antiseptic use, and hand cream application during the COVID-19 pandemic compared to the pre-pandemic period (20). While several studies have addressed the issue, few have focused on identifying key events potentially associated with endocrine-disrupting effects and adverse outcomes following exposure. This is consistent with our product analysis, which revealed a 52.8% lack of available information in this regard (21). A 2022 review by Sui et al. explored the potential endocrine-disrupting risks of disinfection by-products (DBPs). The authors highlighted that water contamination resulting from anthropogenic and industrial activities has led to the widespread use of disinfection methods. However, the release of chemical by-products has been associated with the emergence of various health conditions, including infertility, asthma, stillbirths, and multiple forms of cancer. Although these concerns are well documented, our findings indicate that 77.8% of the products lack safety profile information regarding their toxicity. This absence of information is concerning, as it fails to ensure transparency and raises questions about the safety of the tools and substances in use (22). From an environmental perspective, the lack of information on the potential impact of these chemical agents raises alarms, especially considering the urgency of addressing global environmental concerns. The omission of data regarding the impact on ecosystems and aquatic life signifies a gap in our understanding of the broader consequences of these products (23). A 2017 study (24) described the screening of biocides, metals, and antibiotics in samples obtained from 11 sewage treatment plants in Sweden, including incoming sewage water, treated effluent, and digested sludge, collected over three different days. Thirty organic compounds and ten metals were identified above their respective detection limits. The particulate phases were predominantly composed of quaternary ammonium compounds, reaching levels of up to 370 μg/g, while benzotriazoles were the most prevalent in the aqueous phases, reaching concentrations of up to 24 μg/L. Additionally, several compounds, such as chlorhexidine, hexadecylpyridinium chloride, and 10-benzalkonium chloride, were identified in this study, with limited or no previously reported data. Given the persistent water scarcity affecting numerous countries (25) there has been growing interest in evaluating the aquatic toxicity and ecological risk posed by wastewater-derived halogenated phenolic disinfection by-products (DBPs). Species-specific toxicity assessments suggested that toxicity testing in crustaceans and fish should be prioritised over algae in future investigations (26). Wang et al. (2022) conducted a comprehensive analysis of these compounds, underscoring the significance of assessing their ecological impact (26). Despite the relevance of these findings, our data reveal that only 29.2% of the products examined provide explicit information confirming the absence of both acute and chronic aquatic toxicity. In contrast, 38.9% exhibit confirmed toxic effects, while 31.9% lack any toxicological data. This considerable information gap highlights a pressing need for further research to ensure environmental safety and informed risk management. Our analysis revealed a 58.3% lack of available data concerning the bioaccumulation and persistence of toxic substances. This aligns with previous findings from a quantitative assessment of chlorhexidine accumulation in natural and riverine biofilms, which has expanded current understanding of the ecological consequences associated with the ubiquitous use of broad-spectrum antimicrobials—particularly those found in personal care products (27). In addition, a more recent review—while addressing environmental contaminants more broadly rather than focusing specifically on disinfection by-products—also explored the risks related to bioaccumulation. It highlighted the critical role that biofilms may play in retaining contaminants and facilitating trophic transfer within aquatic food webs (28). The studies converge on the observation that the topic remains substantially underexplored, underscoring the need for further targeted research. The minimal amount of recyclable material and refillable containers is of particular concern. The 5Rs rule (reduce, reuse, recycle, rethink, and research) serves as a framework for medical waste management. Waste management can be enhanced by minimizing waste volume, enhancing waste segregation, reusing specific medical equipment, recycling, reconsidering outdated practices, investing time in research, and developing innovative strategies to decrease the environmental's ecological impact. Additionally, the incorporation of novel technology, renewable energies, and intelligent architectural design can contribute to the goal of waste reduction (29,30). It should be noted that healthcare providers share responsibility with manufacturers in addressing ecological product deficiencies. During procurement, they must balance infection control efficacy with environmental impact. As gatekeepers, the green behavior of providers assumes the significant usage of the four eco-control mechanisms, i.e., belief, boundary, diagnostic, and interactive eco-control, (20) influencing decisions crucial to public health and sustainability. Moreover, governmental institutions play a crucial role in reducing the environmental toxicity of chemical products through stakeholder collaboration, regulatory implementation, public involvement, and investment in research and development efforts. As Guo J et al. (32) indicate, effective monitoring systems are essential to evaluate environmental consequences and guide data-driven responses. Similar to Ecopharmacovigilance (EPV), which prioritises early detection and prevention of environmental contamination through source control and behavioural guidance (33,34), analogous principles may be applied here. The COVID-19 pandemic