Outdoor disinfectant sprays for the prevention of COVID-19: Are they safe for the environment?

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HIGHLIGHTS

- Indoor and outdoor use of disinfectants increased after global pandemic COVID-19.
- Surface runoff accelerates the chance of mixing the disinfectants with waterbodies.
- Biocidal activity of disinfectants not only kill fish lice but also aquatic organisms
- The ecologically important role of sensitive organisms may be a risk of disinfectants.
- There is an urgent need for testing the primary productivity of waterbodies.

GRAPHICAL ABSTRACT
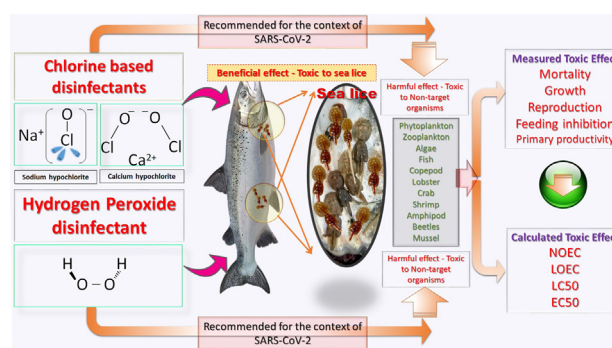
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ABSTRACT

Due to the wide range of viability on inanimate surfaces and fomite transmission of SARS-CoV-2, hydrogen peroxide (0.5%, HP) and hypochlorite-based (0.1%, HC) disinfectants (common biocides) are proposed by World Health Organization to mitigate the spread of this virus in healthcare settings. They can be adopted and applied to outdoor environments. However, many studies have shown that these two disinfectants are toxic to fishes and aquatic non-target organisms (primary producers and macroinvertebrates). The global market of these disinfectants will increase in coming years due to COVID-19. Therefore, it is urgent to highlight the toxicities of these disinfectants. The main findings of this article allow the community to develop a new strategy to protect the environment against the hazardous effects of disinfectants. Therefore, we use the "toxicity calculated ratio (TC ratio)" that refers to the fold increase or decrease in the toxicities reported in the literature (NOEC, LOEC, LC50 and EC50) relative to the WHO-recommended dose of HP and HC. The calculated TC ratios are valuable for policy makers to formulate the regulations to prevent disinfectant exposure in the environment. Our results were collected via PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analysis) guidelines and showed that the TC ratios are from the single digits to several thousand-fold lower than the HP and HC recommended dose, which means these disinfectants are potentially dangerous to non-target organisms. The results also showed that HP and HC are toxic to the growth and reproduction of non-target organisms. Therefore, we recommend policymakers formulate protocols for critical assessment and monitoring of the environment—especially on non-target organisms in water bodies located in and around disinfectant-exposed areas to safeguard the environment in the future.

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Contents

1. Introduction

The 2019 novel corona virus (severe acute respiratory syndrome CoV-2, SARS-CoV-2) is transmitted via contact with a diseased person and the spray of respiratory droplets from a diseased person (WHO, 2020a, 2020b). However, there is little additional information in the literature regarding the life of SARS-CoV-2 outside of its host especially in the environment (Table 1). Various lab tests have confirmed the persistence of this virus on inanimate surfaces (from 3 to 72 h, Table 2) (Kampf et al., 2020; Ong et al., 2020; van Doremalen et al., 2020) especially in toilet areas of isolation wards (Jiang et al., 2020; Lee et al., 2020; Liu et al., 2020; NIPHE and MOHWS, 2020; Ong et al., 2020; Santarpia et al., 2020; Setti et al., 2020) (Table 1); however, there is not yet any clear information on outdoor environments. After the global pandemic of COVID-19, a study in Wuhan revealed the presence of COVID-19 virus in crowded public areas (Liu et al., 2020). The virus was also found in wastewater collected from airports and wastewater treatment plants (NIPHE and MOHWS, 2020). The percent positive cases recorded from these places ranged from <1 to 77.5% (Table 1).

The transmission SARS-CoV-2 has been classified into four phases: 1) first appearance of disease (a COVID-19-positive person carrying the virus from place to place), 2) local transmission (virus transmits from infected travelers to their close contacts with the ability to identify the source of the virus), 3) community transmission (a person tests positive however, it is impossible to identify the source of the virus), and 4) widespread outbreak (epidemic stage and uncontrollable spread) ("Indian Council of Medical Research,", 2020). SARS-CoV-2 is an enveloped virus with a fragile outer membrane (Mousavizadeh and Ghasemi, 2020). It is less stable in the environment and more susceptible to disinfectants (WHO, 2020c). Therefore, disinfectants are often sprayed indoors during the second phase (local transmission) of SARS-CoV-2 transmission. However, cities often spray disinfectants in outdoor environments during the community (third phase) and epidemic transmission (fourth phase) levels. The antimicrobial action of disinfectants either by aerosol spray (CAAC - Civil Aviation Administration of China, n.d.) or by wiping down heavily touched surfaces (Cleaning and Disinfection for Households Detailed Disinfection Guidance, n.d.) may inactivate any virus particles on inert surfaces (Andersen et al., 2006; Liu et al., 2020). The concentration of these disinfectants may vary based on the level of COVID-19 risk to humans.

Even though SARS-CoV-2 behaves like other human coronaviruses, it is unclear how long SARS-CoV-2 survives on outdoor inanimate surfaces (WHO, 2020c). A point to consider here is that the viruses in dried condition on inanimate surfaces may have higher tolerance to disinfectants than hydrated in suspension (Campos et al., 2012; Doerrbecker et al., 2011; Eterpi et al., 2009; Fedorenko et al., 2020).

Table 1
Persistence of SARS-CoV-2 in air, inanimate surfaces, COVID-19 positive patient's personal items, wastewater collected from airports and wastewater treatment plants, hospital areas, and treatment rooms.

Test origin	Sampling site	Sampling period (after January 2020)	Number of samples	Positive cases	Percent positive cases	Reference
Singapore	Inanimate surfaces of COVID-19 positive patient isolated room and toilet areas	Between January 24 to February 4	28	17	61	(Ong et al., 2020)
China	Air samples collected from COVID-19 positive patient isolated rooms and blood collection areas	Sampling period not mentioned	28	1	3.57	(Jiang et al., 2020)
China	Inanimate surfaces of COVID-19 positive patient isolated room and toilet areas	Sampling period not mentioned	130	1	0.77	(Jiang et al., 2020)
South Korea	Inanimate surfaces of COVID-19 positive patient isolated room, patient car, toilet area and medical devices	Between February 4 to March 5	80	2	2.5	(Lee et al., 2020)
China	Air samples collected from patient areas, medical staff areas and public areas of two hospitals in Wuhan	Between February 17 to March 2.	30	20	66.6	(Liu et al., 2020)
Netherlands	Wastewater samples collected from Schiphol airport and two wastewater plants	Between February 17 to March 18	Number of samples not given	Tested positive	–	(NIPHE and MOHWS, 2020)
USA	Surface and aerosol samples collected from hospitals and residential isolation rooms	Samples collected 5 to 18 days later after the patients confirmed with SARS-CoV-2	163	126	77.3	(Santarpia et al., 2020)
USA	Sample collected from personal items in hospitals and residential isolation rooms	Samples collected 5 to 18 days later after the patients confirmed with SARS-CoV-2 (March 5)	147	114	77.5	(Santarpia et al., 2020)
Italy	Outdoor/airborne PM10 from industrial sites	Samples collected from February 21 to March 13	34	7	20.5	(Setti et al., 2020)
Italy	Inanimate surfaces from hospital	Not given	26	2	7.6	(Colaneri et al., 2020)

Table 2
List of inanimate surfaces tested for the surface stability of SARS-CoV-2.

Study condition	Tested inanimate surfaces	Length of stability	Infectious titer[a]	References
Controlled environmental condition (lab scale study)	Aerosols (<5 μm)	Up to 3 h	Reduction of SARS-CoV-2 concentration during 3 h	(van Doremalen et al., 2020)
	Plastic	Up to 72 h	Reduction of SARS-CoV-2 concentration after 72 h	(van Doremalen et al., 2020)
	Stainless steel	Up to 72 h	Reduction of SARS-CoV-2 concentration after 48 h	(van Doremalen et al., 2020)
	Copper	Up to 4 h	No viable SARS-CoV-2 after 4 h	(van Doremalen et al., 2020)
	Cardboard	24 h	No viable SARS-CoV-2 after 24 h	(van Doremalen et al., 2020)

[a] Infectious titer is the viral titration or viral assay or viral count by laboratory test under controlled condition.

Therefore, a list of disinfects recommended by WHO is given in Table 3. Common disinfectants include hydrogen peroxide (H_2O_2) (HP) (HP), alcohols, sodium hypochlorite (bleach), or benzalkonium chloride (HC, chlorine based disinfectants)—these have been successfully tested in the laboratory against human coronaviruses and SARS-CoV-2 on inanimate surfaces like metal, glass, and plastics (Kampf, 2018; Kampf et al., 2020; van Doremalen et al., 2020). The virucidal activity (Campos et al., 2012; Capita et al., 2019; Cramer et al., 2020; Fratantoro, 2020; Kenney et al., 2020; Perkins et al., 2020; Schwartz et al., 2020) and the mechanisms of action on pathogens (Choi et al., 2020; Ioannou et al., 2007; Kály-Kullai et al., 2020) of HPs and HCs has also been proven by many studies.

