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Impact of the COVID-19 pandemic on household disinfectant consumption behaviors and related environmental concerns: A questionnaire-based survey in China

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ABSTRACT
Considering the potential hazardous effects of disinfectant residues on environment, organisms and biodiversity, the sharp rise in use of disinfectants during COVID-19 pandemic has been considered highly likely to cause worldwide secondary disasters in ecosystems and human health. This questionnaire-based survey investigated the impact of COVID-19 outbreak on household disinfectant product consumption levels and behavior of 3667 Chinese residents. In particular, in the context that no strategy is currently available to minimize the disinfectant pollution, based on the similarities between disinfectants and pharmaceuticals, we proposed a perspective of ecopharmacovigilance (EPV), which is an effective measure to minimize the environmental risks posed by pharmaceuticals using drug administration protocols, for disinfectant environmental risk management. The public’s environmental perceptions, attitudes and the related practices regarding household disinfectant consumption from an EPV perspective were also included in the study. The results showed that the COVID-19 outbreak caused a tremendous rise in the public’s household disinfectant consumption and usage levels in China. After the COVID-19 outbreak, the chlorine-based and alcohol-based disinfectants were considered as the most preferred products for household disinfection and hand sanitization, respectively. Importantly, the Chinese public’s environmental perceptions and practice on disinfectants were poor. Less than half respondents had positive attitudes toward the source control of disinfectant pollution. The population groups including females, the middle aged adults, those having healthcare professional background, as well as the higher-educated could be focused on to develop targeted efforts for the future control of disinfectant pollution in environment.

1. Introduction
On March 11, 2020, the World Health Organization (WHO) declared the coronavirus disease 2019 (COVID-19) a global pandemic [31]. As a public health emergency of international concern, this pandemic has attracted an unprecedented level of attention and concern from the general public due to its high infectivity and mortality rate. In China, a first-level public health emergency response to COVID-19 has been initiated on January 25, 2020. In order to slow the virus’ transmission, the Chinese government and health authorities have triggered a mass effort and adopted a series of preventive measures, among which the large scale use of disinfectants in households, community settings, hospitals, and other indoor or outdoor public spaces is believed as one of best-practice strategies [19]. The Chinese public has been recommended to continuously use disinfectants as hand sanitizers and high-touch surface cleaners. Common disinfectants such as 70% ethanol and sodium hypochlorite have been demonstrated effective in inactivating the COVID-19 virus within 1 min [32]. So far, various chemical disinfectants including ethanol, peroxide-based disinfectants (e.g. hydrogen peroxide and peroxyacetic acid), phenol-based disinfectants, quaternary ammonium compounds (QACs), chlorine-releasing agents, formaldehyde and glutaraldehyde, as well as iodine-releasing agents have been considered as effective tools against COVID-19 virus on surfaces [1]. In particular, the WHO has recommended phenolic compounds, hydrogen peroxide, sodium hypochlorite (bleach), ethanol and ammonium compounds as biocides, based on their high effectiveness against COVID-19 virus [23].

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Accordingly, after the COVID-19 outbreak, the global use for disinfectant products is rapidly growing [23]. What’s worse, anxiety and fear in the public triggered by COVID-19 have caused panic buying in an attempt to stockpile and hoard the household disinfectant products [19]. It has been estimated that at least 2000 tons of disinfectants have been dispensed in Wuhan City alone [36], where the first cases of COVID-19 syndrome with unknown origin were identified in early December 2019 [5]. Even fleets of trucks, mini-tankers and drones etc. have been employed to spray massive quantities of disinfectants in outdoor spaces in many parts of the world [17].

However, a substantial concern about the adverse effects of disinfectants on the consumers has been recently raised [17,19,2,20–22,33,35,57]. In addition to health hazards in users (e.g. accidental poisonings, risk of developing asthma) because of unexpected or excessive exposures to disinfectants, the environmental and ecological risks posed by disinfectant residues have attracted more and more attention [2,17,21,22,35]. The high consumption of disinfectants would inevitably result in the frequent occurrence and high residual levels of disinfectants in the environment, subsequently the corresponding ecological issues. For example, chlorine disinfectants can bond with dissolved organic matter in surface water to form disinfection by-products (e.g. trihalomethanes, haloacetic acids), which are harmful for organisms. Other toxic disinfection-by-products such as chloramine or N-nitrosodimethylamine, that were formed from the combination of disinfectants and nitrogen, have been classified as carcinogens. In addition, chlorine released from disinfectants can directly destroy the cell walls or damage proteins of organisms by oxidation [17,36]. A dose-response genotoxic effect has been demonstrated in the earthworm Eisenia andrei Bouche (Lumbricidae) coelomic fluid shelters leukocytes (coelomocytes) following exposure to 15–120 µM hypochlorite [15]. It has been reported that more than one hundred of wild animals belonging to 17 different species such as Siberian weasel Mustela sibirica, common blackbird Turdus merula have died near coronavirus epicenter in China due to the overuse of outdoor disinfectant sprays [17].

