CHAPTER

10

Addressing associated risks of COVID-19 infections across water and wastewater service chain in Asia

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10.1 Introduction

The Asian region continues experiencing severe environmental public health and economic impacts due to poor sanitation and lack of proper wastewater treatment facilities. It is estimated that more than 80% of generated wastewater in Asia was directly discharged into receiving water bodies without adequate treatment (Bao and Kuyama, 2013), causing substantial levels of fecal contamination and microbial risks in drinking water sources, as well as negative impacts on inland and coastal ecosystems. Consequently, many rivers in the region are highly polluted, and more than 2 million people die every year as, mostly children in developing countries, a result of water-related diseases (WHO, 2020b).

Moreover, the ongoing global pandemic of novel coronavirus (or COVID-19 pandemic) caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is having significant public health impacts at global scale, with more than 115 million infected cases have been reported and over 2.5 million deaths have been confirmed throughout over 200 countries according to the latest information from Johns Hopkins University (JHU, 2020). Since the major transmission, routes of SARS-CoV-2 are inhalation of droplets/particles or aerosols through person-to-person contact or during close unprotected contact between carrier and healthy with SARS-CoV-2 contaminated objects (WHO, 2020a). Such droplets or aerosols landing on surfaces can also spread infection. Many countries have imposed "social distancing" and requested people to wear a mask when going out in public as few of the countermeasures to stop the spread of this infectious disease.

Unfortunately, it has been reported and confirmed recently that infectious virions can also be present in human feces (Kitajima et al., 2020; Lin et al., 2020; Wang et al., 2020a; Wang et al., 2005d), which will gradually enter sewerage networks or directly discharged into open environment or nearby water bodies. There are also reports which mention that viral RNA can be persistently shed in feces for a maximum of 33 days even after the patient is tested negative for respiratory viral RNA (Wu et al., 2020b), while some studies demonstrated that RNA concentration even could be detected in SARS-CoV-2 contaminated wastewater at 4–7 days ahead of case detection (WHO, 2020c). Both viable SARS-CoV-2 and viral RNA can shed in bodily excreta, including saliva, sputum and feces, which are subsequently disposed in wastewater (Kitajima et al., 2020). Coronavirus can be remained infectious in sewage for a much longer period, up to 14 days at 4°C (Wang et al., 2005d) in low-temperature regions. It is estimated that 1.8 billion people globally using fecal-contaminated sources as drinking water, thus, potential COVID-19 transmission risk is expected to increase several folds (Bhowmick et al., 2020), if this contaminated wastewater, fecal wastes and drinking water supply sources are not properly managed. Therefore, safely managed wastewater and fecal wastes from infected, recovering and recovered patients is extremely important, but also pose a significant challenge to stop the spread of infections (e.g., sewerage workers, or population affected by sewage flooding events). This chapter

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aims to (i) highlight a strong need to properly address the existing issue of poor wastewater management in many Asian countries in order to minimize the human health risks associated with SARS-COV-2 infection, (ii) discuss possible routes of SARS-CoV-2 infections and contamination across water and wastewater service chain; and (iii) propose preventive countermeasures to stop possible COVID-19 transmission, particularly it highlights the importance role of using regular viral surveillance in wastewater in the affected areas as an early-warning tool for revealing true scale of the coronavirus outbreak, trends of the pandemic, as well as providing early warnings to the community.