According to Business Insider news, affected cities have used aerosol spraying of disinfectants to kill SARS-CoV-2 (Brueck, 2020). Treated areas include residential areas, shops, hospitals, religious sites, streets, railway stations, airports, and other public places located in the outbreak zones as part of preventive measures against the spread of this virus. Although, the effectiveness of HPs and HCs against SARS-CoV-2 in outdoor environments has not yet been proven, the WHO recommends ≥0.5% (5000 mg/l) of HP and 0.1% (1000 mg/l) HC (bleach) to clean the site of infection and death (World Health Organization, 2020). Through September 10, 2020, the EPA has also recommended 490 disinfectants to eliminate SARS-CoV-2 attached to inanimate surfaces (US-EPA, 2020). This list includes toxic compounds like HP and HCs. After the COVID-19 outbreak, the disinfectant global market is expected to increase from 0.66 billion in 2019 to 0.78 billion in 2020 ("Covid-19 Impact on Global Disinfectants Market 2020 Key Players, Trends, Sales, Supply, Analysis and Forecast 2026,", n.d.).

A literature review shows that disinfectants (HPs and HCs) are toxic to terrestrial and aquatic environments (Choi et al., 2020; Deutschle et al., 2006; Gheorghe et al., 2019; Mincarelli et al., 2016; PHE, 2009; Watt et al., 2004). For example, HP is used as a pesticide in salmon aquaculture and is related to the nearby environment where the non-target organisms are at risk of exposure (Escobar-Lux et al., 2019; Van Geest et al., 2014). Therefore, it is important to consider the impact on the environment of such practices especially for the organisms that have a

significant role in ecosystems and are also sensitive to contaminant stress. From an environmental perspective, the community should also analyze the ecological impact due to extensive use of disinfectants. Therefore, this review article compares the toxic potential of HP and HCs on non-target organisms especially in aquatic environments at various trophic level (Fig. 1) with the WHO recommended dose of HP (0.5%) and HC (0.1%) in the context of SARS-CoV-2. An extensive review of the literature in this article may offer a new area of interest for environmentalists working in the sustainable environmental management areas. This article describes testing protocols to evaluate disinfectants that may identify the critical level of disinfectants in the environment and their potential toxic effects.

2. Survey methodology

This study compared the toxicity of HP and HC on freshwater and marine water aquatic organisms with the WHO recommended dose for HP (0.5%) and HC (0.1) in the context of SARS-CoV-2. Therefore, this systematic review was conducted using PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) for comparison of the literature studies (Fig. 2) with recommended HP and HC dose. This work searched the following topics to identify the state-of-the art: "SARS-CoV-2 inanimate surfaces", "coronavirus inanimate surfaces", and "coronavirus mode of transmission." For updated recent information related to COVID-19 collected from the World Health Organization, see https://www.who.int/.

The review was performed to compare disinfectant (HP and HC) toxicity on fishes and non-target aquatic animals using the keywords "toxicity of disinfectants", "toxicity of hydrogen peroxide", "toxicity of

Table 3
List of biocides recommended by World Health Organization (WHO) against SARS-CoV-2.

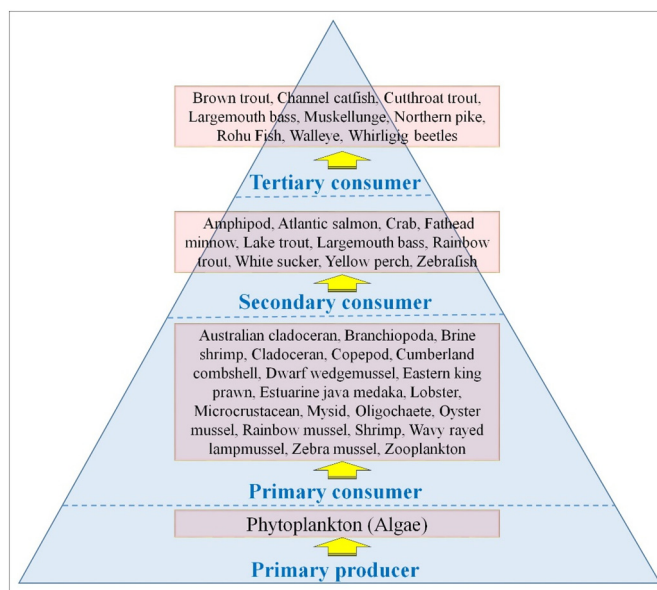| Recommended disinfectants	Recommended concentration	Effectiveness against SARS-CoV-2
Phenolic compounds	As per manufacturer recommendation	Highly effective
Hydrogen peroxide	≥0.5% (5000 mg/l)	Highly effect
Sodium hypochlorite (bleach)	0.1% (1000 mg/l) for general environmental disinfection & 0.5% (10,000 mg/l) for disinfection of blood spills	Highly effective
Ethanol	62 to 71%	Highly effective
Ammonium compounds	As per manufacturer recommendation	Highly effective
Benzalkonium chloride	0.05 to 0.2%	Less effective
Chlorhexidine digluconate	0.02%	Less effective

Fig. 1. Toxicity of hydrogen peroxide and hypochlorite-based disinfectants against the aquatic organisms at various trophic levels tested in the literature.
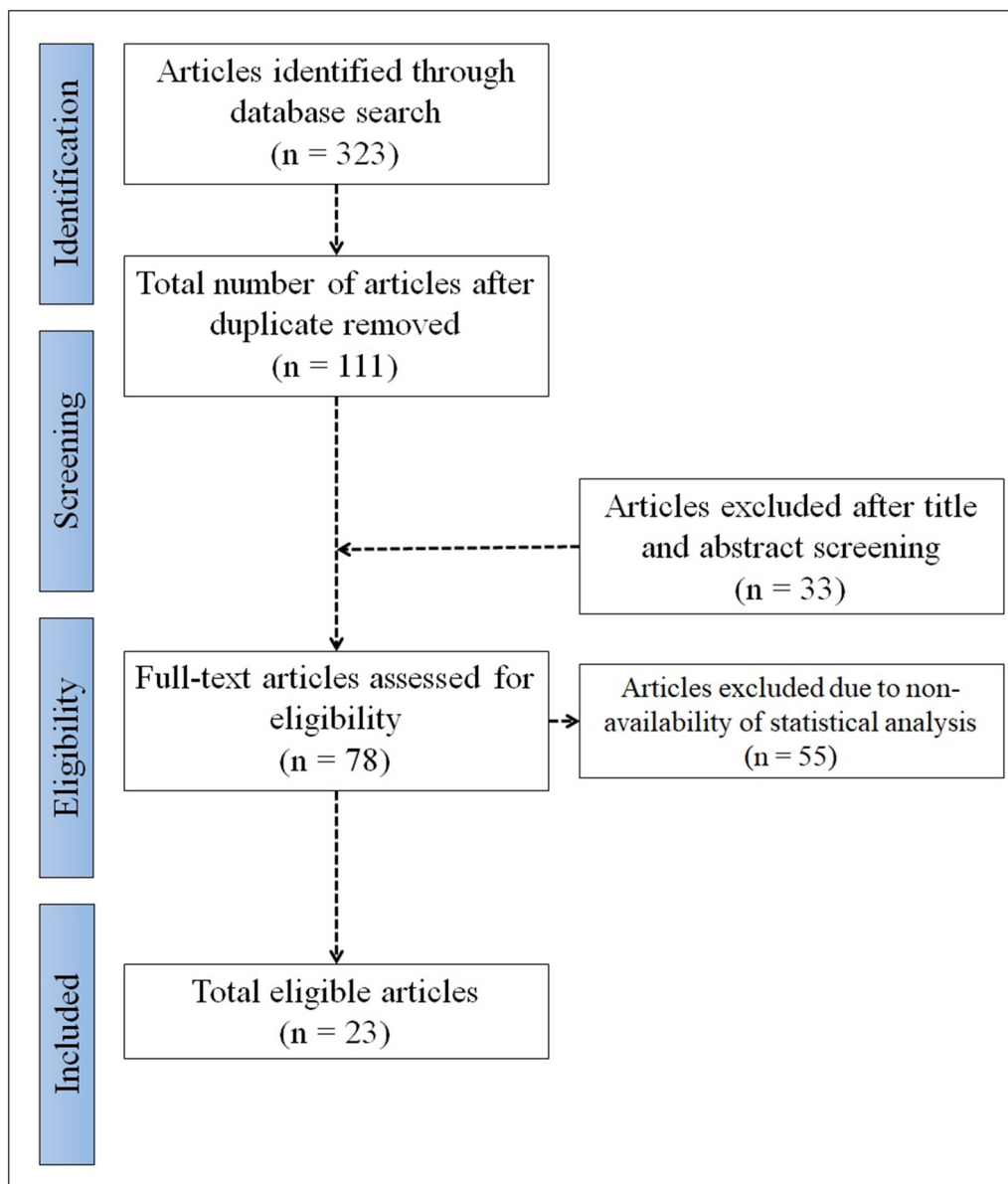
Fig. 2. Flow diagram of the included studies in a systematic review.

hypochlorite", "toxicity of chloride-based disinfectants", "toxicity of hydrogen peroxide on non-target animals", and "toxicity of hypochlorite on non-target animals". The following databases were used to prepare this article: ScienceDirect, Scopus, PubMed, Google Scholar, and Web of Science. For additional information, the query was run on the Google search engine using these search terms. A total of 323 records were found from the above databases after title-based screening based on the HP and HC toxicity to determine the relevance of the studies. Duplicates (n = 212) were removed before screening the articles. Thus, 78 articles were entered into a full-text search after title and abstract screening. Studies were excluded if the statistical analysis did not determine the toxic level of HP and HC especially for NOEC, LOEC, LC50, and EC50 (explained below). Thus, 23 articles were selected and reviewed.