Most importantly, in view of the biocidal property of disinfectants, the excessive disinfectant use in the COVID-19 pandemic is certain to cause the immeasurable impacts on the microbiomes in environments, animals, and humans, therefore accelerate antimicrobial resistance [22]. Exposure to 0.0004% phenolic disinfectant triclosan was associated with a high risk of developing bacterial resistance and cross-resistance in Staphylococcus aureus and Escherichia coli [29]. The use of alcohol-based disinfectants as hand rubs in the control of hospital infections has been found responsible for the emergence of alcohol-tolerant Enterococcus faecium [18]. Use of chlorine disinfectants and calcium hypochlorite against bacteria harvested from drinking water resulted in the existence of bacterial resistance to disinfectants as well as to common antibiotics such as tetracycline, sulfamethoxazole and amoxicillin due to co-selection [10,16]. Continuous exposure of clinical Klebsiella pneumoniae strains to chlorhexidine, a disinfectant widely used in hospitals, led to adaptive resistance to chlorhexidine and cross-resistance to colistin [37]. In addition, disinfectant residues in the environment would “wipe” several commensals in various niches, and induce immeasurable collateral damage to microbial diversity [22]. Considering these potential hazardous effects of disinfectant residues on environment, organisms and biodiversity, the tremendous rise in use of disinfectants during COVID-19 pandemic has been considered highly likely to cause worldwide secondary disasters in ecosystems and human health, which have elicited heighten concerns from scientists [19,36].

Currently, WHO has proposed the disinfectant spraying of outdoor spaces is not recommended to kill the COVID-19 virus [30]. However, the high public consumption and application for household disinfectant products would still undoubtedly result in tremendous environmental burden of disinfectant emissions. So far, no strategy is available to minimize the disinfectant pollution, as an emerging environmental risk triggered by the sudden outbreak of COVID-19 [17]. Nevertheless, based on the similarities between disinfectants and pharmaceuticals in purpose of use, environmental risks, route of entrance in the environment, regulation system, etc., the well-established management measures for pharmaceutical emerging contaminants (PECs) could be adapted and applied into the disinfectant environmental safety evaluation and prevention system. As widely consumed compounds, pharmaceuticals would continuously pour into the environment through excretion by humans and animals following use of medicines, improper disposal of unwanted medications, hospitals, pharmaceutical production facilities, etc. Tarazona et al. [24] have paid attention to unprecedented levels of emissions of antiviral medicinal products as potential treatment for COVID-19 to the aquatic environment, and proposed the environmental impact assessment should be strengthened and improved. Ecopharmacovigilance (EPV) is a kind of pharmaco-vigilance for the environment, and has been considered as an effective drug administration route on environment pollution caused by PECs [8,11,12,27]. The concept of EPV involves the detection, assessment, understanding and prevention of adverse effects or other problems associated with the presence of PECs in the environment. Being different from the efforts made by environmental experts for the removal of PECs from environmental matrices, EPV emphasizes the upstream control of PEC sources and related anthropogenic behaviors to constrain the environmental discharge of PECs, thus has been believed as a more fundamental, economical and feasible solution for PEC pollution in the environment [11,12,27,28]. So far, the well-accepted practice approaches to EPV include: promoting rational use of drugs, in particular, implementing eco-directed sustainable drug prescribing and dispensing practices to reduce the environmental footprints of PECs from the patients’ excretion; improving pharmacy take-back programs and safe management strategies for expired and unused medicines; well-controlling the emissions from pharmaceutical manufacturing and hospitals; as well as accelerating the design and process development of green drugs, etc. [11,12,26–28].

In order to understand the impact of COVID-19 on public consumption behaviors for household disinfectant products and assess the possible environmental burden, this study conducted a questionnaire-based survey among the general public in China. In particular, the public’s perceptions and attitudes toward the environmental pollution of disinfectant contaminants and its source control from an EPV perspective were included in the survey.

2. Methods

2.1. Questionnaire

The initial draft of questionnaire was designed based on information from the relevant literature about environmental risks of disinfectants as well as EPV. The clarity, content validity, relevance and conciseness of the questionnaire items were evaluated by two senior researchers in the fields of pharmacy administration and investigative sociology. Pretesting of the questionnaire was done on a convenient sample of 20 Wuhan citizens, who were not included in the final survey, to examine the acceptability and validity of the questionnaire. After a minor modification, the final survey questionnaire was approved.

