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Secondary exposure and risk assessment of biocides as disinfectant sprays for COVID-19 prevention

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The importance of disinfection has recently increased owing to the spread of infections, such as coronavirus disease 2019 (COVID-19). However, exposure to the biocidal products used for disinfection poses health risks. This study aimed to determine the safe use of biocides and the potential for secondary exposure in the general population. To obtain information on the exposure factors on site, an interview survey was conducted for 2 weeks and 10 days using a questionnaire. Toxicology studies were performed to determine the toxicity of each chemical in various biocidal products. The inhalation and dermal exposure algorithms in ConsExpo 4.0, a software developed by the Dutch National Institute for Public Health and the Environment (RIVM), were used to assess the risk of active substances in biocidal products. The average amounts of disinfectants and pesticides used in indoor environments per unit time were 5948.50 ± 72,434.76 mg and 201.61 ± 305.91 mg, respectively. Ethanol had the highest inhalation hazard quotient (HQ_{inh}) of 1.48E+02 while sodium dichloroisocyanurate had the lowest value of 1.74E−10. The HQ_{inh}/HQ_{der} ratios for the 10 active substances ranged from 1.51E+00 to 2.73E+05 were greater than 1, indicating that inhalation exposure had a greater effect than dermal exposure. The hazard index (HI) of the 10 active substances, excluding ethanol, was less than 1, indicating the absence of potential health risks. Therefore, to reduce the health risks associated with secondary exposure, disinfection should be performed during periods when individuals are away from the site to be disinfected, such as after regular working hours, and individuals should be encouraged to enter this site the following day instead of after the disinfection exercise. Methods, such as applying an active substance from a biocidal product to a cloth or fabric to carry out the disinfection protocol, should also be considered.

Keywords COVID-19, Risk assessment, Secondary exposure, General population, Disinfection, Biocidal product

Biocidal products are commonly used in residential, commercial, and public facilities to prevent the spread of infectious diseases[1]. Recently, the importance of disinfection has increased owing to the spread of infectious diseases, such as coronavirus disease 2019 (COVID-19)[2]. Thus, strengthening the disinfection of multi-use facilities, such as offices, medical facilities, public transportation, and restaurants, is essential to prevent the spread of COVID-19[3]. However, concerns have been raised regarding the damage induced by misuse and overexposure to biocidal products, as their indiscriminate use has increased since the COVID-19 crisis[4]. The use of biocides is strictly regulated worldwide, and efforts are being made to ensure their efficient management[5]. The Federal Insecticide Fungicide Rodenticide Act (FIFRA) in the United States was enacted in 1972 while the Biocide Product Regulation (BPR) was enacted in the European Union (EU) in 1998 to establish and regulate laws for the management of biocidal products[6,7]. The Korean Household Chemical Products and Biocides Safety Act (K-BPR) was enacted in 2019 to ensure comprehensive safety management of biocides[8].

Most previous studies have explored current practices and working environments related to disinfection and biocidal product usage patterns, specifically focusing on their application in both residential and multiuse

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facilities. The use of disinfectants and biocides has increased owing to the spread of COVID-19, and a risk of secondary exposure for the general population could arise as the emitted substances remain and are released into indoor spaces[9]. Sodium hypochlorite exhibits an acute health effect and reacts with ammonia both indoors and outdoors to produce chloramine (NH_2Cl) gas, which can cause respiratory problems[10]. In a study comprising children indirectly exposed to biocides, the use of bleach as a disinfectant at home and school increased the frequency of respiratory symptoms and other associated infections[11]. In addition, a survey of non-occupationally exposed adults and elderly people revealed a dose–response relationship, indicating that asthma symptoms were more likely to occur when irritating disinfectants, such as bleach and ammonia, were used on a weekly basis[12].

Disinfectants are essential for preventing the spread of COVID-19. However, health risks might arise when the general population enters or remains in a recently disinfected area. To address this concern, this study evaluates the exposure and toxicity of biocidal products used by disinfection workers and determines the safe re-entry time for the general population. The hazard quotient (HQ) calculations and risk assessment models provide critical insights into the temporal dynamics of exposure levels. These findings could help establish enhanced safety guidelines and mitigate potential health risks from residual biocides in indoor environments.