10.2 SARS-CoV-2 in feces and wastewater

10.2.1 SARS-CoV-2 in feces

SARS-CoV-2 is known to cause not only respiratory but also gastrointestinal infections (including diarrhea). In a meta-analysis of 60 studies conducted from six countries (China, South Korea, Singapore, Vietnam, United States, and United Kingdom) with a total of 4243 patients infected with SARS-CoV-2, the prevalence of gastrointestinal symptoms and diarrhea were 17.6% and 12.5% (Cheung et al., 2020). Other studies revealed that COVID-19 patients with diarrheal symptoms were in a range from 3.8% to 24.2%, respectively (Guan et al., 2020; Lin et al., 2020; Pan et al., 2020). To date, a number of studies have reported the presence of SARS-COV-2 in stool samples and anal/rectal swabs from COVID-19 patients by using molecular detection methods (Table 10.1). Although the prevalence of SARS-CoV-2 positivity has varied among studies, the presence of SARS-COV-2 in stool specimens was found relatively common. Lin et al. (2020) investigated fecal samples of 65 hospitalized patients in Zhuhai, China and found 31 samples (47.7%) were positive. In other studies examined the stool samples from COVID-19 patients, the positive detection rates ranged from 21.4% to 89% (Table 10.1; Chen et al., 2020b; Wu et al., 2020b; Zhang et al., 2020b). Regarding urine specimens, a few studies reported positive results (Chen et al., 2020b; Pan et al., 2020; Wang et al., 2020c; Xiao et al., 2020).

TABLE 10.1 Prevalence of SARS-CoV-2 in feces or anal rectal swabs collected from COVID-19 patients.

Countries	No. patient	Detection rates[a] No.	Detection rates[a] %	SARS-CoV-2 concentration[b]	Detection methods[c]	References
China	95	31/65	47.7	na	rRT-PCR	Lin et al. (2020)
China	42	6/28	21.4	na	rRT-PCR	Chen et al. (2020b)
China	74	41/74	55	na	rRT-PCR	Wu et al. (2020b)
China	205	44/153	29	<2.6 × 10^4 copies/mL (Ct value >30)	rRT-PCR	Wang et al. (2020c)
China	73	39/73	53.4	na	rRT-PCR	Wu et al. (2020a)
China	178	8/15	53.3	Ct value: 19.5–33.6	RT-qPCR	Zhang et al. (2020b)
China	82	9/17	53	5.5 × 10^2 –1.2 × 10^5 copies/mL	RT-qPCR	Pan et al. (2020)
China	57	11/28	39	Ct value: 24–39	rRT-PCR	Chen et al. (2020a)
Korea	46	2/46	4	Ct value: 27.4–31.6	rRT-PCR	Park et al. (2020)
Singapore	18	4/8	50	Ct value: 20–<40	rRT-PCR	Young et al. (2020)
France	5	2/5	50	6.3 × 10^5–1.3 × 10^8 copies/g-feces	rRT-PCR	Lescure et al. (2020)
Germany	9	8/9	89	10^3–10^8 copies/g-feces	rRT-PCR	Wölfel et al. (2020)

[a]*Detection rate was calculated based on the number of patients examined.*
[b]*The concentration of SARS-CoV-2 was expressed as copies/mL, copies/g-feces or Ct value.*
[c]*Presence of SARS-CoV-2 was determined by real-time reverse transcription-polymerase chain reaction (rRT-PCR) or quantitative reverse transcription-polymerase chain reaction (RT-qPCR).*
na, not available.

SARS-COV-2 was shed into the stool of COVID-19 patients for a long duration (up to 5 weeks from first symptom onset) (Cai et al., 2020; Kim et al., 2020; Pan et al., 2020; Wölfel et al., 2020). Several studies even found that fecal samples remained positive for SARS-CoV-2 RNA fragments after respiratory samples tested negative for SARS-CoV-2 RNA (Chen et al., 2020b; Tian et al., 2020). SARS-CoV-2 RNA was also detected in the feces of infected people who had mild or even no symptoms (Tian et al., 2020). Regarding the concentration of SARS-CoV-2 RNA, up to 10^8 copies/g-feces were reported (Lescure et al., 2020; Wölfel et al., 2020). The virus concentration had highest peak during the first week of symptoms and gradually decreased during the duration of the clinical course (Kim et al., 2020; Wölfel et al., 2020). Wölfel et al. (2020) reported that the concentration of SARS-CoV-2 RNA ranged from 10^3–10^8 copies/g-feces depending on the infectious course.