significantly increased global chemical agents use (35,36), raising environmental concerns due to the disposal of chemical-laden waste and potential ecosystem risks (37,38). While these products were essential for infection control, especially in hospitals, widespread public use highlighted inadequate environmental awareness (32). Additionally, the pandemic disrupted progress toward greener healthcare practices, with urgent infection control needs overshadowing sustainability efforts (39,40), such as reducing single-use items. As healthcare systems evolve post-pandemic, maintaining effective infection control while reinstating and advancing environmentally sustainable practices is vital for long-term ecological and public health resilience. Additionally, concerns persist regarding disinfectants' biomagnification and sub-lethal effects on health and ecosystems. Limited data hinder risk assessment (1), stressing the need for research on antimicrobial co- and cross-resistance mechanisms (24). The limitations of this study include the absence of laboratory or environmental data that could empirically demonstrate the environmental and human hazards of the products under analysis. However, it is worth noting that the active ingredients analyzed have been extensively studied in scientific literature, and their potential toxic effects are well-known. Whilst the relatively small number of hospital facilities (4 of 7) that submitted their chemical agents formularies could be perceived as a limitation and potentially unrepresentative of the wider region, it is not considered to introduce a substantial bias, considering that healthcare facilities within the same area are unlikely to use different products due to centralized procurement procedures. Certainly, the main strength of this study lies in the originality of the investigative model, as there is, to our knowledge, no similar research in the existing literature. Additionally, the rigorous methodology employed to obtain our results highlights an issue with implications in the scientific and healthcare organizational domains. Another strength is that our results are applicable to facilities that address the health needs of approximately 5 million people.

Conclusions

The integration of health, safety, and environment (HSE) is recognized as a pivotal element for the sustainable and high-quality development of human society. In safety and health, effective disinfection is indispensable, especially in hospitals and other densely populated public indoor spaces. The intricate conflicts arising among biosafety, human health, and the environment present an unprecedented dilemma and great challenge that humanity must confront both presently and in the future. A critical gap remains in the current body of knowledge concerning the impacts of disinfectants and other chemical agents on ecosystems and aquatic life, representing a significant limitation to our understanding of their broader consequences. According to Chen W et al. (42), the application of heat treatment, UV irradiation, and hydrogen peroxide vapour is advised to achieve effective disinfection while minimising adverse impacts on health, safety, and the environment. In response to this gap, the implementation of robust regulatory frameworks is essential. It is equally important to engage stakeholders and policymakers through targeted awareness initiatives to ensure that environmental considerations are fully integrated into infection control practices. The lack of detailed information on the environmental risks posed by these products is particularly concerning within the current context of global environmental urgency and climate change mitigation. In essence, the sustainable and responsible use of chemical products for cleaning, antisepsis, disinfection and sterilization demands a holistic approach that encompasses human safety and environmental well-being. Healthcare institutions must also evolve by embedding sustainability into their operational structures. The establishment of dedicated "environmental greening teams" within hospital management is strongly advocated to oversee waste management, water resource optimisation, air quality monitoring, and the development of economically sustainable practices capable of generating medium- to long-term savings. In the context of advancing sustainable healthcare practices, the concept of "green hospitals" gains prominence. Moreover, the routine use of comprehensive technical data sheets should become standard practice to inform purchasing decisions. Policymakers are urged to introduce more stringent regulatory requirements for labelling and environmental risk communication. Furthermore, the designation of specialised green procurement officers within healthcare organisations would ensure that procurement strategies consider not only economic costs but also the environmental footprint of products. Stakeholders and policymaker should choice -eco-friendly chemical products, promotion of responsible use, development of usage protocols, staff training, monitoring and evaluation, research and development, and collaboration with suppliers. In this context, the procurement of disinfectants and other chemical agents for public healthcare facilities by local health authorities should assess the environmental impact throughout the process. By adopting green and eco-friendly practices, healthcare organizations can significantly contribute to limiting the environmental toxicity associated with the use of chemical products within their facilities. Moreover, the active involvement of governmental institutions is imperative to address the environmental challenges disinfectants and other chemical agents pose. Ultimately, the convergence of sustainable procurement practices, informed policymaking, and environmental governance within healthcare settings will be pivotal to achieving the dual goals of promoting public health and safeguarding the environment for future generations.