The study design, experimental conditions, and statistical results of all 23 articles compared HP and HC recommended doses in the context of SARS-CoV-2 and are listed in Tables 4 to 12. In addition, the "toxicity calculated ratio (TC ratio)" refers to the fold increase or decrease in statistically measured toxicities in the literature including NOEC, LOEC, LC50, and EC50 versus the WHO recommended dose of HP (≥0.5%; the

">" sign is neglected for calculations) and HC (0.1%); this process was further calculated and discussed (Tables 4 and 9). For calculations of the TC ratio, all literature values measured in mg/l or μl/l were converted to percentage and compared.

3. Toxicity of disinfectants to non-target organisms

In toxicology, two key factors are considered when assessing the risks of disinfectants: the concentration where no harmful health effects are observed and the levels to which organisms may be exposed. However, the results have poor consistency when monitoring these two factors in real field conditions due to the influence of environmental factors. Therefore, various experiments have been tested in the literature in controlled environmental conditions (especially in lab-scale studies) to monitor the impact of HP or HC on non-target organisms.

HP and HC are biocidal active substances and can kill pathogenic microbes (Capita et al., 2019; Cheng et al., 2020; Cramer et al., 2020; Fratantoro, 2020; Hirose et al., 2017; Kály-Kullai et al., 2020; Kenney et al., 2020; Perkins et al., 2020; Schwartz et al., 2020); however, HC

Table 4

Comparison of toxicity calculated ratios (TC ratio of NOEC, LC50 and EC50) with WHO recommended concentration of hydrogen peroxide (HP, 0.5%). The fold lower (−), higher (+) or equal and above (≥) than WHO recommended dose (HP) given in parenthesis. The literature value for a TC ratio calculation after the symbol "<" or ">" implies that it is negligible.

Reference table number in this article	Type of organisms	Measured toxicity	Life stage of organisms	Recorded value (μl/l or mg/l) (A)		Value in μl/l or mg/l (A) converted to % (B) [B = Recoded value (A) / 10,000]		Fold - increase, decrease or equal (toxicity calculation ratio, TC ratio) [TC ratio = WHO recommended dose (HP 0.5%) or (HC 0.1%) / B]	
				Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Hydrogen peroxide (recommendation of 0.5% in the context of SARS-CoV-2 by WHO)									
Table 5	Freshwater Fish	NOEC (mortality)	Sac fry	–	<1000 μl/l	–	<0.1%	–	(−5)
			Fry	47 μl/l	500 μl/l	0.0047%	0.05%	(−106.4)	(−10)
			Fingerling	32 μl/l	500 μl/l	0.0032%	0.05%	(−156.3)	(−10)
			Small adult	–	<500 μl/l	–	0.05%	–	(−10)
			Adult fish	<100 μl/l	1000 μl/l	0.01%	0.1%	(−50)	(−5)
Table 6	Freshwater Fish	LC50	Fry	207 μl/l	636 μl/l	0.0207%	0.0636%	(−24.15)	(−7.86)
			Fingerling	142.8 μl/l	574 μl/l	0.01428%	0.0574%	(−35.1)	(−8.71)
			Adult	31.3 μl/l	3540 μl/l	0.00313%	0.354%	(−159.7)	(−1.41)
			Adult (LC50 value above WHO recommended dose)	–	>5000 μl/l	–	>0.5%	–	(≥1)
			Adult (LC50 value above WHO recommended dose)	–	>8660 μl/l		0.866%		(+0.58)
Table 7	Marine non-target organisms	NOEC (mortality)	Adult	–	0.75 mg/l		0.000075%		(−6666)
	Marine non-target organisms	LC50	Young	77.1 mg/l	1637 mg/l	0.0071%	0.1642%	(−70.4)	(−3.05)
			Adult	2.54 mg/l	>3750 mg/l	0.000254%	0.375%	(−1968)	(−1.33)
	Marine non-target organisms	EC50 (feeding inhibition)	Larvae	2.6 mg/l	10 mg/l	0.00026%	0.001%	(−1923)	(−500)
		EC50 (dead + dying)	Adult	–	1036 mg/l	–	0.1036	–	(−4.83)
Table 8	Wastewater treatment plant non-target organisms	NOEC (mortality)	Adult - Zooplankton	1.5 mg/l	3 mg/l	0.00015%	0.0003%	(−3333.3)	(−1666.6)
	Wastewater treatment plant non-target organisms	LC50	Adult – Zooplankton	2 mg/l	5.6 mg/l	0.0002%	0.00056%	(−892.9)	(−2500)
	Freshwater non-target organisms	NOEC (Primary productivity)	Adult - Phytoplankton	0.34 mg/l	34 mg/l	0.000034%	0.0034%	(−14,705.9)	(−147.05)
	Freshwater non-target organisms	LC50	Adult	1 mg/l	1152.6 mg/l	0.0001%	0.11526%	(−5000)	(−4.3)

and HP may also destroy the cell function of sensitive non-target organisms. Experimental evidence in aquatic environments has proven this statement as discussed below with HP and HC. Metrics include the observed effective concentration (tested highest concentration not showing/starting to show any significant effects on the measured parameters like growth and reproduction when compared to control, NOEC/LOEC), median lethal concentration (measure the mortality of organisms where the specific concentration is lethal to 50% of the exposed animals, LC50), and effective concentration (concentrations that cause a 50% reduction of growth and reproduction, EC50). These are all statistical yardsticks to measure the toxicity of chemicals on organisms (Sivakumar, 2015) and were considered in this article.

4. Hydrogen peroxide (HP)

4.1. Nature of hydrogen peroxide in the environment

Hydrogen peroxide persists in the environment either via natural reactions or through anthropogenic contributions as a biocide in aquaculture (Sunday et al., 2020). It is short-lived in the environment: Its estimated half-life in the atmosphere is 24 h and a few hours in natural water bodies. However, the half-life of HP was 3.5 d (at 8.7 °C) to 28 d (at 12 °C) in seawater (Fagereng, 2016). HP degrades in nature either abiotically or biotically. The abiotic degradation of HP is due to the disproportionation [$2H_2O_{2(aq)} \rightarrow 2H_2O_{(l)} + O_{2(g)}$] or by reaction with metals and organic compounds. However, in the case of biotic degradation, HP is converted into water and oxygen via enzymes in aerobic

bacteria (ATSDR, 2002). Henry's law constant for HP ($7.1 \times 10-4$ Pa. m³/mol at 20 °C) indicates that their volatilization ability in surface water and in moist soil is low. Similarly, the measured log Kow (Kow = concentration in the octanol phase/concentration in aqueous phase = −1.5) and Koc (organic carbon partition coefficient = 0.2) values indicate high soil mobility (ATSDR, 2002).

4.2. Biocidal effect of hydrogen peroxide

Hydrogen peroxide is widely used as a biocide because HP decomposes into water and oxygen (Linley et al., 2012). HP is used for a variety of commercial, industrial, and medical purposes; it is particularly important as a biocide in cultured freshwater and marine water fish to control parasitic, bacterial, and fungal infections. Therefore, in aquaculture, the US Food and Drug Administration approved the dosage limit of HP as 50 to 1000 mg/l (0.05 to 0.1%) for fish (Yanong, 2014); depending on temperature, it may reach up to 2100 mg/l (0.21%) (Escobar-Lux et al., 2019). The applied dose between these ranges for fish depends on the type and life stages of the fish to control particular types of parasites, bacteria, and fungi (Arndt and Wagner, 1997; Yanong, 2014). The HP dose limits mentioned above are generally recommended for aquaculture due to the control of fish pathogens. In reality, if the HP dose is less than the recommended level then it may impair the growth and mortality of fishes (Arndt and Wagner, 1997; Clayton and Summerfelt, 1996; Escobar-Lux et al., 2019; Rach et al., 1997) (Tables 4, 5, 6, 7, and 8). Tables 4, 5, and 6 compare the HP recommended dose (5000 mg/l or 0.5%) by WHO in the context of SARS-CoV-2 to identify the HP

Table 5
NOEC (no observed effective concentration) of hydrogen peroxide (μl/l) to freshwater fish.