A total of 32 structured questions (Q1–32) organized into three sections were included in the final questionnaire (Supplementary material 1):

- The first section consisted of five questions (Q1–5) about the sociodemographic characteristics of respondents, including gender, age, healthcare professional background, education level, and place of residence.
- The second section including 20 questions (Q6–25) was to investigate the general public’s actual use/consumption behaviors and preference regarding household disinfectant products. Concretely speaking, the respondents were required to recall the frequency of using products for environmental disinfection in the home (Q6,7)
and hand sanitization (Q9), as well as the most commonly used type of environmental disinfectant product/hand sanitizer (Q8/Q10) before the COVID-19 outbreak. Furthermore, the current frequency of using household products for environmental disinfection in the home (Q11,12) and hand sanitization (Q14), as well as the most preferred products for home environment/hand disinfection (Q13/Q15) were surveyed to capture the actual disinfectant use/consumption behaviors after the COVID-19 outbreak. Accordingly, Q16 and Q17 were designed for self-evaluation of the impact of COVID-19 outbreak on the use levels of products for environmental disinfection in the home and hand sanitization, respectively. Moreover, a 5-point Likert scale (1, strongly disagree; 2, disagree; 3, neutral; 4, agree; and 5, strongly agree) was used to assess the perceived importance of possible factors, including the disinfectant products’ disinfection activity (Q18), safety (Q19), cost and economy (Q20), expert advice (Q21) and the disinfectant products’ environmental impact (Q22), in affecting their own current household disinfectant consumption choice. The public’s home storage (Q23) and disposal (Q24) behaviors for household disinfectant products were surveyed. At the end of the second section, the respondent was asked whether he/she was the disinfectant product chooser (consumption decision-maker) in the family (Q25).

The third section of this survey included seven items to investigate the public’s perceptions and attitudes toward disinfectant pollution and its source control from an EPV perspective. The first three question items with response options on a 5-point Likert-scale format were designed to assess the respondents’ perceptions regarding the entrance of disinfectants into the environment (Q26), the environmental/ecological risks (Q27) and the bacterial resistance (Q28) caused by disinfectant residues, respectively. Another two statements using 5-point Likert scales in this section were “It is necessary to minimize the entrance of disinfectants into the environment and its environmental risks.” (Q29) and “If there is an upstream intervention for controlling disinfectant entry to the environment, you would endorse it, and be very pleased to participate in its implementation.” (Q30), respectively. In addition, the other two single-choice questions were designed to evaluate the most important perceived barrier of disinfectant pollution control (Q31) and the preferred disinfectant pollution management approach (Q32), respectively.

The Cronbach’s α value or the Kaiser-Meyer-Olkin (KMO) measure of the final questionnaire was higher than 0.700. The questionnaire was developed in English as the original language, then translated into Chinese and back translated into English.

2.2. Data collection

In this observational cross-sectional survey, the self-developed questionnaire was sent through online and offline survey platforms to a convenience sample of the Chinese population via the personal connections of the authors. The online survey link was shared through social media platforms including WeChat and Tencent QQ. Offline data collections were conducted in three large communities in Wuhan (the original epicenter of COVID-19, Hubei provincial capital), two and one large communities in Xi’an and Chongqing (provincial capital cities at low risk of COVID-19 located in the northwest and southwest of China, respectively). When the respondents felt uncertain about the type of the household disinfectant products that they used (Q8, 10, 13 and 15 in the second section of the questionnaire), the experienced researchers would provide them professional guidance based on the brand names of products provided by respondents. Survey data was collected between October and December 2020. The target respondents were adults over 18 years old, who were willing to be anonymously involved in the study. The study protocol was approved by the Ethics Committee of Medicine College, Wuhan University of Science and Technology.

2.3. Statistical analysis

The collected data were entered into SPSS 24.0 for analysis. Results were presented as numbers (percentages) for categorical variables and mean±standard deviation (SD) for quantitative variables. The categorical data was statistically analyzed using χ² test. Independent t-test was applied to compare the mean perception scores of the two groups. The one-way analysis of variance (ANOVA) with post hoc Tukey’s honestly significant difference (HSD) analysis for multiple comparisons was conducted to detect differences between pair wise groups. When the P value was less than 0.05 or 0.01, differences were statistically significant.

3. Results

3.1. Respondents’ characteristics

By the end of the study period, a total of 3667 completed questionnaires were collected. The respondents’ socio-demographic information was shown in Table 1 and Table S1 (Supplementary material 2). Among these 3667 Chinese participants, 2005 (54.7%) were female; 297 (8.1%) respondents aged below 20, 1499 (40.9%) aged between 20 and 40 years old, 1685 (46.0%) aged between 41 and 65 years old, and 186 (5.1%) were over the age of 65. The majority of respondents (73.1%) had not the healthcare professional background. The educational levels of about half (47.7%) respondents were below undergraduate, while 1556 (42.4%) held a undergraduate degree and 361 (9.8%) respondents had completed postgraduate education. The residence distribution of respondents was approximately equal, with 1971 (53.7%) lived in the COVID-19 original epicenter Wuhan area and 1696 (46.3%) lived in areas outside Wuhan.