Methods
Interview survey
Interview surveys were conducted using a questionnaire and by recruiting disinfection companies in the metropolises of Seoul, Busan, Daejeon, Daegu, and Gwangju, South Korea, from April to September 2021. A total of 300 disinfection workers participated in interview surveys conducted over a period of 10 days within 2 weeks, while considering the frequency of disinfection at each location. In addition to survey responses, direct field observations were conducted to improve the accuracy of exposure assessment. The researcher accompanied the disinfection workers during their tasks to evaluate key exposure factors, including the amount of disinfectant used, exposure duration, and biocidal active substances. Based on the survey responses and field observations, a total of 4762 exposure cases were identified and categorized according to the type of biocidal products used and the site of application. The volume of the room was measured using a laser distance meter (SMART-300, Korea). The total amount of disinfectant sprayed at the site was determined using the difference in weight before and after. To ensure data reliability, a cross-validation process was applied by comparing self-reported data with direct measurements from field observations. If inconsistencies were detected, additional interviews with disinfection workers were conducted to verify the accuracy of reported exposure cases. The disinfectants and pesticide-active substances used for disinfection were selected as targets, and the weight fraction and dilution factor of each product were investigated, as shown in Table 1. All methods were carried out in accordance with relevant guidelines and regulations. Informed consent was obtained from all subjects and their legal guardian. This study was approved by the Institutional Review Board of Daegu Catholic University (IRB No. CUIRB-2022-056).

Toxicity values for the active substances in biocidal products
Inhalation and absorption through the skin were selected as the exposure routes depending on the purpose and type of product used. As shown in Table 2, the toxicity of the active substances in the biocidal product was assessed based on official and reliable experimental reports as well as studies[13–22]. To determine the dose level at which adverse effects can occur, point of departure (POD) values, such as the no observed adverse effect level (NOAEL) and no observed adverse effect concentration (NOAEC), were employed. The toxicity reference concentration (RfC) and reference dose (RfD) for the general population were calculated by applying the ECHA's assessment factor (AF) based on reliable toxicity values[23].

Assessing exposure and health risk
Secondary exposure is assumed to occur when the general population remains in or enters the site after disinfection[24]. Secondary exposure scenarios include inhalation due to the volatilization of disinfectants and pesticides that remain on surfaces after disinfection and dermal exposure from contact with active substances

			Dilution factor	
Biocidal product categories	**Active substance in biocidal product**	**Weight fraction (%)**	**Min**	**Max**
Disinfectants	Sodium hypochlorite	0.013–0.3	1	1
	Ethanol	83	1	1
	C12-18 Benzalkonium chloride	9–20	200	300
	Oxone	49.7	100	100
	Quaternary ammonium compounds	0.07–4.5	1	200
	Sodium dichloroisocyanurate	1.08	1000	1000
Pesticides	Deltamethrin	1.01–2.5	40	400
	Cypermethrin	5	150	285
	λ-Cyhalothrin	2.5	50	300
	Permethrin	30	100	600
	Etofenprox	10	200	500

Table 1. Weight fractions and dilution factors of the active substances in biocidal products.

Active substances in biocidal products	Toxicity value	References
Sodium hypochlorite	NOAEC = 1.5 mg/m^3 (available chlorine, inhalation)	13
Ethanol	NOAEL = 2400 mg/kg/day (90 days/rat, oral)	14
Benzalkonium chloride	LOAEL = 0.22 mg/m^3 (13 weeks/rat, inhalation)	15
Oxone	LOAEL = 600 mg/kg/day (13 weeks/rat, oral)	16
Quaternary ammonium compounds	LOAEL = 0.11 mg/m^3 (13 weeks/rat, inhalation)	17
Sodium dichloroisocyanurate	NOAEC = 1.5 mg/m^3 (available chlorine, inhalation)	13
Deltamethrin	NOAEL = 1 mg/kg/day (104 weeks/rats, oral)	18
Cypermethrin	NOAEL = 5 mg/kg/day (2 years/rat, oral)	19
λ-Cyhalothrin	NOAEL = 0.5 mg/kg/day (52 weeks/dog, oral)	20
Permethrin	NOAEL = 1000 mg/kg/day (90 days/rat, dermal)	21
Etofenprox	NOAEL = 1000 mg/kg/day (4 weeks/rabbit, dermal)	22