Organisms	Species	Life stage	Measured toxicity effect (NOEC)	Concentration (μl/l)	Exposure time (h)	Exposure temperature (°C)	Reference
Rainbow trout	*Oncorhynchus mykiss*	Sac fry	Mortality	<500	0.25	12	(Rach et al., 1997)
				1000	0.75	12	
Rainbow trout	*Oncorhynchus mykiss*	Fry	Mortality	<500	0.25	12	(Rach et al., 1997)
				500	0.75	12	
Rainbow trout (cold water species)	*Oncorhynchus mykiss*	Fry	Mortality	188	1	12	(Gaikowski et al., 1999)
				78	3	12	
Muskellunge (coolwater species)	*Esox masquinongy*	Fry	Mortality	104	1	17	(Gaikowski et al., 1999)
				54	3	17	
Northern pike (coolwater species)	*Esox lucius*	Fry	Mortality	98	1	17	(Gaikowski et al., 1999)
				54	3	17	
Pallid sturgeon (coolwater species)	*Scaphirhynchus albus*	Fry	Mortality	<144	1	17	(Gaikowski et al., 1999)
				28	3	17	
Walleye (coolwater species)	*Stizostedion vitreum*	Fry	Mortality	<72	1	17	(Gaikowski et al., 1999)
				72	3	17	
White sucker (coolwater species)	*Catostomus commersoni*	Fry	Mortality	47	1	17	(Gaikowski et al., 1999)
				28	3	17	
Pallid sturgeon (coolwater species)	*Scaphirhynchus albus*	Fry	Mortality	93	1	17	(Gaikowski et al., 1999)
				47	3	17	
Bluegill (warmwater species)	*Lepomis macrochirus*	Fry	Mortality	78	1	17	(Gaikowski et al., 1999)
				47	3	22	
Channel catfish (warmwater species)	*Ictalurus punctatus*	Fry	Mortality	78	1	22	(Gaikowski et al., 1999)
				28	3	22	
Fathead minnow (warmwater species)	*Pimephales promelas*	Fry	Mortality	47	1	22	(Gaikowski et al., 1999)
				28	3	22	
Largemouth bass (warmwater species)	*Micropterus salmoides*	Fry	Mortality	179	1	22	(Gaikowski et al., 1999)
				91	3	22	
Yellow perch (warmwater species)	*Perca flavescems*	Fry	Mortality	<47	1	22	(Gaikowski et al., 1999)
				42	3	22	
Atlantic salmon (cold water species)	*Salmo salar*	Fingerling	Mortality	221	1	12	(Gaikowski et al., 1999)
				120	3	12	
Lake trout (cold water species)	*Salvelinus namaycush*	Fingerling	Mortality	298	1	12	(Gaikowski et al., 1999)
				113	3	12	
Rainbow trout (cold water species)		Fingerling	Mortality	162	1	12	(Gaikowski et al., 1999)
				81	3	12	
Muskellunge (coolwater species)	*Esox masquinongy*	Fingerling	Mortality	108	1	17	(Gaikowski et al., 1999)
				78	3	17	
Northern pike (coolwater species)	*Esox lucius*	Fingerling	Mortality	<76	1	17	(Gaikowski et al., 1999)
				<32	3	17	
Walleye (coolwater species)	*Stizostedion vitreum*	Fingerling	Mortality	<96	1	17	(Gaikowski et al., 1999)
				<47	3	17	
White sucker (coolwater species)	*Catostomus commersoni*	Fingerling	Mortality	78	1	17	(Gaikowski et al., 1999)
				47	3	17	
Bluegill (warmwater species)	*Lepomis macrochirus*	Fingerling	Mortality	78	1	22	(Gaikowski et al., 1999)
				47	3	22	
Channel catfish (warmwater species)	*Ictalurus punctatus*	Fingerling	Mortality	78	1	22	(Gaikowski et al., 1999)
				47	3	22	
Fathead minnow (warmwater species)	*Pimephales promelas*	Fingerling	Mortality	78	1	22	(Gaikowski et al., 1999)
				47	3	22	
Largemouth bass (warmwater species)	*Micropterus salmoides*	Fingerling	Mortality	130	1	22	(Gaikowski et al., 1999)
				47	3	22	
Yellow perch (warmwater species)	*Perca flavescems*	Fingerling	Mortality	<130	1	22	(Gaikowski et al., 1999)
				78	3	22	
Rainbow trout	*Oncorhynchus mykiss*	Fingerlings	Mortality	<500	0.25	12	(Rach et al., 1997)
				< 500	0.75	12	
Rainbow trout	*Oncorhynchus mykiss*	Small adult	Mortality	<500	0.25	12	(Rach et al., 1997)
				< 500	0.75	12	
Brown trout	*Salmo trutta*	Adult	Mortality	1000	0.25	12	(Rach et al., 1997)
				250	0.75	12	
Lake trout	*Salvelinus namaycush*	Adult	Mortality	1000	0.25	12	(Rach et al., 1997)
				>500	0.75	12	
Channel catfish	*Ictalurus punctatus*	Adult	Mortality	1000	0.25	12	(Rach et al., 1997)
				>500	0.75	12	
Fathead minnow	*Pimephales promelas*	Adult	Mortality	1000	0.25	12	(Rach et al., 1997)
				>500	0.75	12	
Bluegill	*Lepomis machrochirus*	Adult	Mortality	1000	0.25	12	(Rach et al., 1997)
				>500	0.75	12	
Walleye	*Stizostedion vitreum*	Adult	Mortality	100	0.25	12	(Rach et al., 1997)
				<100	0.75	12	
Rainbow trout	*Oncorhynchus mykiss*	Large adult	Mortality	<500	0.25	12	(Rach et al., 1997)
				< 500	0.75	12	

Table 6
LC50 (median lethal concentration) of hydrogen peroxide to freshwater fish.

Organisms	Life stage	Concentration (μl/l)	Exposure time (h)	Exposure temperature (°C)	Reference
Rainbow trout	Fry	514	0.3	15	(Arndt and Wagner, 1997)
		207	2	15	
Cutthroat trout	Fry	636	0.3	15	(Arndt and Wagner, 1997)
		280	2	15	
Walleye	Fingerling	145.1	12	12	(Clayton and Summerfelt, 1996)
		142.8	96	12	
Rainbow trout	Fingerling	574	0.3	15	(Arndt and Wagner, 1997)
		189	2	15	
Cutthroat trout	Fingerlings	514	0.3	15	(Arndt and Wagner, 1997)
		197	2	15	
Rainbow trout	Adult	>5000	0.5	7	(Rach et al., 1997)
		69.4	24	7	
Rainbow trout	Adult	8660	0.5	12	(Rach et al., 1997)
		42	24	12	
Rainbow trout	Adult	520	0.5	17	(Rach et al., 1997)
		34	24	17	
Rainbow trout	Adult	393	0.5	22	(Rach et al., 1997)
		31.3	24	22	
Channel catfish	Adult	>5000	0.5	7	(Rach et al., 1997)
		369	24	7	
Channel catfish	Adult	>5000	0.5	12	(Rach et al., 1997)
		76.6	24	12	
Channel catfish	Adult	>5000	0.5	17	(Rach et al., 1997)
		57.4	24	17	
Channel catfish	Adult	>5000	0.5	22	(Rach et al., 1997)
		55.5	24	22	
Bluegill	Adult	>5000	0.5	7	(Rach et al., 1997)
		290	24	7	
Bluegill	Adult	3540	0.5	12	(Rach et al., 1997)
		165	24	12	
Bluegill	Adult	3540	0.5	17	(Rach et al., 1997)
		165	24	17	
Bluegill	Adult	2010	0.5	22	(Rach et al., 1997)
		71.5	24	22	

potential risk for various life stages of fishes and non-target organisms in marine and freshwater environments.

The NOEC, LC50, and EC50 of HP on various freshwater and marine organisms have been documented in the literature (Tables 5, 6, 7, and 8) without the cellular accumulation due to its short half-life (HERA Project, 2005). The sensitivity of the fish species is the yardstick for HP toxicity in most laboratory-based tests. Other studies have focused on non-target organisms in freshwater and marine water environments (Tables 7 and 8). Generally, the HP toxicity tests were conducted in all experiments between 0.25 and 96 h except one study (2 to 3 weeks) using various types of freshwater and marine water fishes and non-target organisms at different life stages (sac fry, fry, fingerlings, and small and large adults) (Tables 5 to 8). In general, HP is more toxic during long-term exposure treatments than short-term treatments (Tables 5 to 8).

In light of the COVID-19 pandemic, HP from indoor or outdoor environments may end up in wastewater treatment plants, wastewater stabilization ponds, or local water bodies especially if drainage systems are not properly managed. Further, the toxic effect of various stages of organisms mentioned in Tables 4 to 8 might be HP exposure time-dependent due to their short-lived nature in the environment. This means that the exposed water bodies near effluent (immediate exposure) may severely damage areas from the discharge zone. This damage is lower farther from the discharge site.

The documented toxicity values from the literature studies were compared with the HP recommended dose (0.5%) in terms of the "TC ratio" (Table 4). The no observed effective concentration (NOEC) for

Table 7
NOEC (no observed effective concentration), LC50 (median lethal concentration), and EC50 (effective concentration) of hydrogen peroxide to marine organisms.