As shown in Table 10.1, the presence of SARS-CoV-2 in feces was commonly determined by molecular detection methods such as real-time reverse transcription-polymerase chain reaction (rRT-PCR) and quantitative reverse transcription-polymerase chain reaction (RT-qPCR). These molecular methods can detect SARS-CoV-2 genomes with high sensitivity, specificity and rapidity. Notably, the detection of viral genomes does not indicate viral infectivity. Therefore, the information on the infectivity of SARS-CoV-2 in feces was not discussed in the previous studies (Chen et al., 2020b; Pan et al., 2020; Wang et al., 2020c; Xiao et al., 2020). At the moment, only few studies indicated the infectivity of SARS-CoV-2 in feces based on the cultivation of SARS-CoV-2 isolated from stool specimens (Wang et al., 2020c; Wölfel et al., 2020; Zhang et al., 2020c). Wölfel et al. (2020) were not able to isolate culturable SARS-CoV-2 from fecal samples which had a high copy number of SARS-CoV-2 as determined by rRT-PCR. However, two recent studies confirmed the presence of live or infectious SARS-CoV-2 in feces from COVID-19 patients (Wang et al., 2020c; Zhang et al., 2020c). The detection of infectious virus in feces might imply the potential of oral–fecal transmission. However, the findings of these previous studies were based on a small number of patients who had high RNA viral genomes in feces. Thus, more studies are necessary to investigate the prevalence and concentration of infectious SARS-CoV-2 in feces of infected individuals.

10.2.2 SARS-CoV-2 in raw and treated wastewater

SARS-CoV-2 are shed in feces, urine and other human excreta which subsequently reach the sewerage systems. To date, the presence of on-infective RNA fragments of SARS-CoV-2 (or SARS-CoV-2 RNA) in wastewater has been reported around the world (Table 10.2). During the epidemic peak (between March 5th and April 23rd) in the Parisian area in France, Wurtzer et al., (2020a) examined raw wastewater from three wastewater treatment plants (WWTPs) for the presence of SARS-CoV-2 RNA. All the samples (23/23, 100%) were found positive for SARS-CoV-2. In similar studies conducted in United States of America, France, Australia, and Spain, the detection rates of SARS-CoV-2 RNA in raw wastewater ranged from 22% to 83% (Table 10.2; Ahmed et al., 2020; Medema et al., 2020; Randazzo et al., 2020; Sherchan et al., 2020). The range of SARS-CoV-2 RNA concentration in raw wastewater widely varied from 1.2×10^2–3.0×10^6 copies/L. When comparing between feces and wastewater, the concentration of SARS-CoV-2 in wastewater was 3–5 orders of magnitude less than that in feces (Tables 10.1 and 10.2). Although these previous studies obviously indicate the presence of SARS-CoV-2 in wastewater, the investigation about infectivity of SARS-CoV-2 in wastewater remained limited. To date, only two studies investigated the presence of SARS-CoV-2 in wastewater using both rRT-qPCR and cell culture methods, which can determine the infectivity of viruses (Rimoldi et al., 2020; Wang et al., 2020b). These two studies reported that infectious SARS-CoV-2 was not detected in wastewater by cell culture method despite the positive detection of SARS-CoV-2 RNA. Since the survival of SARS-CoV-2 in wastewater might vary depending on environmental factors (e.g., pH and temperature), more studies are needed to investigate the infectivity of SARS-CoV-2 in wastewater.