Table 2. Weight fractions and dilution factors of the active substances in biocidal products.

that remain on surfaces. (Eq. 1) and (Eq. 2) were employed for the inhalation and dermal exposure algorithms, with reference to the RIVM report[24]. The fraction released into the air (F) was obtained using the inhalation algorithm of the European Center for Ecotoxicology and Chemical Toxicology (ECETOC), which assigns a value between 0.001 and 1 based on the vapor pressure of the substance[25]. Air changes per hour (ACH) were applied using the default value of 0.6 h^{-1} for all sites based on the exposure factors provided by the Ministry of Environment (MoE) of Korea[26]. By applying the Korean general exposure factors, the secondary exposure time and emission duration by site were 0.51 h for bars, 1.62 h for transportation, 2.45 h for other sites, 4.28 h for work and school, and 14.90 h for homes[27]. The surface area of the exposed skin, including the arms, hands, and calves, was assumed to be 6888.74 cm^2, assuming that short sleeves and shorts were worn during the summer[27].

$$C_a = \frac{A_o \times W_f / t_r \times F}{q \times V} \times 1 - e^{-qt} \times e^{-q(t-t_r)} \tag{1}$$

where C_a is the substance concentration in the indoor air (mg/m^3), A_o is the product amount (mg), W_f is the weight fraction of the substance in the product, t_r is the emission duration (h), F is the fraction released into the air, q is the room ventilation rate (h^{-1}), V is the room volume (m^3), and t is the exposure time (h).

$$L_d = A_c \times W_f \times A_s \tag{2}$$

$$A_c = \frac{A_o}{(S_{max} \times 10^4)}$$

where L_d is the dermal load (mg), A_c is the dislodgeable amount (mg/cm^2), W_f is the weight fraction of the substance in the product, A_s is the surface area of the exposed skin (cm^2), A_o is the amount of product (mg), and S_{max} is the room-floor area (m^2).

The assigned protection factor (APF) was applied to calculate the inhalation exposure for the general population. The exposure concentration (C_{exp}) was calculated using (Eq. 3), which accounts for the APF of 10 resulting from mask usage, as all members of the general population were wearing half-masks as a precaution against COVID-19[28]. The dermal load (L_d) was calculated by considering the absorption fraction and body weight of the general population in the dermal dose (D_{der}) in the exposure algorithm, as shown in (Eq. 4)[29].

$$C_{exp} = C_a \times n \times \frac{t_n}{24} \times \frac{1}{APF} \tag{3}$$

where C_{exp} is the exposure concentration (mg/m^3), C_a is the concentration of the substance in the indoor air (mg/m^3), n is the frequency of use of the biocidal products, t_n is the exposure duration per use (h/use), and APF is the assigned protection factor.

$$D_{der} = L_d \times abs \times N \times \frac{1}{BW} \tag{4}$$

where D_{der} is the dermal dose (mg/kg/day), L_d is the dermal load (mg), abs is the absorption fraction (fraction), N is the frequency of biocidal product use (use/day), and BW is the body weight (kg).

The hazard quotient (HQ) of a non-carcinogenic active substance was derived by calculating C_{exp} and D_{der} using the exposure algorithm and dividing them by RfC and RfD, respectively, as shown in (Eq. 5)[30]. The hazard index (HI) was evaluated by adding the inhalation hazard quotient (HQ_{inh}) and dermal hazard quotient (HQ_{der}), as shown in (Eq. 6). An HI of 1 or greater indicates a potential health risk[31].

$$HQ_{inh} = \frac{C_{exp}}{RfC}, HQ_{der} = \frac{D_{der}}{RfD} \quad (5)$$

where HQ_{inh} is the inhalation hazard quotient (mg/m^3), C_{exp} is the exposure concentration, RfC is the reference concentration (mg/m^3), HQ_{der} is the dermal hazard quotient (mg/kg/day), D_{der} is the dermal dose (mg/kg/day), and RfD is the reference dose (mg/kg/day).

$$HI = \sum HQ \quad (6)$$

where HI is the hazard index and HQ is the hazard quotient.