Organisms	Species	Life stage	Measured toxicity effect	Concentration (mg/l)	Exposure time (h)	Exposure temperature (°C)	Reference
Copepod	*Calanus finmarchicus*	Adult	NOEC; mortality	0.75	96	10	(Hansen et al., 2017)
Copepod	*Calanus* spp.	Young (Stage V)	LC50	214.1	1	15	(Escobar-Lux et al., 2019)
Copepod	*Calanus* spp.	Young (Stage V)	LC50	77.1	25	15	(Escobar-Lux et al., 2019)
Crab	*Metacarcinus edwardsii*	Young (Larvae)	LC50	1642	0.3	15	(Gebauer et al., 2017)
Lobster	*Homarus americanus*	Young	LC50	1637	1	8 to 14	(Burridge et al., 2014)
Copepod	*Calanus* spp.	Adult	LC50	48.6	1	15	(Escobar-Lux et al., 2019)
Copepod	*Calanus* spp.	Adult	LC50	30.6	25	15	(Escobar-Lux et al., 2019)
Copepod	*Calanus finmarchicus*	Adult	LC50	6	24	10	(Hansen et al., 2017)
Copepod	*Calanus finmarchicus*	Adult	LC50	2.54	96	10	(Hansen et al., 2017)
Lobster	*Homarus americanus*	Adult	LC50	>3750	1	8 to 14	(Burridge et al., 2014)
Shrimp	*Crangon septemspinosa*	Adult	LC50	3182	1	8 to 14	(Burridge et al., 2014)
Mysid	*Mysid* spp.	Adult	LC50	973	1	8 to 14	(Burridge et al., 2014)
Amphipod	*Corophium volutator*	Adult	LC50	46	96	15	(Smit et al., 2008)
Crab larvae	*Metacarcinus edwardsii*	Larvae	EC50; dead + dying	1036	96	15	(Gebauer et al., 2017)
Copepod	*Acartia hudsonica*	Adult	EC50; feeding inhibition	2.6–10	1	9	(Van Geest et al., 2014)

Table 8

NOEC (no observed effective concentration), LC50 (median lethal concentration), and EC50 (effective concentration) and of hydrogen peroxide to freshwater organisms.

Organisms	Species	Life stage	Measured toxicity effect	Concentration (mg/l)	Exposure time (h)	Exposure temperature	Reference
Study in wastewater stabilization pond							
Zooplankton	*Moina* sp.	Adult	NOEC; mortality	1.5	48	21 °C	(Reichwaldt et al., 2012)
Zooplankton	*Daphnia* sp.	Adult	NOEC; mortality	3	48	21 °C	(Reichwaldt et al., 2012)
Zooplankton	*Moina* sp.	Adult	LC50	2	48	21 °C	(Reichwaldt et al., 2012)
Zooplankton	*Daphnia* sp.	Adult	LC50	5.6	48	21 °C	(Reichwaldt et al., 2012)
Study in freshwater environment							
Phytoplankton	Mixture of *Dinobryon* spp., *Ochromonas* spp. and *Chrysochromulina* spp	Adult	NOEC; primary productivity	0.34–34	24	20–23	(Xenopoulos and Bird, 1997)
Microcrustacean	*Ceriodaphnia dubia*	Adult	LC50	1	<24	23 °C	(Geer et al., 2016)
Benthic amphipod	*Hyalella azteca*	Adult	LC50	3.6	2–3 (weeks)	23 °C	(Geer et al., 2016)
Fathead minnow	*Pimephales promelas*	Adult	LC50	19.7	<24	23 °C	(Geer et al., 2016)
Amphipods	*Gammarus lacustris*	Adult	LC50	231.2	24	6–8 °C	(Fedoseeva and Stom, 2013)
Amphipods	*Eulimnogammarus vittatus*	Adult	LC50	238	24	6–8 °C	(Fedoseeva and Stom, 2013)
Amphipods	*Eulimnogammarus verrucosus*	Adult	LC50	1152.6	24	6–8 °C	(Fedoseeva and Stom, 2013)
Amphipods	*Eulimnogammarus cyaneus*	Adult	LC50	119	24	6–8 °C	(Fedoseeva and Stom, 2013)
Amphipods	*Gmelinoides fasciatus*	Adult	LC50	20.4	24	6–8 °C	(Fedoseeva and Stom, 2013)

mortality values were recorded over a wide range of concentrations in the literature at different life stages of various fishes (Tables 4 and 5). The mortality of sac fry (immobile fish after egg hatching), fry (swimming stage), fingerling (young stage of fish), and adults (mature fish) were tested against the HP toxicity. The NOEC is HP exposure time- (between 0.25 and 3 h), temperature- (12 to 22 °C), and species-dependent

(Table 5). In the case of sac fry, no mortality (NOEC) was recorded up to <500 μl/l (0.05%) for 0.25 h and 1000 μl/l (0.1%) for 0.75 h of HP exposure. The recorded minimum and maximum NOEC values varied: from 47 μl/l (0.0047%) for 3 h to 500 μl/l (0.05%) for 0.75 h of exposures for fry; from <32 μl/l (0.0032%) for 3 h to 500 μl/l (0.05%) for 0.25 and 0.75 h of exposures for fingerling; <500 μl/l (0.05%) for 0.25 and

Table 9

Comparison of toxicity calculated ratios (TC ratio of NOEC, LOEC, LC50 and EC50) with WHO-recommended concentration of hypochlorite biocides (HC, 0.1%). The fold lower (−), higher (+) or equal (=) than WHO recommended dose (HC) given in parenthesis.

Reference Table number in this article	Type of organisms	Measured toxicity	Life stage of organisms	Recorded value (mg/l) (A)		Value in mg/l (A) converted to % (B) [B = Recoded value (A) / 10,000]		Fold - increase, decrease or equal (toxicity calculation ratio, TC ratio) [TC ratio = WHO recommended dose (HP 0.5%) or (HC 0.1%) / B]	
				Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Hypochlorite based disinfectants (recommendation of 0.1% in the context of SARS-CoV-2 by WHO)									
Table 10	Freshwater non-target organisms	NOEC	Mortality	–	20	–	0.002%	–	(−50)
	Freshwater non-target organisms	LOEC	Mortality	–	40	–	0.004%	–	(−25)
	Marine water non-target organisms	NOEC	Growth	0.25	0.75	0.000025%	0.000075%	(−1333)	(−4000)
	Marine water non-target organisms	NOEC	Reproduction	–	0.048	–	0.0000048%	–	(−20.83)
	Marine water non-target organisms	LOEC	Reproduction	–	0.066	–	0.0000066%	–	(−15,151)
Table 11	Fresh water fish	LC50	Juvenile	–	28	–	0.0028%	–	(−35.7)
	Fresh water fish	LC50	Adult	–	48	–	0.004%	–	(−20.8)
	Freshwater non-target organisms	LC50	Adult	0.005	87.30	0.0000005%	0.00873%	(−200,000)	(−11.5)
	Freshwater non-target organisms – (sediment mixed with water)	LC50	Adult	0.70	1014	0.00007%	0.1014%	(−1428)	(=1)
	Synthetic salt water non-target organisms	LC50	Adult	–	0.3	–	0.00003%	–	(−3333)
	Sea water Fish	LC50	Larvae	0.19	0.32	0.000019	0.000032%	(−5263)	(−3125)
	Sea water non-target organisms	LC50	Juvenile	0.05	0.32	0.000005%	0.000032%	(−20,000)	(−3125)
	Sea water non-target organisms	LC50	Adult	0.12	0.28	0.000012%	0.000028%	(−8333)	(−3571)
Table 12	Marine non-target organisms (algae)	EC50	Growth inhibition	1.73	2.91	0.000173%	0.000291%	(−578)	(−343)
	Marine non-target organisms (amphipod)	EC50	Biomass	1.1	2.2	0.00011%	0.00022%	(−909)	(−454)

Table 10

NOEC (no observed effective concentration) and LOEC (lowest observed effective concentration) of chlorine (as sodium hypochlorite) to freshwater and marine water organisms.

Test substance	Organisms	Species	Life stage	Measured toxicity effect (NOEC/LOEC)	Concentration (mg/l)	Exposure time (h)	Exposure temperature °C	Reference
Freshwater								
NaClO	Whirligig beetles	*Orectogyrus alluaudi*	Adult	NOEC - Mortality	20	24	18–22	(Fajana et al., 2017)
NaClO	Whirligig beetles	*Orectogyrus alluaudi*	Adult	NOEC - Mortality	20	48	18–22	(Fajana et al., 2017)
NaClO	Whirligig beetles	*Orectogyrus alluaudi*	Adult	LOEC - Mortality	40	24	18–22	(Fajana et al., 2017)
NaClO	Whirligig beetles	*Orectogyrus alluaudi*	Adult	LOEC - Mortality	40	48	18–22	(Fajana et al., 2017)
Marine water								
NaClO	Algae	*Isochrysis galbana*	–	NOEC - Growth	0.25	96	20	(López-Galindo et al., 2010a)
NaClO	Algae	*Dunaliella salina*	–	NOEC - Growth	0.5	96	20	(López-Galindo et al., 2010a)
NaClO	Algae	*Isochrysis galbana*	–	NOEC - Growth	0.75	96	20	(López-Galindo et al., 2010a)
NaClO	Algae	*Dunaliella salina*	–	NOEC - Growth	0.75	96	20	(López-Galindo et al., 2010a)
NaClO	Australian cladoceran	*Ceriodaphnia dubia*	Adult	NOEC- Reproduction	0.048	10 (days)	23	(Manning et al., 1996)
NaClO	Australian cladoceran	*Ceriodaphnia dubia*	Adult	LOEC - Reproduction	0.066	10 (days)	23	(Manning et al., 1996)

0.75 h exposures for small adults; and from <100 μl/l (<0.01%) for 0.75 h exposure to 1000 μl/l (0.1%) for 0.25 h exposure for the adult fish. There was a decrease in TC ratio (shown as "–" in Table 4 parentheses) when all these NOEC values were compared with the WHO-recommended dose of HP (0.5%). Table 4 shows that the TC ratio for NOEC ranges from 5- to 156-fold lower than the WHO recommended dose (0.5%). This indicates that the WHO-recommended dose (0.5%) may or may not be dangerous to freshwater fishes. In other words, the value of 156-fold is close to risk and 5-fold is far from the risk.