Several studies also investigated the presence of SARS-CoV-2 in treated wastewater and river waters (Haramoto et al., 2020; Randazzo et al., 2020; Rimoldi et al., 2020; Sherchan et al., 2020; Wurtzer et al., 2020a). The studies conducted in Japan (Haramoto et al., 2020) and Spain (Randazzo et al., 2020) found SARS-CoV-2 in secondary-treated wastewater with the concentration ranging from 2.4×10^3 copies/L to 2.5×10^5 copies/L. The presence of SARS-CoV-2 RNA up to 10^5 copies/L was also reported in final treated wastewater in a study conducted in France during the peak of the epidemic (Wurtzer et al., 2020a). Currently, there were only two studies investigating the presence of SARS-CoV-2 in river waters (Haramoto et al., 2020; Rimoldi et al., 2020). Haramoto et al. (2020) reported all river water samples (0/3) were negative for SARS-CoV-2, indicating the concentration of SARS-CoV-2 was less 3.7×10^2 copies/L (limit of detection). However, Rimoldi et al. (2020) detected SARS-CoV-2 RNA in 67% (4/6) of river water samples. Notably, this study was not able to detect any SARS-CoV-2 RNA in final treated wastewater. Therefore, it was hypothesized that a fraction of untreated wastewater has been directly discharged into surface waters due to noncollected domestic discharges or to the lack of separation of urban runoff waters from the domestic effluents

TABLE 10.2 Presence of SARS-CoV-2 in wastewater and river water.

		Detection results				
Countries	**Type of sample**	**No. (%)**	**Concentration (copies/L) or (Ct value)**	**LOD (copies/L)**	**Detection methods**	**References**
Japan	-Raw wastewater -Secondary-treated wastewater -River water	−0/5 (0%) −1/5 (29%) −0/3 (0%)	− nd -2.4×10^3 − nd	$-<6.6 \times 10^4$ $-<1.4 \times 10^2$ $-<3.7 \times 10^2$	RT-qPCR	Haramoto et al. (2020)
USA	-Raw wastewater -Secondary-treated wastewater -Final treated wastewater	−2/7 (28.6%) −0/4 (0%) −0/4 (0%)	-3.1×10^3 − nd − nd	-1.0×10^3 -1.0×10^3 -1.0×10^3	RT-qPCR	Sherchan et al. (2020)
France	-Raw wastewater -Final treated wastewater	−23/23 (100%) −6/8 (75%)	-2×10^4–5×10^6[a] $-<10^4$–10^5[a]	-10^3 -10^3	RT-qPCR	Wurtzer et al. (2020a)
The Netherlands	-Raw wastewater	18/30 (60%)	-1.2×10^4–1.9×10^6	− na	RT-qPCR	Medema et al. (2020)
Italy	-Raw wastewater -Final treated wastewater -River water	−4/8 (50%) −0/8 (0%) −4/6(67%)	− na − nd − na	− na	rRT-PCR	Rimoldi et al. (2020)
Australia	-Raw wastewater	−2/9, (22 %)	-1.2–1.9×10^2	− na	RT-qsPCR	Ahmed et al. (2020)
Spain	-Raw wastewater -Secondary-treated wastewater -Tertiary-treated wastewater	−35/42 (83%) −2/18 (11%) −0/12 (0%)	-1.2–3.2×10^5 -2.5×10^5 − nd	-2.8–8.1×10^4 -2.8–8.1×10^4 -2.8–8.1×10^4	RT-qPCR	Randazzo et al. (2020)
India	-Raw wastewater -Final treated wastewater	−2/2(50%) −0/2(0%)	− Ct: 32.6–35.5	− na	rRT-PCR	Kumar et al. (2020)
Pakistan	-Raw wastewater	−21/78 (27%)	− na	− na	rRT-PCR	Sharif et al. (2020)
Israel	-Raw wastewater	−10/26 (38%)	− Ct: 32.7–38.5	− na	RT-qPCR	Bar Or et al. (2020)

[a] *The concentrations were estimated from the graph.*
LOD, limit of detection; na, not available; nd, not detected.

(Rimoldi et al., 2020). In addition, it should be noted that the presence of viral genomes determined by molecular methods does not always correlate to the presence of infectious virus particles. In the study of Rimoldi et al. (2020) when testing the positive river water samples with SARS-CoV-2 RNA by rRT-PCR, no infectious SARS-CoV-2 was detected by the cell culture method, suggesting a low risk of infection from river waters.