Results

Exposure factors for the general population

The exposure factors of 4762 cases were divided into disinfectants (2806 cases) and pesticides (1956 cases) according to the site. The averages and standard deviations of the usage amount and room volume by location are listed in Table 3. Detached houses had the highest amount of disinfectant and pesticide usage, with an average of 49,468.44 ± 173,721.19 mg, followed by public baths, with an average of 2625.45 ± 3737.11 mg. The

Place		Biocidal product	Amount used (mg/use)		Volume (m^3)	
			Mean	S.D	Mean	S.D
Public facilities	General restaurants and pub (N = 1420)	Disinfectant	136.25	259.65	438.81	2787.17
		Pesticide	132.25	190.30	386.78	1956.44
	Academy school (N = 671)	Disinfectant	605.71	4936.92	2982.69	11,607.25
		Pesticide	323.90	284.23	3123.82	8880.66
	Nursing home (N = 451)	Disinfectant	7709.18	43,036.76	2026.20	19,716.36
		Pesticide	321.37	406.00	1389.43	2114.23
	Gymnasiums (N = 131)	Disinfectant	26,513.36	167,939.45	11,301.94	15,684.71
		Pesticide	580.07	766.89	58,852.32	105,116.98
	Cafes and karaoke (N = 111)	Disinfectant	108.59	177.61	233.05	217.74
		Pesticide	102.57	100.80	283.11	281.38
	Medical facility (N = 67)	Disinfectant	114.57	150.92	2521.18	4513.73
		Pesticide	380.37	459.42	2327.99	3328.66
	Hypermarkets and market (N = 60)	Disinfectant	92.39	117.06	3719.43	9537.55
		Pesticide	326.91	333.73	3457.69	10,481.39
	Religious facility (N = 51)	Disinfectant	10.32	12.46	3695.93	6107.45
		Pesticide	207.30	281.52	584.20	547.77
	Viewing exhibition facility (N = 38)	Disinfectant	101.03	181.97	5200.70	8803.02
		Pesticide	571.11	440.31	7044.85	7184.27
	Internet cafe (N = 26)	Disinfectant	19.20	36.30	916.10	416.48
		Pesticide	184.28	153.24	697.30	212.40
	Public bath (N = 14)	Disinfectant	24.27	16.42	946.45	1451.81
		Pesticide	2652.45	3737.11	743.80	350.63
Housing	Detached house (N = 668)	Disinfectant	49,468.44	173,721.19	136.33	92.37
		Pesticide	107.50	121.83	210.79	109.16
	Apartment (N = 186)	Disinfectant	102.43	143.61	223.39	178.97
		Pesticide	482.99	389.88	4026.36	3657.72
Office (N = 666)		Disinfectant	8509.01	116,350.75	2986.00	15,082.31
		Pesticide	200.44	279.95	3344.86	9297.21
Public transport (N = 202)		Disinfectant	20,270.67	69,805.53	917.42	2053.85
Total (N = 4762)		Disinfectant	5948.50	72,434.76	2326.77	11,884.10
		Pesticide	201.61	305.91	1427.74	9529.97

Table 3. Exposure factors for biocidal products according to the general population based on location. S.D.: Standard Deviation.

gymnasium had the largest room volume for disinfection of 58,852.32 ± 105,116.98 m^3 and the detached houses had the smallest room volume of 136.33 ± 92.37 m^3. The average disinfectant usage was 5948.50 ± 72,434.76 mg and the average pesticide usage was 201.61 ± 305.91 mg, which is approximately 30-fold lower than the amount of disinfectant usage.

Dose–response assessment of active substances

Sodium hypochlorite and sodium dichloroisocyanurate ($C_3Cl_2N_3NaO_3$) were considered to emit chlorine gas and an NOAEC of 1.5 mg/m^3 was used as the toxicity value[13]. The toxicity values of benzalkonium chloride (BKC) and quaternary ammonium compound (QAC) were 0.22 mg/m^3 and 0.11 mg/m^3, respectively. These values were reported by the U.S. RED and the Korea Occupational Safety and Health Agency (KOSHA), respectively[15,17]. Oral toxicity values of 600 mg/kg/day for oxone ($KHSO_5$) and 2400 mg/kg/day for ethanol (C_2H_6O) were used and were obtained from the ECHA and OECD reports[13,14]. By consulting ECHA's pesticide assessment report, the toxicity values for deltamethrin ($C_{22}H_{19}Br_2NO_3$), λ-cyhalothrin ($C_{23}H_{19}ClF_3NO_3$), etofenprox ($C_{25}H_{28}O_3$) and permethrin ($C_{21}H_20Cl_2O_3$) were determined[18,20–22]. Finally, the toxicity values for cypermethrin ($C_{22}H_{19}Cl_2NO_3$) was obtained from the U.S. RED reports[19]. Table 4 shows the RfC and RfD values applied to the general population using the ECHA AF[23].