Similar to the NOEC values, the LC50 in various experiments (at various temperature and exposure time ranges) also showed a wide range of variations (Table 6). The minimum and maximum LC50 values for fry are between 207 μl/l (0.0207%) at 2 h to 636 μl/l (0.0636%) at 0.3 h of treatment periods. Similarly, for fingerlings, the recoded minimum and maximum LC50 values ranged between 142.8 μl/l (0.01428%) at 96 h to 574 μl/l (0.0574%) at 0.3 h. Both fry and fingerlings LC50s are less than the HP dose (0.5%) recommended by WHO.

There are two datasets in the literature for adult fish: The first set of LC50s (fry, fingerling, and adult) are lower than the WHO-recommended dose (31.3 to 3540 μl/l or 0.00313 to 0.354%), and the second set LC50s (adult) are higher than the WHO-recommended dose (>5000 and 8660 μl/l or >0.5 and 0.866%) (Tables 4 and 6). The TC ratios in the first set (fry, fingerlings and adults) are lower (1.41- to 159.7-fold) and the second set (some adult fishes) is higher (0.58 to >1-fold) than the WHO-recommended dose (Table 4). This means that the first set of organisms are receiving a higher risk than the second set of organisms (Tables 4 and 6). Therefore, HP toxicity is influenced by the temperature and exposure time as well as the life stage of the fish; of course, toxicity is also species-dependent (Rach et al., 1997). In other aspects, all fishes mentioned in Table 6 are commercially important food sources and are grown in freshwater aquaculture. Table 6 shows that fry and fingerlings are the young stages of the fishes and are more sensitive against the HP toxicity than the adult stage. Therefore, the WHO-recommended dose of HP not only contaminates the water bodies, but the use of this water in aquaculture may also retard fish growth. HP-contaminated water may also harm primary productivity of an aquatic ecosystem (Fig. 1).

In addition to edible fishes, other studies have examined the effect of HP on marine and freshwater non-target organisms (Burridge et al., 2014; Escobar-Lux et al., 2019; Sinha et al., 2020, 2018; Van Geest et al., 2014; Yang et al., 2018) (Tables 7 and 8). For example, the algae-cide activity of HP at ≥20 mg/l (0.002%) was successful against harmful algal blooms. This same concentration had significant toxicity against

non-target organisms like zooplankton (Yang et al., 2018). Similarly, a 100% mortality of copepod (a non-target organism) was found after 1 h at 20% of the recommended dose (340 mg/l, 0.034%) of HP for the treatment of salmon lice (Escobar-Lux et al., 2019). Both of these non-target organisms (zooplankton and copepod) are ecologically important in the aquatic food chain: These organisms serve as an intermediary species to transfer energy from primary producers to larger invertebrate predators who in turn feed on them (Fig. 1). Therefore, in connection with the recommendation of HP by WHO (0.5%) in the context of SARS-CoV-2 outbreak, the literature-documented LC50 values (Table 7) were calculated for the fold increase or decrease with 0.5% of HP and given in Table 4.

The NOEC, LC50, and EC50 values of different species of marine and freshwater non-target organisms are given in Tables 7 and 8. In the case of marine adult organisms, only one study for copepods has recorded the NOEC value for mortality (0.75 mg/l or 0.000075%) with a TC ratio of 6666-fold lower than the WHO-recommended dose. This means that the copepod has strong risk when this organism is exposed to the WHO-recommended concentration (0.5%). In addition, due to differences in test time and temperature, a wide range of LC50 values were recorded for young and adult animals in different studies (Table 7). Stage V copepods, crab larvae, and young lobster are considered "young animals" versus "adult" non-target organisms. The range of LC50 for young non-target organisms is 77.1 to 1642 mg/l (0.0071 to 0.1642%) and for adults is 2.54 to >3750 mg/l (0.000254 to >0.375%). The TC ratio for young animals is 3.05 to 70.4-fold lower than the WHO-recommended dose; for adult animals, it is 1.33- to 1968-fold lower (Table 4). These values indicate that any life stage of an animal can be effected by HP when the animal is exposed to concentrations below the WHO-recommended dose (0.5%).

However, the risk level for some non-target organisms like young crab, young and adult lobster, and adult shrimp are lower (LC50 is >1000) than the other remaining tested animals (LC50 is <1000). In the case of EC50 (inhibition of 50% of the animal performance), feeding inhibition was at 2.6 to 10 mg/l (0.00026 to 0.001%) for copepod and 1036 mg/l (0.1036%) for crab larvae. The feeding inhibition of copepod led to a TC ratio reduction of 500- to 1923-fold; it was 4.83-fold for dead and dying crab larvae (Tables 4 and 7). Therefore, 0.5% of HP exposure to non-target animals not only risks mortality but can also impact the feeding behavior of the animals. The non-target organisms mentioned in Table 7 are ecologically significant in the food chain of marine environments. The above-mentioned values (NOEC, LC50 and EC50) are environmentally relevant because the range of HP doses is between

Table 11
LC50 (median lethal concentration) of chlorine (as calcium hypochlorite or sodium hypochlorite) to freshwater/synthetic salt water and marine organisms.

Test substance	Organisms	Species	Life stage	Concentration (mg/l)	Exposure time (h)	Exposure temperature °C	Reference
Fresh water fish							
Ca(ClO)$_2$	Rohu Fish	*Labeo rohita*	Juvenile	28	96	25	(Aswale et al., 2020)
NaOCl	Zebrafish	*Danio rerio*	Adult	48	24	23–26	(Magalhães et al., 2007)
Freshwater non-target organisms							
NaClO	Whirligig beetles	*Orectogyrus alluaudi*	Adult	87.30	24	18–22	(Fajana et al., 2017)
NaClO	Whirligig beetles	*Orectogyrus alluaudi*	Adult	72.32	48	18–22	(Fajana et al., 2017)
NaClO	Amphipod	*Hyalella azteca*	Adult	3.70	24	21	(Sano et al., 2004)
NaClO	Oligochaete	*Lumbriculus variegatus*	Adult	0.70	24	21	(Sano et al., 2004)
NaClO	Cladoceran	*Dahnia magna*	Adult	0.4	24	21	(Sano et al., 2004)
NaClO	Zebra mussel	*Dreissena polymorpha*	Adult	23	48	21	(Sano et al., 2004)
Cl*	Branchiopoda	*Ceriodaphnia dubia*	Adult	<0.02 to 0.14[b]	24	25	(Taylor, 1993)
Cl*	Branchiopoda	*Ceriodaphnia dubia*	Adult	0.012 to 0.048[c]	24	25	(Taylor, 1993)
Cl*	Branchiopoda	*Ceriodaphnia dubia*	Adult	0.005 to 0.027[d]	24	25	(Taylor, 1993)
Ca(ClO)$_2$	Rainbow mussel	*Villosa iris*	Adult	0.22	24	20	(Valenti et al., 2006)
Ca(ClO)$_2$	Rainbow mussel	*Villosa iris*	Adult	0.26	48	20	(Valenti et al., 2006)
Ca(ClO)$_2$	Rainbow mussel	*Villosa iris*	Adult	0.18	72	20	(Valenti et al., 2006)
Ca(ClO)$_2$	Wavy rayed lampmussel	*Lampsilis fasciola*	Adult	0.145	24	20	(Valenti et al., 2006)
Ca(ClO)$_2$	Wavy rayed lampmussel	*Lampsilis fasciola*	Adult	0.080	48	20	(Valenti et al., 2006)
Ca(ClO)$_2$	Wavy rayed lampmussel	*Lampsilis fasciola*	Adult	0.090	72	20	(Valenti et al., 2006)
Ca(ClO)$_2$	Oyster mussel	*Epioblasma capsaeformis*	Adult	0.107	24	20	(Valenti et al., 2006)
Ca(ClO)$_2$	Cumberland combshell	*Epioblasma brevidens*	Adult	0.07	24	20	(Valenti et al., 2006)
Ca(ClO)$_2$	Dwarf wedgemussel	*Alasmidonta heterodon*	Adult	0.107	24	20	(Valenti et al., 2006)
Ca(ClO)$_2$	Dwarf wedgemussel	*Alasmidonta heterodon*	Adult	0.095	48	20	(Valenti et al., 2006)
Freshwater non-target organisms (Sediment + water mixed experiments)							
NaClO	Amphipod	*Hyalella azteca*	Adult	3.70 to 67[a]	24	21	(Sano et al., 2004)
NaClO	Oligochaete	*Lumbriculus variegatus*	Adult	0.70 to 1014[a]	24	21	(Sano et al., 2004)
Synthetic salt water non-target organisms							
NaClO	Brine shrimp	*Artemia* spp.	Cysts	0.3	72	21	(Sano et al., 2004)
Sea water fish							
NaClO	Fish	*Oryzias javanicus*	Larvae	0.32	24	26	(Añasco et al., 2008)
NaClO	Fish	*Oryzias javanicus*	Larvae	0.29	48	26	(Añasco et al., 2008)
NaClO	Fish	*Oryzias javanicus*	Larvae	0.20	72	26	(Añasco et al., 2008)
NaClO	Fish	*Oryzias javanicus*	Larvae	0.19	96	26	(Añasco et al., 2008)
Sea water non-target organisms							
NaClO	Amphipod	*Hyale barbicornis*	Juveniles	2.5	48	20	(Añasco et al., 2008)
NaClO	Amphipod	*Hyale barbicornis*	Juveniles	2.3	72	20	(Añasco et al., 2008)
NaClO	Amphipod	*Hyale barbicornis*	Juveniles	2.2	96	20	(Añasco et al., 2008)
NaClO	Estuarine java medaka	*Oryzias javanicus*	Juvenile	0.05	96	27	(Koyama et al., 2008)
NaClO	Australian cladoceran	*Ceriodaphnia dubia*	Adult	0.28	1	23	(Manning et al., 1996)
NaClO	Australian cladoceran	*Ceriodaphnia dubia*	Adult	0.12	24	23	(Manning et al., 1996)
NaClO	Easter king prawn	*Penaeus plebejus*	Adult	0.18	24	23	(Manning et al., 1996)