Although several studies quantified the concentration of SARS-CoV-2 in raw and treated wastewater, the efficiency of SARS-CoV-2 removal from WWTPs remained limited. Indeed, Sherchan et al. (2020) detected 3.1×10^3 copies/L of SARS-CoV-2 in raw wastewater, which was close to the limit of detection (1×10^3 copies/L). Additionally, no SARS-CoV-2 RNA was detected in secondary-treated and final treated wastewaters, indicating the concentration of SARS-CoV-2 RNA in treated wastewaters was less than the limit of detection (1×10^3 copies/L). Thus, the removal of SARS-CoV-2 was not clear in this study. At present, only Wurtzer et al. (2020a) clearly observed the reduction of SARS-CoV-2 from WWTPs. In this study, all raw wastewater samples (23/23) were positive for SARS-CoV-2 with the concentration of around 10^7 copies/L. In addition, most of the treated wastewater samples (6/8) were positive for SARS-CoV-2 with the concentration of round 10^5 copies/L. Thus, the concentration of SARS-CoV-2 was reduced 100 times (or 99%) through the WWTP in this study (Wurtzer et al., 2020a). However, the virus removal efficiency can vary depending on wastewater quality and treatment processes applied, thus more studies are needed to have better understanding about the removal of SARS-CoV-2 throughout wastewater treatment plants.

10.3 Addressing potential risks associated with water and wastewater services

Possible routes of SARS-CoV-2 infections and contamination across water and wastewater service chain are identified and described as in Fig. 10.1. As mentioned earlier, since SARS-CoV-2 has been detected in the human feces, urine, or vomit of the infected person, thus it will gradually enter the sewerage system or directly discharged into nearby receiving water bodies, where sewerage system is not available. Beside the possible hotspots of infection

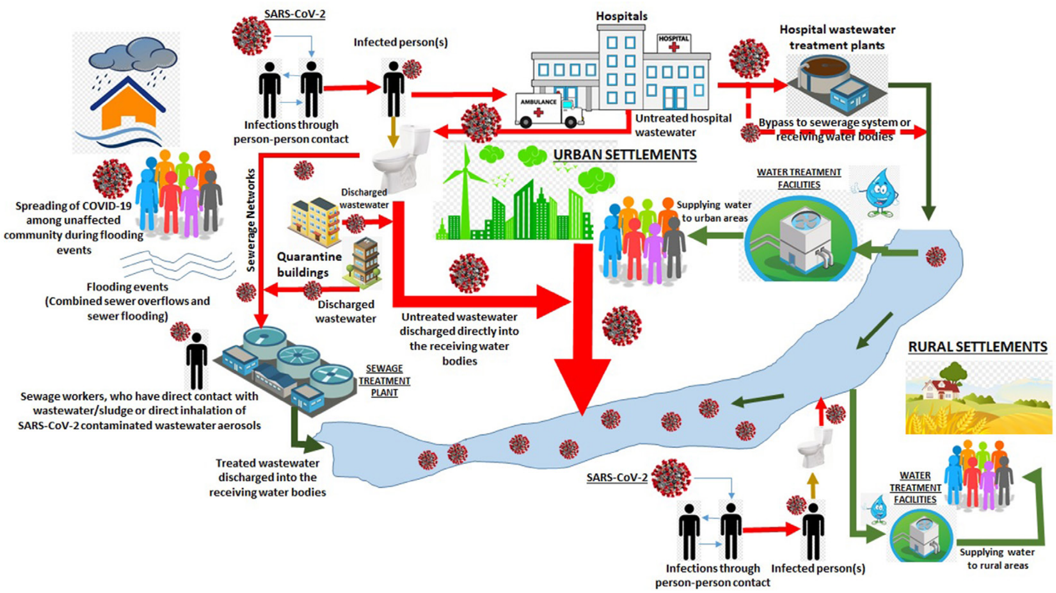

FIG. 10.1 Possible routes of SARS-CoV-2 infections and contamination in water and wastewater services sector. *Source: The figure was developed by authors, 2020.*