Exposure assessment

The C_{exp} and D_{der} values for the 11 active substances were calculated using the exposure algorithm and are presented in Table 5. Ethanol had the highest C_{exp} of 2.28E+01 mg/m^3, whereas sodium dichloroisocyanurate had the lowest concentration of 4.66E−13 mg/m^3. Ethanol had the highest D_{der} (6.47E−03 mg/kg/day) while sodium dichloroisocyanurate had the lowest D_{der} (1.54E−13 mg/kg/day).

Health risk assessment

The values of HQ_{inh}, HQ_{der}, HI, and the HQ_{inh}/HQ_{der} ratios for the 11 active substances are presented in Table 6. Ethanol had the highest HQ_{inh} (1.48E+02) while sodium dichloroisocyanurate had the lowest HQ_{inh} (1.74E−10). Ethanol had the highest HQ_{der} (5.39E−04) while sodium dichloroisocyanurate had the lowest HQ_{der} (9.99E−14), with a value of less than 1, indicating no potential health risks. Ethanol was associated with a potential health risk, with an HI greater than 1, whereas the remaining 10 active substances had values ranging from 1.74E−10 to 7.71E−04, with HI values of less than 1, implying no potential health risk. Ethanol had the highest HQ_{inh}/HQ_{der} ratio of 2.73E+05 while λ-cyhalothrin had the lowest ratio of 7.94E−01.

Discussion

Exposure factors, such as usage amount, room volume, and information about biocidal products, were evaluated through interview surveys with disinfection workers. C_{exp} and D_{der} were calculated using an algorithm for 11 active substances in the biocidal products, and risk assessment was performed by applying RfC and RfD, which are toxicity values for the general population.

The increased use of disinfectants in homes and public facilities is due to the enhanced disinfection guidelines implemented during the COVID-19 pandemic[3]. As disinfection has been strongly recommended to prevent the spread of COVID-19, detached houses were found to have the highest usage per unit volume of disinfectants. Therefore, the use of disinfectants has significantly increased compared to that of pesticides to prevent the spread of COVID-19 and maintain a safe indoor environment[32]. Consequently, the active substances of biocidal products that remain on the disinfected surface pose potential health risks[33].

Ethanol has a high vapor pressure, and its fraction released into the air is 1. The volatility and high weight fraction of the active substance are expected to affect C_{exp}, and the results were similar to those of previous studies[34]. Ethanol and sodium hypochlorite are volatile and short-lived, whereas the other active substances are nonvolatile compounds that remain in the indoor environment for longer periods[35]. In a study that obtained actual measurements after the spraying of a disinfectant, QAC, which has a low vapor pressure, was found to be

Active substances in biocidal products	RfC (mg/m^3)	RfD (mg/kg/day)
Sodium hypochlorite	2.68E−03	5.00E−02
Ethanol	1.54E−01	1.20E+01
Benzalkonium chloride	9.82E−05	1.00E−01
Oxone	4.50E+00	3.00E+00
Quaternary ammonium compounds	2.98E−05	1.87E−01
Sodium dichloroisocyanurate	2.68E−03	1.54E+00
Deltamethrin	2.14E−02	1.43E−02
Cypermethrin	7.50E−02	5.00E−02
λ-Cyhalothrin	1.07E−02	7.14E−03
Permethrin	5.99E−04	5.00E+00
Etofenprox	3.57E−02	2.78E+00

Table 4. Reference concentration (RfC) and reference dose (RfD) values according to a dose–response assessment of the active substances based on the general population.