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References

1. Musee N, Ngwenya P, Motaung LK, Moshuhla K, Nomngongo P. Occurrence, effects, and ecological risks of chemicals in sanitizers and disinfectants: a review. Environ Chem Ecotoxicol. 2023;5:62–78. doi:10.1016/j.enceco.2023.01.003.
2. Pradhan D, Biswasroy P, Kumar Naik P, Ghosh G, Rath G. A review of current interventions for COVID-19 prevention. Arch Med Res. 2020;51(5):363–74. doi:10.1016/j.arcmed.2020.04.020.
3. Daverey A, Dutta K. COVID-19: eco-friendly hand hygiene for human and environmental safety. J Environ Chem Eng. 2021;9(2):104754. doi:10.1016/j.jece.2020.104754.
4. Choi K, Sim S, Choi J, et al. Changes in handwashing and hygiene product usage patterns in Korea before and after the outbreak of COVID-19. Environ Sci Eur. 2021;33(1):79. doi:10.1186/s12302-021-00517-8.
5. Berardi A, Perinelli DR, Merchant HA, et al. Hand sanitizers amid COVID-19: a critical review of alcohol-based products on the market and formulation approaches to respond to increasing demand. Int J Pharm. 2020;584:119431. doi:10.1016/j.ijpharm.2020.119431.
6. Zhang H, Tang W, Chen Y, Yin W. Disinfection threatens aquatic ecosystems. Science. 2020;368(6487):146–7. doi:10.1126/science.abb8905.
7. Rozman U, Pušnik M, Kmetec S, Duh D, Šostar Turk S. Reduced susceptibility and increased resistance of bacteria against disinfectants: a systematic review. Microorganisms. 2021;9(12):2550. doi:10.3390/microorganisms9122550.
8. Quirce S, Barranco P. Cleaning agents and asthma. J Investig Allergol Clin Immunol. 2010;20(7):542–50.
9. Bhat SA, Sher F, Kumar R, et al. Environmental and health impacts of spraying COVID-19 disinfectants with associated challenges. Environ Sci Pollut Res Int. 2022;29(57):85648–57. doi:10.1007/s11356-021-16575-7.
10. Nason SL, Lin E, Eitzer B, Koelmel J, Peccia J. Changes in sewage sludge chemical signatures during a COVID-19 community lockdown, part 1: traffic, drugs, mental health, and disinfectants. Environ Toxicol Chem. 2022;41(5):1179–92. doi:10.1002/etc.5217.
11. Lattanzio S, Stefanizzi P, D'Ambrosio M, et al. Waste management and the perspective of a green hospital: a systematic narrative review. Int J Environ Res Public Health. 2022;19(23):15812. doi:10.3390/ijerph192315812.
12. Italian Ministry of Environment and Energy Security. Green public procurement [Internet]. Available from: https://gpp.mase.gov.it/Home/CosaEGPP . Accessed November 28, 2023.