within infected communities, hospitals and quarantine buildings/centers are other major hotspots. Wastewater discharged from hospitals must gradually enter in-situ treatment facilities of hospitals/quarantine building/centers, before reaching to the sewerage system or directly bypassing into nearby water bodies. Unfortunately, in many cases in Asian countries, a large percentage of hospital wastewater might not be properly treated and disinfected separately; as a result, this SARS-CoV-2 contaminated wastewater is often discharged into common municipal sewerage system or bypassed directly into nearby receiving water bodies. Direct consumption of this SARS-CoV-2 contaminated water sources by rural people having no access to water treatment facilities, or only access to improperly water treatment facilities may pose a risk of infection to these people. In addition, SARS-CoV-2 can be spreading among infected communities during heavily flooding events, which often occurs in urban areas recently in many big Asian cities. Moreover, sewage workers, who have directly contacted with SARS-CoV-2 contaminated wastewater or inhaled SARS-CoV-2 contaminated aerosols formed over the uncovered aerobic wastewater treatment process within wastewater treatment plants, will also have a high-associated risk of infection.

As summarized in Table 10.1, SARS-CoV-2 RNA was commonly present in feces of COVID-19 patients (21.4–89%) at concentration ranged from 10^3–10^8 copies/g-feces depending on the infectious course. This viral concentration will significantly decrease to 1.2×10^2–3.0×10^6 copies/L due to the dilution of feces with municipal wastewater. At present, there are only few comprehensive studies on the fate of SARS-CoV-2 along the entire chain of a wastewater treatment plant. Two recent studies have reported the investigation of SARS-CoV-2 in treated wastewater (Randazzo et al., 2020; Wurtzer et al., 2020a). In the first study, Wurtzer et al. (2020a) found a 100-fold reduction in SARS-CoV-2 (10^5 copies/L) in final treated wastewater compared to raw wastewater (10^7 copies/L). Meanwhile, in the second study, Randazzo et al. (2020) found that all tertiary treated wastewater was negative, whereas only the secondary treated wastewater was positive, with a viral load of 5.40 $\log_{10}$ copies/L. These results suggest that secondary wastewater treatment may contribute to the reduction of virus concentration, but removal ratio is largely variable. Therefore, in order to improve the level of virus inactivation in wastewater treatment plants, disinfection will play a significant role.

Recent published data (Chin et al., 2020; Doremalen et al., 2020; Nghiem et al., 2020) suggested that SARS-CoV-2 can remain viable on different surfaces in the environment for several hours and up to 7 days or more (Fig. 10.2), depending on outside environmental conditions such as temperature, humidity, pH, light exposure, types of surface, medium, etc. For instance, survival time of SARS-CoV-2 on cardboard, wood and cloth, plastic, glass and paper money surface can last long from 1 to 4 days, which suggests that any objects made of these materials previously hold or used by infected person(s) or suspected COVID-19 patients, either within communities, households, hospitals or quarantine buildings/centers can be a source of infection.