Active substances in biocidal products	C_{exp} (mg/m^3)				D_{der} (mg/kg/day)			
	Mean	S.D	Min	Max	Mean	S.D	Min	Max
Sodium hypochlorite (N = 552)	2.07E−06	9.81E−06	3.08E−10	1.50E−04	4.63E−10	2.17E−09	8.85E−14	3.05E−08
Ethanol (N = 50)	2.28E+01	2.52E+01	3.53E−02	1.09E+02	6.47E−03	6.56E−03	6.26E−06	3.11E−02
Benzalkonium chloride (N = 119)	9.76E−10	1.06E−09	2.57E−11	3.41E−09	2.50E−10	2.34E−10	5.65E−12	7.83E−10
Oxone (N = 59)	1.83E−07	5.22E−07	8.08E−11	2.57E−06	6.99E−08	1.99E−07	2.32E−11	8.86E−07
Quaternary ammonium compounds (N = 2015)	2.32E−09	9.85E−09	1.66E−13	3.10E−07	8.21E−10	2.55E−09	4.76E−14	6.86E−08
Sodium dichloroisocyanurate (N = 11)	4.66E−13	1.14E−12	2.46E−15	3.84E−12	1.54E−13	4.01E−13	1.86E−15	1.36E−12
Deltamethrin (N = 658)	8.45E−10	2.36E−09	3.64E−13	3.17E−08	4.36E−10	9.68E−10	4.28E−13	9.82E−09
Cypermethrin (N = 838)	1.06E−09	1.97E−09	5.74E−12	2.99E−08	2.39E−10	4.22E−10	1.38E−12	6.09E−09
λ-cyhalothrin (N = 305)	8.84E−11	1.32E−10	2.64E−12	1.31E−09	7.10E−11	8.35E−11	2.97E−12	4.75E−10
Permethrin (N = 97)	4.55E−09	1.31E−08	2.55E−10	9.36E−08	3.04E−09	4.22E−09	2.95E−10	2.95E−08
Etofenprox (N = 58)	4.99E−09	1.27E−08	1.68E−11	6.67E−08	1.35E−09	2.99E−09	9.21E−12	1.47E−08

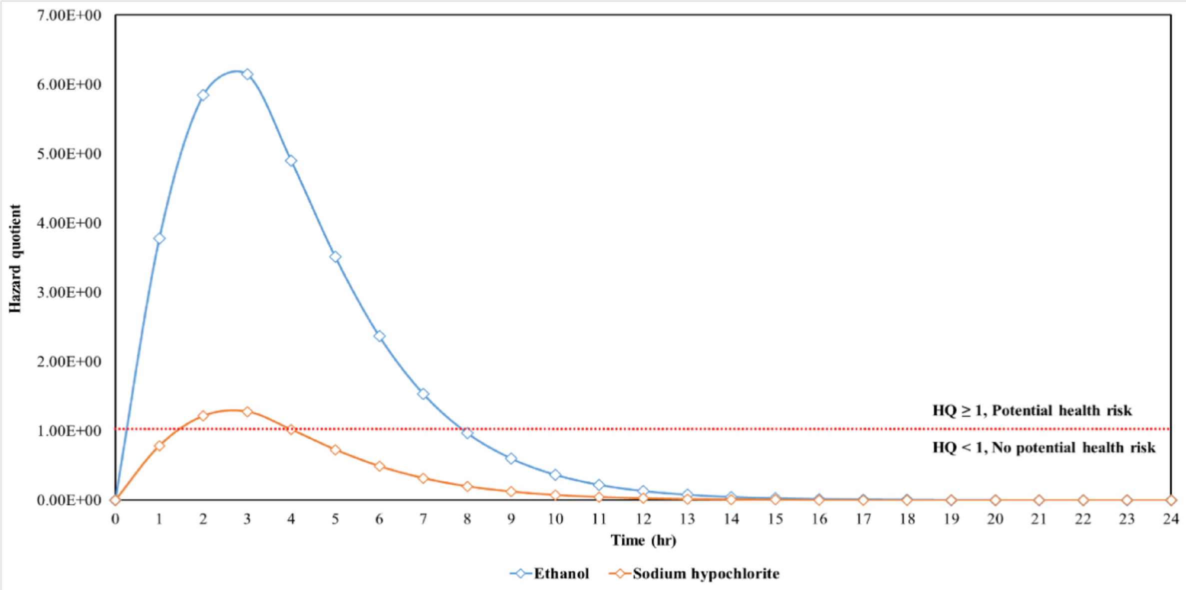
Table 5. Estimated exposure concentration (C_{exp}) and dermal dose (D_{der}) of the active substances in biocidal products in the general population. S.D., standard deviation.