13. Chiarini A, Vagnoni E. Environmental sustainability in European public healthcare. Leadersh Health Serv. 2016;29(1):2–8. doi:10.1108/LHS-10-2015-0035.
14. Kenneally R, Lawrence Q, Brydon E, et al. Inactivation of multiple human pathogens by Fathhome's dry sanitizer device: rapid and eco-friendly ozone-based disinfection. Med Microecol. 2022;14:100059. doi:10.1016/j.medmic.2022.100059.
15. Rowan NJ, Meade E, Garvey M. Efficacy of frontline chemical biocides and disinfection approaches for inactivating SARS-CoV-2 variants of concern that cause coronavirus disease with the emergence of opportunities for green eco-solutions. Curr Opin Environ Sci Health. 2021;23:100290. doi:10.1016/j.coesh.2021.100290.
16. Orias F, Perrodin Y. Characterisation of the ecotoxicity of hospital effluents: a review. Sci Total Environ. 2013; 454–455:250–76. doi:10.1016/j.scitotenv.2013.02.064.
17. Rutala WA, Weber DJ; Healthcare Infection Control Practices Advisory Committee (HICPAC). Guideline for disinfection and sterilization in healthcare facilities [Internet]. 2008 [updated 2024 Jun; cited 2024 Feb 10]. Available from: https://www.cdc.gov/infection-control/hcp/disinfection-and-sterilization/index.html
18. European Union. Regulation (EC) No 1272/2008 on classification, labelling and packaging of substances and mixtures (CLP) [Internet]. Luxembourg: EU; 2008 [cited 2023 Dec 1]. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008R1272
19. Lachenmeier DW. Antiseptic drugs and disinfectants with experience of the second year of COVID-19 pandemic-related side effects. Side Eff Drugs Annu. 2022;44:365–78. doi:10.1016/bs.seda.2022.07.006.
20. Aydın Aİ, Atak M, Özyazıcıoğlu N, Dalkızan V. Hand dermatitis among nurses during the COVID-19 pandemic: frequency and factors. Adv Skin Wound Care. 2021;34(12):651–5. doi:10.1097/01.ASW.0000765916.20726.41.
21. Sui S, Liu H, Yang X. Research progress of the endocrine-disrupting effects of disinfection byproducts. J Xenobiot. 2022;12(3):145–57. doi:10.3390/jox12030013.
22. Pandian AMK, Rajamehala M, Singh MVP, Sarojini G, Rajamohan N. Potential risks and approaches to reduce the toxicity of disinfection by-product: a review. Sci Total Environ. 2022;822:153323. doi:10.1016/j.scitotenv.2022.153323.
23. Xu X, Xu Y, Xu N, Pan B, Ni J. Pharmaceuticals and personal care products in water, sediment and freshwater mollusks of the Dongting Lake downstream the Three Gorges Dam. Chemosphere. 2022;301:134721. doi:10.1016/j.chemosphere.2022.134721.
24. Östman M, Lindberg RH, Fick J, Björn E, Tysklind M. Screening of biocides, metals and antibiotics in Swedish sewage sludge and wastewater. Water Res. 2017;115:318–28. doi:10.1016/j.watres.2017.03.011.
25. Ren D, Yang Y, Yang Y, Richards K, Zhou X. Land-water-food nexus and indications of crop adjustment for water shortage solution. Sci Total Environ. 2018;626:11–21. doi:10.1016/j.scitotenv.2018.01.071.
26. Wang Y, Liu H, Yang X, Wang L. Aquatic toxicity and aquatic ecological risk assessment of wastewater-derived halogenated

phenolic disinfection byproducts. Sci Total Environ. 2022;809:151089. doi:10.1016/j.scitotenv.2021.151089.
27. Dynes JJ, Lawrence JR, Korber DR, Swerhone GD, Leppard GG, Hitchcock AP. Quantitative mapping of chlorhexidine in natural river biofilms. Sci Total Environ. 2006;369(1–3):369–83. doi:10.1016/j.scitotenv.2006.04.033.