Cl* - Cl in the form of OCl, HOCl, NH$_2$Cl, NHCl$_2$.
[a] Sodium hypochlorite experiments were conducted with water alone and water mixed with different ratios of sediments.
[b] Experiment with food in static media.
[c] Experiment without food in static media.
[d] Continuous-flow of media without food.

1200 and 1500 mg/l (0.12 to 0.15%). This is a normal treatment concentration for killing salmon lice (Kiemer and Black, 1997), which is less than the WHO-recommended concentration of 0.5%. Therefore, ecologists should consider the negative effect of applied HP in the context of SARS-CoV-2 when HP is mixed with marine water. We assume that the mixed concentration of HP in water undergoes rapid dilution (Hansen et al., 2017), low degradation of active ingredient (Burridge et al., 2014), and more diffuse spread in exposure regimes. Therefore, we may expect a longer exposure duration for non-target organisms that might also be sensitive to the toxin.

The application of HP in a wastewater stabilization pond is challenging for the removal of toxic cyanobacteria due the wide range of natural and beneficial flora (e.g., Zooplanktons) (Reichwaldt et al., 2012). A study of a wastewater stabilization ponds showed that the NOEC and

Table 12
EC50 (effective concentration) of chlorine (as sodium hypochlorite) on marine organisms.

Test substance	Organisms	Species	Life stage	Measured toxicity effect (EC50)	Concentration (mg/l)	Exposure time (h)	Exposure temperature °C	Reference
NaClO	Amphipod	*Hyale barbicornis*	Juveniles	Growth	2.2	24	20	(Añasco et al., 2008)
NaClO	Amphipod	*Hyale barbicornis*	Juveniles	Growth	1.6	48	20	(Añasco et al., 2008)
NaClO	Amphipod	*Hyale barbicornis*	Juveniles	Growth	1.2	72	20	(Añasco et al., 2008)
NaClO	Amphipod	*Hyale barbicornis*	Juveniles	Growth	1.1	96	20	(Añasco et al., 2008)
NaClO	Algae	*Isochrysis galbana*	–	Growth	2.91	96	20	(López-Galindo et al., 2010a)
NaClO	Algae	*Dunaliella salina*	–	Growth	1.73	96	20	(López-Galindo et al., 2010a)

LC50 value of the two non-target zooplanktons like Moina (1.5 mg/l or 0.00015% for NOEC and 2 mg/l or 0.0002% for LC50) and Daphnia (3 mg/l or 0.0003% for NOEC and 5.6 mg/l or 0.00056% for LC50) were below the required dose of HP (40 mg/l or 0.004%) for the removal of toxic cyanobacteria (Reichwaldt et al., 2012) (Table 8). The recommended dose of HP for cyanobacteria was also harmful to bacterioplankton—a non-target organism (Xenopoulos and Bird, 1997). The required concentration of HP 0.004% for the removal of toxic cyanobacteria in wastewater stabilization pond is 125-fold lower than then WHO-recommended concentration of HP (0.5%). In addition, the TC ratio for both NOEC and LC50 of beneficial zooplankton is 892.9- to 3333-fold lower than the WHO-recommended dose (Table 4). Therefore, the drained runoff of flushed or wiped HP (0.5%) used as biocidal agent against SARS-CoV-2 in hospitals or public places and/or the residential areas may ultimately reach wastewater stabilization ponds; thus, there is a potential risk to beneficial flora like zooplanktons in wastewater stabilization ponds. Similarly, the NOEC of phytoplankton primary productivity 0.34 to 34 mg/l (in percent 0.000034% to 0.0034%) is 147- to 14,705-fold lower (TC ratio) than the WHO recommended dose. This is also evidence of the risk of primary production in a freshwater environment due to HP at 0.5%.

A wide range of LC50 values for freshwater non-target organisms are also recorded in the literature (Table 8). The LC50 value for various adult non-target organisms ranges from 1 to 1152.6 mg/l (0.0001 to 0.11526%), which is 4.3- to 5000-fold higher (TC ratio) than the HP recommended by WHO (0.5%) (Table 4). Consistent with the seawater non-target organisms, there is an environmentally significant role of freshwater non-target organisms; these also pose a risk to the exposure of HP below the WHO recommended dose.

In addition to acute toxicity, chronic HP exposure (continuous exposure of HP on target or non-target organisms over a period of long time) may also damage organisms. Toxicity due to HP exposure on non-target organisms includes benthic animals (Abeleoeschger et al., 1994; Buchner et al., 1996; da Rosa et al., 2008; Escobar-Lux, 2016; Fagereng, 2016; Fang et al., 2018) and crustaceans (Chhetri et al., 2019). Damage was seen to the gills in fish and crabs (Arndt and Wagner, 1997; Rach et al., 1997; Wang et al., 2014). There were negative effects on daphnia growth and reproduction (Meinertz et al., 2008), solution-avoidance behavior of amphipods (Fedoseeva and Stom, 2013), change in feeding behavior and paralysis of copepods (Van Geest et al., 2014), decreased swimming speed, and decreased crustacean heart rate (Bownik and Stępniewska, 2015). There was a reduced abundance of phytoplankton, zooplankton, and macro-fauna (Matthijs et al., 2012). Here, the exposed HP concentrations were much lower than those used to treat sea lice (Urbina et al., 2019), which could affect the behavioral responses of some crustaceans. The adverse physiological responses include mitochondrial membrane and DNA damage in freshwater crab (Wang et al., 2014) and Daphnia magna (Pellegri et al., 2014). The increased oxidative stress in the digestive glands of freshwater mussels is also a symptom of HP toxicity (Labieniec and Gabryelak, 2007). Therefore, other than mortality and growth reduction, many biochemical changes are also expected in non-target organisms due to HP exposure.

Soil spiked with HP up to 60 mM could enhance the growth and biological parameters of the plant Ficus deltoidea and promote the mineral uptake (Nurnaeimah et al., 2020). Even though it is beneficial for plant growth, no reports are available in the literature at high HP exposure (>60 mM). One study proved that the plant tissue accumulation of Cu and Zn in contaminated soil was enhanced by the addition of HP (Qi et al., 2004). Millimolar HP levels inhibit plant growth, but yeast (Semchyshyn and Valishkevych, 2016) and mammalian cell (Nakamura et al., 2003) toxicity occurs at micromolar levels. HP does not accumulate in the tissues of fish and earthworms due to its reactive nature and short half-life (ATSDR, 2002); however, HP may damage DNA at the millimolar level (Mincarelli et al., 2016). Further studies are required including statistical analysis of HP toxicity in terrestrial environments.

5. Chlorine-based disinfectants

5.1. Nature of chlorine-based disinfectants in the environment

Chlorine-based disinfectants have a long history and are used as disinfectants in swimming pools and hospitals. The anti-fouling biocidal nature of chlorine is used to control the biofouling that occurs in coolant water intake systems in electric power plants (White, 1999). Sodium hypochlorite (NaOCl) is a widely used disinfectant in many sectors especially in sewage treatment and aquaculture management. The action of NaOCl depends on the concentration of residual chlorine and the pH of the solution (Emmanuel et al., 2004). The commercially available HC (sodium or calcium hypochlorite) contains various active compounds of free chlorine like hypochlorite ion (OCl-), hypochlorous acid (HOCl), and chlorine (Cl_2). Trihalomethanes (THMs) are a carcinogenic compound that can be produced by the reaction of chlorine compounds with organic materials like the humic and fulvic acids present in natural water ("Formation of Haloforms during Chlorination of Natural Waters,", 2002). The cytotoxicity, genotoxicity, and mutagenicity of THMs were extensively reviewed by Medeiros et al. (de Castro Medeiros et al., 2019). Unlike hydrogen peroxide, the half-life of HC with an active chlorine concentration of 10% w/w is 800 days at 15 °C, 220 days at 25 °C, 3.5 days at 60 °C, and less than 2 h at 100 °C. However, the half-life of HC with an active chlorine concentration of 5% w/w is 5000 days at 15 °C, 790 days at 25 °C, 13.5 days at 60 °C, and 6 h at 100 °C (Commission Regulation (EC), 2017). The decomposition of HC in air is accelerated by direct exposure to light.