Active substances in biocidal products	HQ_{inh}		HQ_{der}		HI ($HQ_{inh} + HQ_{der}$)		HQ_{inh}/HQ_{der} ratio
	Mean	S.D	Mean	S.D	Mean	S.D	
Sodium hypochlorite (N = 552)	7.71E−04	3.66E−03	9.25E−09	4.33E−08	7.71E−04	3.66E−03	6.31E+04
Ethanol (N = 50)	1.48E+02	1.63E+02	5.39E−04	5.46E−04	1.48E+02	1.63E+02	2.73E+05
Benzalkonium chloride (N = 119)	9.94E−06	1.08E−05	2.50E−09	2.34E−09	1.92E−05	3.87E−05	6.55E+04
Oxone (N = 59)	4.07E−08	1.16E−07	2.33E−08	6.62E−08	6.40E−08	1.80E−07	1.99E+00
Quaternary ammonium compounds (N = 2015)	7.80E−05	3.31E−04	4.39E−09	1.36E−08	7.80E−05	3.31E−04	1.05E+05
Sodium dichloroisocyanurate (N = 11)	1.74E−10	4.24E−10	9.99E−14	2.61E−13	1.74E−10	4.24E−10	1.71E+03
Deltamethrin (N = 658)	3.95E−08	1.10E−07	3.05E−08	6.77E−08	7.00E−08	1.66E−07	1.51E+00
Cypermethrin (N = 838)	1.41E−08	2.63E−08	4.77E−09	8.44E−09	1.88E−08	3.45E−08	3.03E+00
λ-cyhalothrin (N = 305)	8.26E−09	1.23E−08	9.94E−09	1.17E−08	1.82E−08	2.30E−08	7.94E−01
Permethrin (N = 97)	7.60E−06	2.19E−05	6.08E−10	8.43E−10	7.60E−06	2.19E−05	9.82E+03
Etofenprox (N = 58)	1.40E−07	3.57E−07	4.84E−10	1.07E−09	1.40E−07	3.58E−07	2.55E+02

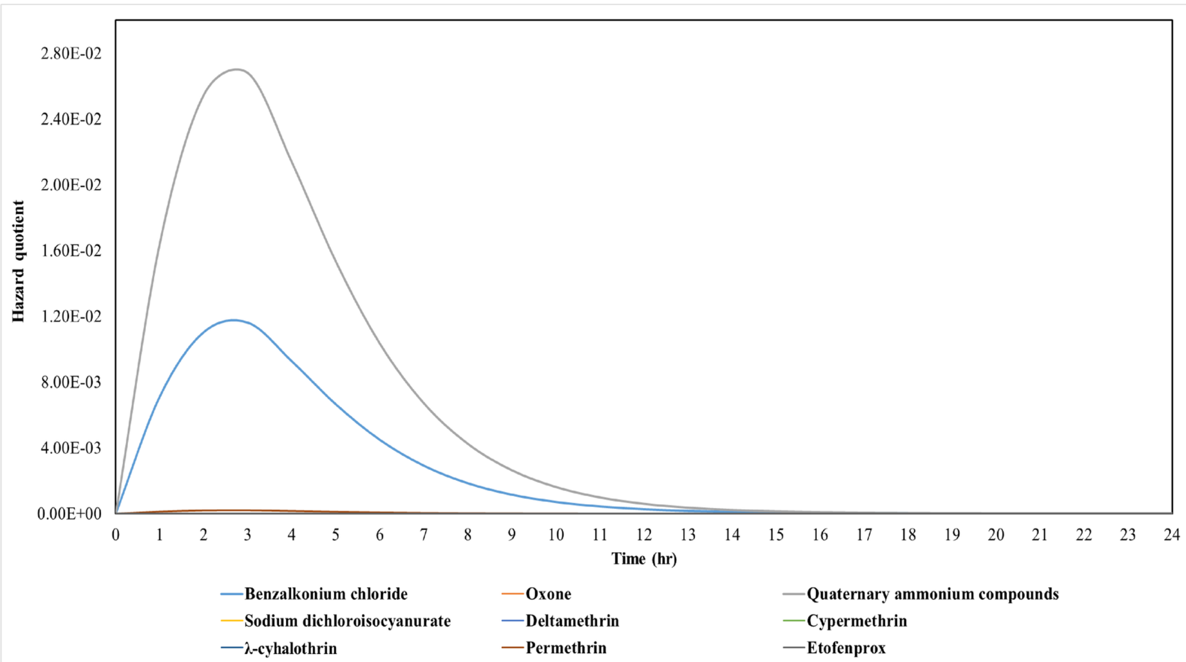
Table 6. Estimated inhalation hazard quotient (HQ_{inh}), dermal hazard quotient (HQ_{der}), and hazard index (HI) of the active substances in biocidal products in the general population. S.D., standard deviation.