3.2. Impact of COVID-19 outbreak on the disinfectant product consumption and usage levels in the home-based setting

When the respondents were required to recall the frequency of using products for environmental disinfection in their homes before the COVID-19 outbreak, a large group (37.3%) reported they used household disinfectant products for disinfection of environmental surfaces 1–2 days a month, followed by respondents reporting 3–9 days a month (34.9%), and only 3.6% disinfected their home environment everyday. Among those reporting they disinfected everyday, most (96.2%) reported disinfecting 1–2 times a day. However, during the survey implementation (after the COVID-19 outbreak), 26.2% respondents used household disinfectant products for environment disinfection in their homes everyday, of whom 4.5% disinfected more than 5 times a day (Fig. 1A).

In terms of hand sanitization, as shown in Fig. 1B, a major of respondents (64.7%) recalled that they never disinfected their hands before COVID-19 outbreak. However, when they were asked the current frequency of hand sanitization, only 0.4% never disinfected their hands using sanitizers, 43.5% disinfected their hands more than five times a day, and 10.3% reported they disinfected their hands all the time, as long as they could remember.

Accordingly, the self-evaluation results (Fig. 1C and D) showed that 96.0% and 96.8% respondents felt the COVID-19 more than 2-fold increased their use levels of products for environmental disinfection in the home and hand sanitization, respectively; 17.6% and 26.5% respectively believed that, compared to the disinfectant use before the COVID-19 outbreak, their use levels of products for home environment disinfection and hand sanitization increased more than 10 times after COVID-19 outbreak.

These findings strongly suggested that the COVID-19 outbreak caused a tremendous rise in the public’s household disinfectant consumption and usage levels in China.
3.3. The public’s household storage and disposal behaviors for disinfectant products

As for PECs, improper household disposal of unwanted medicines has been well-accepted as an important source of entrance of pharmaceuticals into the environment, particularly, as the easiest target for the EPV source control of PEC contamination [14,34]. Similarly, the improper household disposal of leftover disinfectant products that are unused or

Table 1

Socio-demographic information and the public’s attitudes towards disinfectant contaminants’ environmental risks and management (n=3667).

| Participant attribute               | Number (%) | Disinfectant chooser (consumption decision-maker) in the family | Importance of environmental factor in disinfectant consumption choice | Perceptions towards environmental and ecological risks posed by disinfectants | Attitudes towards disinfectant environmental risk management |
|------------------------------------|------------|-----------------------------------------------------------------|-------------------------------------------------------------------|--------------------------------------------------------------------------|-----------------------------------------------------------------|
|                                    |            | Yes | No | P value | Mean score±SD | P value | Average score±SD | P value | Average score±SD | P value |
| Gender                             |            |     |    |         |              |         |                |         |                |         |
| Male                               | 1662(45)   | 457(12) | 1205(33) | <0.001 ** | 2.9±1.2 | 0.063 | 3.2±1.5 | 0.062 | 3.5±1.9 | 0.103 |
| Female                             | 2005(55)   | 1656(45) | 349(9)   |           | 3.0±1.9 |         | 3.1±1.7 |         | 3.4±1.8 |         |
| Age                                |            |     |    |         |              |         |                |         |                |         |
| <20                                | 297(8)     | 28(1)  | 269(7)   | <0.001 ** | 3.0±1.1 | 0.543 | 3.1±1.2 | 0.109 | 3.4±0.7 | 0.001 **|
| 20–40                              | 1499(41)   | 1005(27) | 494(13)  |           | 2.9±1.2 |         | 3.2±1.8 |         | 3.6±1.5 |         |
| 41–65                              | 1685(46)   | 1018(28) | 667(18)  |           | 3.0±0.8 |         | 3.2±1.6 |         | 3.4±1.6 |         |
| >65                                | 186 (5)    | 71(2)  | 115(3)   |           | 2.9±1.2 |         | 3.0±1.5 |         | 3.9±1.5 |         |
| Healthcare professional background |            |     |    |         |              |         |                |         |                |         |
| Yes                                | 988(27)    | 824(22) | 164(4)   | <0.001 ** | 3.0±1.3 | 0.064 | 3.6±0.8 | 0.000 **| 3.6±1.6 | 0.002 **|
| No                                 | 2679(73)   | 1298(35) | 1381(38) |           | 2.9±1.5 |         | 3.0±1.9 |         | 3.4±1.8 |         |
| Education level                    |            |     |    |         |              |         |                |         |                |         |
| Junior college or below            | 1750(48)   | 991(27) | 759(21)  | 0.223      | 2.7±1.7 | 0.000 **| 3.1±1.4 | 0.000 **| 3.3±1.5 | 0.000 **|
| Undergraduate                      | 1556 (42)  | 926(25) | 630(17)  |           | 3.2±1.4 |         | 3.2±1.7 |         | 3.6±2.0 |         |
| Postgraduate                       | 361 (10)   | 205(6)  | 156(4)   |           | 3.2±1.6 |         | 3.5±1.0 |         | 3.7±1.1 |         |
| Residence                          |            |     |    |         |              |         |                |         |                |         |
| Wuhan area                         | 1971 (54)  | 1132(31) | 839(23)  | 0.565      | 3.0±1.8 | 0.102 | 3.2±1.7 | 0.061 | 3.5±1.9 | 0.130 |
| Non-Wuhan areas                    | 1696 (46)  | 990(27) | 706(19)  |           | 2.9±1.9 |         | 3.1±1.5 |         | 3.4±2.1 |         |