5.2. The biocidal effect of chlorine-based disinfectants on non-target organisms

A variety of reports are available in the literature concerning the impact of residual chlorine on marine and freshwater organisms or the biocidal chlorine (sodium hypochlorite or calcium hypochlorite) exposure to aquatic animals (Tables 9, 10, 11 and 12). The observed NOEC, LOEC, LC50, and EC50 shows evidence of chlorine toxicity to non-target organisms (Tables 9 to 12). The NOEC of chlorite-based biocides were dependent on the life stage and species of animals tested, type of biocide, exposure time, and the nature of water (sea water or freshwater) (Table 10).

In the literature, the NOEC/LOEC (LOEC, the measured effect has been observed at the lowest exposure concentration tested) is calculated for mortality in freshwater organisms and for growth and reproduction in marine water organisms (Table 10). The NOEC and LOEC for mortality are 20 and 40 mg/l (0.002 and 0.004%), respectively, for freshwater organisms. However, the range of NOEC for growth of marine organisms is 0.25 to 0.75 (0.000025 to 0.000075%). In the case of reproduction, the recoded NOEC and LOEC for reproduction is 0.048 (0.0000048%) and 0.066 mg/l (0.0000066%), respectively. Table 9 shows that all LOECs and NOECs are several fold (>25-fold) to several thousand fold (15,151-fold) lower (TC ratio) than the WHO recommended dose (0.1%). Moreover, although the tested parameters vary between freshwater and marine water (NOEC; mortality for freshwater and growth and reproduction for marine water and LOEC; mortality for freshwater and reproduction for marine water), comparative results from Table 9 showed that the toxicity level of HC is higher in marine water than in freshwater. This means that the exposed HC in the context of SARS-CoV-2 is more toxic to marine non-target organisms than freshwater organisms.

The LC50 uses a minimum of 1 to a maximum of 96 h per the standard protocols, and the tested temperature ranged from 18 to 27 °C per the habitat of the animals in freshwater and seawater aquatic organisms (Table 11). Various chlorine-based substances like commercial household bleach (NaClO, 3.5% w/v), NaClO, Ca(ClO)$_2$, OCl, HOCl, NH$_2$Cl, and NHCl$_2$ have been used. The LC50 fixed for juvenile (28 mg/l or 0.0028%) and adult freshwater fishes (48 mg/l or 0.0048%) are 35.7- and 20.8-fold (TC

ratio) lower than the WHO-recommended dose (Table 11). Similarly, the TC ratio had a 11.5- to 200,000-fold decrease for freshwater non-target organisms. However, the LC50 value (0.1014%) for non-target organism is similar to the WHO-recommended dose of HC (0.1%) when water is mixed with the sediment (Tables 9 and 11). The LC50 of various types of non-target organisms (juvenile, larvae and adult) in fresh water media or in synthetic saltwater media also showed a wide range of variations—all are above the TC ratio and 3000-fold lower than the WHO recommended dose of HC. Thus, these results clearly showed that spraying of bleach or other chlorinated disinfectants at the WHO-recommended dose (0.1%) is potentially lethal to fish and non-target organisms in both fresh and marine water ecosystems. In addition, high LC50 values (means low toxicity) and the value equal for the WHO-recommended dose of 0.1% HC (the TC ratio fold equal to 1, Table 9) in sediment mixed water indicates the protective action of sediments. This might be due to organic materials in the sediment reacting with hypochlorite and reducing their biocidal action (Table 9) (Sano et al., 2004). Therefore, the risk might be lower for non-target organism in water enriched with sediment and/or organic materials than the clean water. In the case of EC50 values, growth development is the end-point parameter in the literature for marine organisms (Table 10). The observed EC50 for algae and amphipods was 1.73 to 2.91 mg/l (0.000173% to 0.000291%) and 1.1 to 2.2 mg/l (0.00011 to 0.00022%), respectively (Table 12). The EC50 TC ratios are less than the WHO recommended dose of HC where the TC ratios range from 343- to 909-fold. Therefore, marine non-target organisms have an ecologically significant role in oceans and may also be due to HC exposure.

In addition to the direct toxic effect of hypochlorite on aquatic animals, indirect effects have also been documented. Chlorine-based compounds have been studied against pathogenic and invasive species. However, the residual chlorine carried by ballast water (Añasco et al., 2008) and nuclear power plant effluent (Padhi et al., 2019) carried the residual chlorines, which may have adverse effects on non-target marine organisms especially on a long-term basis. The main symptoms are behavioral changes (Aswale et al., 2020; Fajana et al., 2017; Nimkerdphol and Nakagawa, 2008), morphological changes (Rock et al., 2011), histopathological alterations in gill and liver of fishes (Aswale et al., 2020; López-Galindo et al., 2010c, 2010b), cytotoxicity and genotoxicity (Gül et al., 2009; Hutchinson et al., 1998), alteration of enzyme activity (Ebenezer et al., 2012; Elia et al., 2006; Pesonen and Andersson, 1992), HC-exposed organism failure to recover in uncontaminated water (Chavan et al., 2017; Valenti et al., 2006), and reduction in phytoplankton biomass (Ahamed et al., 1993; Chuang et al., 2009; Poornima et al., 2005). Although these studies emphasize the toxic potential of chlorine-based disinfectants in the environment, they are still used indiscriminately due to the biocidal nature of residual chlorine in water; discharge is barely regulated (Magalhães et al., 2007). Therefore, it is necessary to monitor the local environment including the toxic effects on aquatic organisms.

6. Concluding remarks and recommendations

After the COVID-19 pandemic, guidelines released by Environmental Protection Agency provided step-by-step instructions for cleaning public and work places, business centers, schools, and homes. A list of disinfects are recommended by WHO including common disinfectants like hydrogen peroxide (0.5%, HP) and chlorine-based disinfectants (0.1%, HC). These have been successfully tested in the laboratory against human coronaviruses and SARS-CoV-2 on inanimate surfaces like metal, glass, and plastics. The disinfectants used to control SARS-CoV-2 in outdoor environments are oxidative. The biocidal activity of hydrogen peroxide and hypochlorite disinfectants has long been used against sea lice ranging from 50 to 1000 mg/l; this dose is based on the life stage of the fish and environmental factors like temperature. However, they can also be toxic to aquatic organisms like macroinvertebrates (a non-target organism) at a very low dose. Although most biocides are biodegradable in field conditions, the degradation compounds can be harmful to non-target

organisms. Surface runoff accelerates the chance of mixing the disinfectants from exposed areas to local waterbodies, which can lead to toxicity on the aquatic macro invertebrates. In addition, the waste generated from the broad use of hydrogen peroxide and hypochlorite can contaminate the freshwater environment via runoff.

In this literature review, a wide range of statistical yardsticks for toxicity like LOEC, NOEC, LC50, and EC50s were recorded for HP and HC in different studies for different life stages of freshwater and seawater aquatic animals. The recorded minimum and maximum values of NOEC, LC50, and EC50 were far from the recommended dose for sea lice control. The difference between the toxicity values recorded in the literature studies and the WHO-recommended dose was calculated and compared (toxicity calculated ratio, TC ratio). The following findings are obtained from the TC ratio for overall comparison of the results:

1) TC ratios range from single digit to several thousand-fold lower than the recommended dose for HP (0.5%) and HC (0.1%).
2) High and low TC ratios indicate that the organisms are nearing risk and far from the risk, respectively, in terms of NOEC, LOEC, LC50, and EC50.
3) Generally, young animals have a higher risk than adults as measured by NOEC, LOEC, LC50, and EC50.
4) A high TC ratio in terms of EC50 showed that 0.5% of HP exposure to non-target animals not only risks mortality but can also impact animal feeding behavior.
5) In general, the toxic level of HP and HC is higher in marine water-sensitive organisms than freshwater organisms.
6) The HP recommended concentration (0.5%) not only risks freshwater- and marine water-sensitive organisms but also beneficial flora like zooplankton in wastewater stabilization ponds.

These results suggest that the exposure of HP and HC to aquatic environment may primarily affect the macroinvertebrates—an important component in the food web that alters the biota structure. Therefore, we conclude that it is urgent to critically assess and monitor the environment—especially non-target organisms in water bodies located in and around disinfectant-exposed areas. While HP and HC have long been used as a biocidal agent, the literature suggests that they are toxic to aquatic organisms. Therefore, work should be done in real field conditions considering the following aspects: The amount of disinfectants used, correlation to the levels measured in biotic and abiotic settings, disinfectant mobility in aquatic environments, disinfectant action on non-target aquatic and terrestrial organisms, potential phytotoxicity to non-target aquatic plants, and degree of loss of gross primary productivity in waterbodies. These parameters should be tested as soon as possible to understand and avoid the toxicity risk of disinfectants in the future under real environmental conditions. Furthermore, better guidance is needed to manage aquatic environments in light of disinfectant use. If disinfectant exposure is not compliant with the existing policies and regulations related to water management, then we recommend that policy-makers revise the policies for critical assessment and monitoring of areas exposed to disinfectants.

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Declaration of competing interest

The author has no conflicting interest.

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