primarily deposited on the floor, whereas alcohol, which has a high vapor pressure, mainly evaporated into the air[36].

The 10 active substances had an HQ_{inh}/HQ_{der} ratio greater than 1, indicating that inhalation exposure had a greater effect than dermal. Dermal exposure is not considered when calculating body surface area (BSA) when clothes are worn[29]. The risk assessment for secondary exposure to the active substances, except for ethanol, did not reveal an HI ≥ 1, indicating no potential health risk. Spraying ethanol with a weight fraction of 30% or more can cause rapid changes in the chemical composition of indoor air, and increased concentrations of volatile organic compounds (VOCs) and particles after spraying can be harmful to one's health through inhalation



(a)



(b)

Fig. 1. Trend in the hazard quotient of the active substances over time; (**a**) volatile active substances; and (**b**) non-volatile active substances.

exposure[37]. The concentration of ethanol was higher than that of the other active substances because it was used in a stock solution with a high weight fraction of 83%. Ethanol accounts for 70–90% of the concentration of active substance recommended by the World Health Organization (WHO). However, spraying these substances is associated with a high risk of inhalation exposure[38]. Calculating the change in HQ for each active substance over time is crucial for suggesting a safe entry time after disinfection for the general population. The median values of 266.12 m^3 and 2.45 h were used for the volume of the site and duration of emission, while the average value in Table 2 was used for the amount of disinfectants and pesticides used. As shown in Fig. 1, sodium hypochlorite, a highly volatile active substance, poses a potential health risk for up to 4 h after disinfection, while ethanol poses a risk for up to 7 h. Therefore, the general population may face health risks from secondary exposure to the active substances if they enter the room immediately after disinfection.

The significance of exposure and risk assessment in the general population is increasing owing to the persistence of COVID-19. Of note, the actual exposure concentration of the active substance may differ from the estimated concentration calculated using the exposure algorithm, which serves as a limitation of this study. However, considering the difficulty in measuring secondary exposure, an algorithm can be used to estimate the health risks of each active substance. Although this study incorporated site volume, the potential for underestimation exists in larger spaces, such as gymnasiums and viewing facilities. Therefore, attempting the application of personal volumes, such as 2 m^3 and 5 m^3, would be appropriate[39,40].

Conclusions

Exposure and risk assessments were conducted for 11 types of biocidal substances, with specific focus on the general population that may be indirectly exposed to these substances after a disinfection protocol. The RfC and RfD values for the general population were derived using the representative toxicity values for each active substance. Ethanol and sodium hypochlorite pose potential health risks if an individual is present in or enters the room immediately after disinfection. Therefore, the spraying of disinfecting biocides should be avoided and replaced with a method that involves soaking a cloth to disinfect the surface.

Data availability

The data used and/or analyzed in this study will be available from the corresponding author upon reasonable request.

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Author contributions
Gihong Min and Wonho Yang designed the study, wrote the original draft, and carried out project administration, supervision, study design, data analysis, manuscript review, and manuscript editing. Jihun Shin, Youngtae Choe, Dongjun Kim, Jaemin Woo, Byunglyul Woo, Jangwoo Lee, Mansu Cho, and Kilyong Choi gave advice regarding data analysis and results interpretation and contributed to manuscript writing. All authors read and approved the final manuscript.

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Declarations

Competing interests
The authors declare no competing interests.

Ethical approval
This study was performed according to standard procedures after obtaining IRB approval from Daegu Catholic University (IRB No. CUIRB-2022-0056).

Additional information
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