** P<0.01.
a: shown as the mean score±SD of a question (Q22) framed into a 5-point Likert-scale format.
b: shown as the average score±SD of three questions (Q26–28), each of which was framed into a 5-point Likert-scale format.
c: shown as the average score±SD of two questions (Q29 and 30), each of which was framed into a 5-point Likert-scale format.

Fig. 1. Impact of COVID-19 outbreak on the disinfectant consumption and usage levels in the home-based setting. A: Frequency of using products for environmental disinfection in the home before and after the COVID-19 outbreak; B: frequency of using products for hand sanitization before and after the COVID-19 outbreak; C: self-evaluation of the impact of COVID-19 outbreak on the use levels of products for environmental disinfection in the home; D: Self-evaluation of the impact of COVID-19 outbreak on the use levels of products for hand sanitization. n=3667.

3.3. The public’s household storage and disposal behaviors for disinfectant products

As for PECs, improper household disposal of unwanted medicines has been well-accepted as an important source of entrance of pharmaceuticals into the environment, particularly, as the easiest target for the EPV source control of PEC contamination [14,34]. Similarly, the improper household disposal of leftover disinfectant products that are unused or
have expired would also result in the entrance of disinfectants into the environment. Therefore, we assessed the public practice regarding disposal for unwanted household disinfectant products from an EPV perspective. We found that 86.8% respondents kept disinfectant products in their homes. When the respondents were asked the question “If you have ever disposed of unused disinfectant products, how did you dispose of them? If you have not ever disposed of unused disinfectant products, how would you dispose of them?” (Q24), the most (81.3%) tend to throw household disinfectant products away in household garbage. In addition, 15.1% claimed that they wanted to flush or wash the unused disinfectant products down the sink or toilet; 2.2% are more likely to throw in river or lake; and only 1.4% chose the item “Return to hospital or pharmacy”.

3.4. Impact of COVID-19 outbreak on the public’s household disinfectant product consumption tendency

The respondents’ household disinfectant product consumption tendencies before and after the COVID-19 outbreak were presented in Fig. 2A and B. Before COVID-19 outbreak, most (58.6%) respondents felt unsure about the most commonly used product for environmental disinfection in their homes; and 82.5% tend to wash their hands using solid or liquid soap. However, after the COVID-19 outbreak, 48.7% chose the chlorine-based disinfectants as the most preferred products for household disinfection; and 65.9% preferred to use alcohol-based disinfectants as hand sanitizers.

As for the factors affecting the respondents’ current disinfectant consumption choice (Fig. 2C), 99.5% respondents agreed or strongly agreed that the disinfection activity was important for their own disinfectant consumption choices, the importance of the factor “Expert advice” was agreed or strongly agreed by 88.5% respondents. However, only 12.3% considered the environmental impact of household disinfectant products as an important factor affecting their own current disinfectant consumption choice.

3.5. The public’s perceptions and attitudes toward disinfectant pollution and its source control from an EPV perspective

As shown in Table 2, 26%, 20% and 47% respondents agreed or strongly agreed that disinfectants used in healthcare practices “could finally enter into the environment” (Q26), then “could cause adverse effects on ecosystem and wildlife species” (Q27), as well as “could cause the emergence of drug-resistant bacteria” (Q28), respectively. However, 45–66% felt undecided about the occurrence and environmental risks of disinfectant contaminants. These data suggested that, overall, the respondents’ understanding of disinfectant pollution and its impacts on the environment was poor.

In terms of the Chinese public’s attitudes toward the source control of disinfectant pollution from an EPV perspective, nearly half of respondents (47%) agreed or strongly agreed the importance for minimizing the entrance of disinfectants into the environment and its environmental risks (Q29). In addition, 45% claimed that they would be very pleased to participate in the implementation of upstream intervention for controlling disinfectant entry to the environment (Q30).