28. Bonnineau C, Artigas J, Chaumet B, et al. Role of biofilms in contaminant bioaccumulation and trophic transfer in aquatic ecosystems: current state of knowledge and future challenges. Rev Environ Contam Toxicol. 2021;253:115–53. doi:10.1007/398_2019_39.
29. Wyssusek KH, Keys MT, van Zundert AAJ. Operating room greening initiatives: the old, the new, and the way forward: a narrative review. Waste Manag Res. 2019;37(1):3–19. doi:10.1177/0734242X18793937.
30. Guetter CR, Williams BJ, Slama E, et al. Greening the operating room. Am J Surg. 2018;216(4):683–8. doi:10.1016/j.amjsurg.2018.07.021.
31. Sisdyani EA, Subroto B, Saraswati E, Baridwan Z. Levers of eco-control and green behavior in medical waste management. Int J Energy Econ Policy. 2020;10(4):194–204.
32. Guo J, Liao M, He B, et al. Impact of the COVID-19 pandemic on household disinfectant consumption behaviors and related environmental concerns: a questionnaire-based survey in China. J Environ Chem Eng. 2021;9(5):106168. doi:10.1016/j.jece.2021.106168.
33. Wang J, Li S, Zhu Y, Guo J, Liu J, He B. Targeted ecopharmacovigilance as an optimized management strategy for adverse effects of pharmaceuticals in the environment. Environ Toxicol Pharmacol. 2021;82:103565. doi:10.1016/j.etap.2020.103565.
34. Holm G, Snape JR, Murray-Smith R, Talbot J, Taylor D, Sörme P. Implementing ecopharmacovigilance in practice: challenges and potential opportunities. Drug Saf. 2013;36(7):533–46. doi:10.1007/s40264-013-0049-3.
35. Miyah Y, Benjelloun M, Lairini S, Lahrichi A. COVID-19 impact on public health, environment, human psychology, global socioeconomy, and education. ScientificWorldJournal. 2022;2022:5578284. doi:10.1155/2022/5578284.
36. Çelebi H, Bahadır T, imşek İ, Tulun. Coronavirus (COVID-19): what could be the environmental effects of disinfectant use in the pandemic? Med Sci Forum. 2021;4(1):27. doi:10.3390/ECERPH-3-08981.
37. Mahmood A, Eqan M, Pervez S, et al. COVID-19 and frequent use of hand sanitizers: human health and environmental hazards by exposure pathways. Sci Total Environ. 2020;742:140561. doi:10.1016/j.scitotenv.2020.140561.
38. Parveen N, Chowdhury S, Goel S. Environmental impacts of the widespread use of chlorine-based disinfectants during the COVID-19 pandemic. Environ Sci Pollut Res Int. 2022;29(57):85742–60. doi:10.1007/s11356-021-18316-2.
39. Chu J, Ghenand O, Collins J, et al. Thinking green: modelling respirator reuse strategies to reduce cost and waste. BMJ Open. 2021;11(7):e048687. doi:10.1136/bmjopen-2021-048687.
40. Torres FG, De-la-Torre GE. Face mask waste generation and management during the COVID-19 pandemic: an overview and the Peruvian case. Sci Total Environ. 2021;786:147628. doi:10.1016/j.scitotenv.2021.147628.
41. Akter S, Zakia MA, Mofijur M, et al. SARS-CoV-2 variants and environmental effects of lockdowns, masks and vaccination: a review. Environ Chem Lett. 2022;20(1):141–52. doi:10.1007/s10311-021-01323-7.
42. Chen W, Yang H, Peng C, Wu T. Resolving the health vs environment dilemma with sustainable disinfection during the COVID-19 pandemic. Environ Sci Pollut Res Int. 2023;30(9):24737–41. doi:10.1007/s11356-023-25167-6.

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