In response to the question about the most important perceived barrier of disinfectant pollution control (Q31), 64% chose the answer “Environmental concerns of disinfectants might be detrimental to infection prevention and control during COVID-19 pandemic,” which was the most significant barrier perceived by the Chinese public. In addition, the answer “Poor public awareness of disinfectant environmental pollution” was chosen by 28% respondents. Three other options, including “Lack of the related administrative guides”, “No designated place for disposal of surplus or unwanted household disinfectant products” and “It conflicts with the established hygiene and health habits”, were only agreed by 4%, 2% and 2% respondents, respectively.

When asked “If you participate in the control for disinfectant pollution, what are you going to do first?” (Q32), 53% respondents wanted to firstly acquire the related knowledge and information; 32% reported that they would adopt a wait-and-see approach; the practice of “Throwing surplus or unwanted household disinfectant products away in designated places” was endorsed by 13% of respondents; and only 2% chose the answer “Reducing unnecessary household consumption and use of disinfectant products.”

3.6. Group comparisons

No gender, age, profession, education level or residence difference was found in the use/consumption behaviors and preference regarding household disinfectant products.

Based on the fact that the pharmaceutical-related human behaviors leading to PEC pollution appear to vary among different population groups, EPV program has been advised to focus on some key populations to develop targeted efforts for the control of anthropogenic sources of pharmaceutical emission [27]. In order to identify the potential key population groups that would be targeted in the future implementation of strategy minimizing the disinfectant pollution, we asked the respondents a question “Are you the disinfectant product chooser (consumption decision-maker) in the family?” (Q25). As shown in Table 1, the females, the middle aged adults and those having healthcare professional background tended to act as the household disinfectant product choosers (P<0.01).

In addition, the response from Q22 on attitudes toward the environmental impact as an important factor affecting the respondents’ own current household disinfectant consumption choices could be significantly influenced by educational level. Compared with less-educated respondents, those who completed undergraduate and postgraduate education attached greater importance to the environmental safety of household disinfectant products (P<0.01). Moreover, the higher-educated respondents and those having healthcare professional background appeared to be more aware of environmental and ecological risks posed by disinfectants, and offer significantly more support for the disinfectant environmental risk management (P<0.01).

4. Discussion

Ten years later, considering the established associations of many ingredients in disinfectant products with human health conditions as well as with environmental risks, Bondi [4] has proposed to apply a Precautionary Principle-based model to account for the potential for environmental harm from antibacterial household product. In view of the significant increase of disinfectant usage triggered by COVID-19 pandemic and its potential environmental risks, it has become more urgent to practice this idea. The present survey involving 3667 Chinese residents conducted the comparison of disinfectant product consumption and usage levels in home-based settings before and after COVID-19 outbreak. The results showed that the COVID-19 outbreak caused a sharp increase in the household product consumption for environmental disinfection and hand sanitation, which was in accordance with the reports showing an upward trend of disinfectant sprays and wipes market in Italy, the United Kingdom, Saudi Arabia, etc. [35] A recently published survey involving 1090 Iranian citizens conducted from March to April, 2020 [5] showed that the mean frequencies of hand disinfecting and the clean-up in case of surfaces were 10.74 and 2.99 times per a day, respectively. Similarly, our survey showed that 10.3% Chinese respondents disinfected their hands all the time, as long as they could remember; 4.5% disinfected the home environment more than five times a day. More importantly, when compared with the recalled levels before COVID-19 outbreak, the tremendous rise in household disinfectant consumption and usage triggered by the pandemic was further confirmed.

In the study conducted by Dindarloo et al. [5], the most commonly used substances by Iranian participants to disinfect their hands and
Fig. 2. The public’s household disinfectant product consumption tendency. A: the most preferred products for environmental disinfection in the home before and after the COVID-19 outbreak; B: the most preferred products for hand sanitization before and after the COVID-19 outbreak; C: factors affecting the public’s current disinfectant consumption choice. Data shown as the proportion of respondents who agreed or strongly agreed the corresponding factor was important for their own disinfectant consumption choices. n=3667.
Table 2: The Chinese public’s perceptions and attitudes toward disinfectant pollution and its source control from an EPV perspective (n=3667).

| Survey question/statement | Responses, number (%) |
|---------------------------|-----------------------|
| Q26: Disinfectants used in healthcare practices could finally enter the environment. | Strongly agree | Agree | Undecided | Disagree | Strongly disagree |
|                           | 216 (6) | 728 (20) | 2101 (57) | 525(14) | 97 (3) |
| Q27: Disinfectant residues in environment could cause adverse effects on ecosystem and wildlife species. | 211 (6) | 502 (14) | 2402 (66) | 493 (13) | 59 (2) |
| Q28: Disinfectant residues in environment could cause the emergence of drug-resistant bacteria. | 390 (11) | 1302 (36) | 1660 (45) | 291 (8) | 24 (1) |
| Q29: It is necessary to minimize the entrance of disinfectants into the environment and its environmental risks. | 357 (10) | 1339 (37) | 1671 (46) | 268 (7) | 32 (1) |
| Q30: If there is an upstream intervention for controlling disinfectant entry to the environment, I would endorse it, and be very pleased to participate in its implementation. | 334 (9) | 1307 (36) | 1717 (47) | 283 (8) | 26 (1) |

Environmental surfaces were found to be alcoholic solutions (51.4%) and sodium hypochlorite bleach (57.3%), respectively. This finding was in line with our survey in which we found that, after the COVID-19 outbreak, the chlorine-based and alcohol-based disinfectants were considered as the most preferred products for household disinfection and hand sanitization, respectively. In China, the General Office of the National Health Commission of the People’s Republic of China [6] issued the Guideline for the Use of Disinfectants on February 18, 2020, in which 70% ethanol and chlorinated disinfectants have been highly recommended for the effective microbial inactivation of COVID-19. Our study found that the Chinese consumers tended to select the household disinfectant products based on their disinfection activities and according to the advises provided by experts, which might be a reflection of the sufficient practical implementation of this national guideline.

Most importantly, in this study, we proposed the idea of EPV, which aims to decrease the emission from the PEC pollution sources using drug administration protocols, could be adapted and applied into the control of disinfectant pollution. Because the PEC pollution sources can ultimately be traced back to pharmaceutical-related anthropogenic behaviors, EPV emphasizes the control of anthropogenic environmental inputs of PECs [11,28]. Therefore, our study focused on and firstly evaluated the public’s environmental perceptions, attitudes and the related practices regarding household disinfectant consumption from an EPV perspective, in order to further develop and implement the targeted environmentally preferred behavior interventions in future. The positive perceptions and attitudes are prerequisite to subsequent behavioral change, thus could increase the effectiveness of future strategies against disinfectant pollution. In recent years, along with the practice of ecological civilization construction strongly advocated and promoted by the Chinese government, environmental awareness of the Chinese people has been gradually awakened [11]. The previous surveys on the Chinese respondents’ environmental perceptions and attitudes toward the PECs conducted by our team [11,13,34] showed that most respondents perceived the environmental problem posed by PECs to be an urgent issue, and strongly supported the implementation of EPV. However, the present study showed that only a fraction of respondents were concerned about the disinfectants’ environmental impacts when they consumed household disinfectant products, and sure of the existence and potential ecosystem hazards of disinfectant residues in environment, suggesting that the Chinese public’s environmental perceptions on disinfectants were poor. Accordingly, 53% respondents stated that they want to firstly acquire the related knowledge and information if they participated in the disinfectant pollution control. In addition, we found less than half respondents had positive attitudes toward the source control of disinfectant pollution from an EPV perspective. Relative poor environmental perceptions regarding disinfectant pollution and conservative attitudes toward its control might be due to the fact that the disinfectant pollution is a very emerging environmental issue triggered by the sudden outbreak of COVID-19. Therefore, it is necessary to develop the public education to enhance the awareness of environmental risks posed by disinfectant residues and their control.

On the other hand, under the current situation that COVID-19 pandemic continues to wreak havoc, the effective control of COVID-19 spreading is indisputably the most important. In this study, 99.5% respondents considered the disinfection activity as a key factor affecting their own disinfectant consumption choices. Accordingly, 64% believed that the environmental concerns of disinfectants might be detrimental to infection prevention and control during COVID-19 pandemic, and only 2% were willing to reduce unnecessary household consumption and use of disinfectant products for the control for disinfectant pollution. These data suggested that how to balance the disinfection effectiveness and the environmental factors of disinfectants is critical for the further control of disinfectant pollution in the environment. So far, the disinfectant usage frequency has not been specifically recommended in the Chinese national Guideline for the Use of Disinfectants [6]. Thus, the Chinese public do not currently receive the official advice with regards to disinfectant usage frequency to effectively fight coronavirus. Perhaps because of fear of COVID-19 infection, the public preferred to frequently use disinfectants. Some academic studies [5,9] recommended that, during the pandemic, the person should disinfect his/her hands when doing certain activities, including after going to the toilet, before and after eating, after shopping, after touching contaminated surfaces, etc.; and the frequency of disinfections recommended for environmental surfaces is two times per day. However, the present academic support is not sufficient enough. Based on the further studies on the disinfection effectiveness against COVID-19 and the environmental safety of disinfectants, more detailed information about the optimized usage of disinfectants for COVID-19 control should be provided by public health organizations.

Obviously, based on our survey results on the current household disinfectant product consumption and usage levels, some Chinese people tend to overuse the disinfectants. Moreover, we found that household storage of disinfectant products was a common practice among the Chinese public, therefore, there would be a considerable amount of leftover disinfectants which need to be properly disposed. Otherwise, these unwanted or expired disinfectants would generate a high environmental load of disinfectant residues. Moreover, throwing away in “household garbage” was a main disposal mechanism for unused disinfectant products among the respondents, which would lead to disinfectant contamination of landfill leachate, subsequently, disinfectant contamination of downgradient groundwater and surface water, according to the environmental behavior model of PECs [25,34]. Encouraging environment-friendly pharmaceutical disposal behaviors is...
one of essential elements involved in EPV-related pharmacy administrative interventions [25,34]. The well-established pharmacy take-back system as an environmentally appropriate method to dispose of unused medications could be adopted in the source control of disinfectant pollution, in order to minimize the environmental load caused by expired or unwanted household disinfectant products.

Our previous study [27] proposed that, because the pharmaceutical-related consumption and disposal behaviors leading to PEC pollution vary among different population groups, EPV practice should target some key population groups. In this study, we found that, as the consumption decision-makers in the family, the females, the middle aged adults and those having healthcare professional background should be focused on to promote rational consumption of household disinfectant products in the future stewardship program for minimizing the disinfectant pollution. Moreover, the higher-educated and those having healthcare professional background tend to pay more attention to the environmental issues caused by disinfectants, importantly, appreciate the disinfectant environmental risk management, suggesting these population groups had the potential to become “forerunners” in the future disinfectant environmental risk management program. Once there has been an official consensus on the disinfectant usage which could balance environmental concerns with infection prevention and control, the above population groups should be primarily informed. In this survey, half of the respondents were from Wuhan area, the original epicenter of COVID-19. The other half lived in non-Wuhan areas with low risk of COVID-19 infection. No significant difference of household disinfectant consumption behaviors and related environmental concerns was found between respondents living in Wuhan and in non-Wuhan areas, suggesting that the impact of COVID-19 on household disinfectant consumption and its possible environmental burden might be a national problem in China.

The present study has some limitations. Firstly, our survey was distributed within the co-authors’ personal networks. This is not a random sample and it is unclear whether the respondents were representative of the general population of China. In addition, this anonymous study allowed multiple individuals from the same household to answer the survey, which might result in some repeated measures of consumption data of products used to disinfect the home environment. Moreover, in order to obtain as many completed questionnaires as possible, this survey was available off and online. Among all the involved questionnaires, 12.0% were collected via online panels, and most (88.0%) were collected using traditional paper-based instruments. As shown in Table S1 (Supplementary material 2), the younger and the high-educated were more likely to be involved in the online survey (P<0.01). The equivalence of online and paper-based survey data in this study was difficult to determine. Besides, the self-reported data that this questionnaire-based survey collected might be subject to recall bias and other biases, and the related results could be affected by subjective judgment.

5. Conclusions

This survey involving 3667 Chinese residents demonstrated that the COVID-19 outbreak caused a tremendous rise in the public’s household disinfectant consumption and usage levels in China. After the COVID-19 outbreak, the chlorine-based and alcohol-based disinfectants were considered as the most preferred products for home environment disinfection and hand sanitization, respectively. Most importantly, considering the potential environmental risks posed by disinfectant residues, we firstly assessed the environmental perceptions, attitudes and practice regarding household disinfectant consumption. In particular, in the context that no strategy is currently available to minimize the disinfectant pollution, based on the similarities between disinfectants and pharmaceuticals, this study proposed an EPV perspective for disinfectant environmental risk management. The survey results suggested that the Chinese public’s environmental perceptions and practice on disinfectants were poor. Less than half respondents had positive attitudes toward the source control of disinfectant pollution. Contradiction between the environmental concerns of disinfectants and the disinfection effectiveness against COVID-19 was perceived as the most important barrier of disinfectant pollution control. About half respondents tended to firstly acquire the related knowledge and information when they were required to participate in the control for disinfectant pollution. In addition, the females, the middle aged adults and those having healthcare professional background usually acted as the disinfectant product consumption decision-makers in the family. Environmental awareness of the higher-educated and those having healthcare professional background in regard to disinfectant pollution and its source control using the idea of EPV appeared to be at a higher level. These population groups could be focused on to develop targeted efforts for the future control of disinfectant pollution in environment.

Supplementary materials

Supplementary material 1-Translated Questionnaire.
Supplementary material 2-Table S1. Respondents’ socio-demographic information collected online and offline.

CRediT authorship contribution statement

Jie Guo: Writing – original draft, Software, Validation, Visualization, Formal analysis. Mengfan Liao: Software, Validation, Visualization, Formal analysis, Methodology. Bingshu He: Writing – original draft, Software, Validation, Visualization. Juan Liu: Conceptualization, Methodology, Xianmin Hu: Methodology. Dan Yan: Writing – review & editing. Jun Wang: Conceptualization, Methodology, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jece.2021.106168.

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