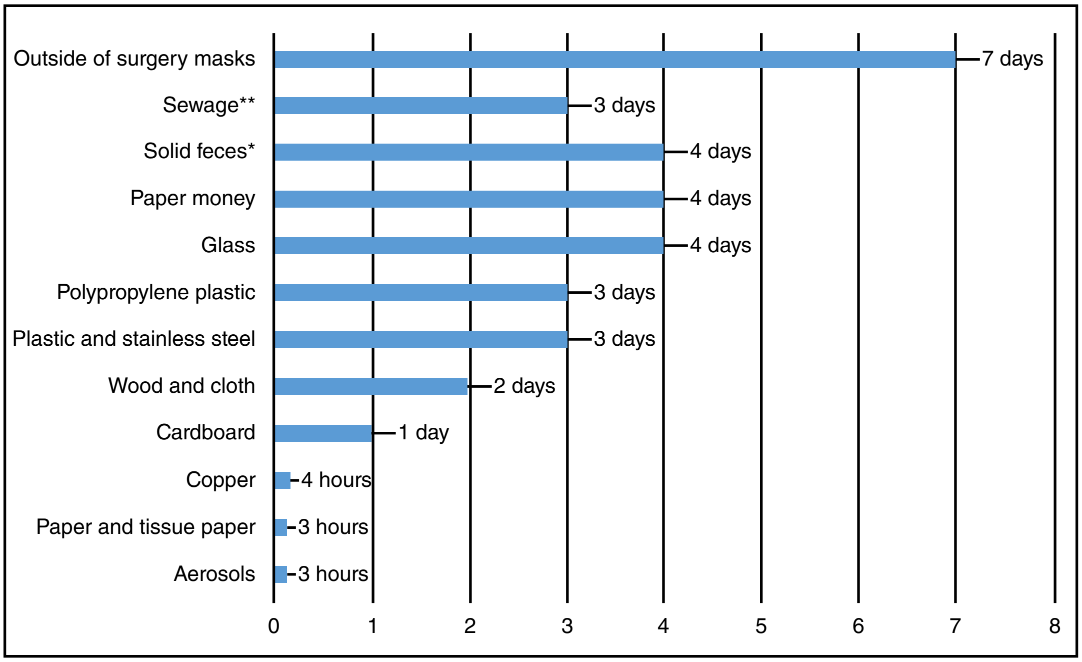

FIG. 10.2 Lifespan of COVID-19 on different surfaces. Note: * can be from 3 to 4 days. ** can be from 4 up to 14 days, depending on environmental conditions. *Source: Chin et al., 2020; Doremalen et al., 2020; Nghiem et al., 2020.*

10.3.1 Risks associated with SARS-CoV-2 contaminated wastewater from hospitals and quarantine buildings/spots

So far, most of studies focus on the detection of SARS-CoV-2 in indoor environment since its main transmission routes via human respiratory droplets and direct contact. Thus, it is still unclear whether SARS-CoV-2 can spill over and impose transmission risks to outdoor environments. Zhang et al. (2020a) has investigated the presence of SARS-CoV-2 by measuring viral RNA in 73 samples from outdoor environment of three hospitals in Wuhan. The results showed that SARS-CoV-2 was detected in soils (205–550 copies/g), aerosols (285–1130 copies/m^3) and wastewater (255–18,744 copies/L) in locations close to hospital departments receiving COVID-19 patients or in wastewater treatment facilities (e.g., septic tank and different wastewater treatment units). This result has clearly revealed significant viral spill over in hospital's outdoor environment, which was possibly caused by respiratory droplets from patients or aerosolized particles from SARS-CoV-2 contaminated wastewater facilities. The finding from this study was well supported and with many other recent published scientific works (Adelodun et al., 2020; Ghernaout and Elboughdiri, 2020; Wang et al., 2020a), where SARS-CoV-2 has been widely detected from wastewater samples in hospitals and quarantine spots, where COVID-19 infected patients were being treated, particularly from inlets of the wastewater treatment facilities and preprocessing disinfection pool. The authors call for effective measures such as introduction of decentralization of wastewater treatment facilities, community-wise monitoring and testing of SARS-CoV-2 in wastewater samples, improved sanitation and water quality, and more focused policy interventions. A special attention is also required for the surveillance and efficient disinfection (e.g., chlorination, UV irradiation, ozonation disinfection) of wastewater from COVID-19 related facilities, before discharging into receiving water bodies or sewerage networks.

10.3.2 Risks associated with the discharges and treatment of SARS-CoV-2 contaminated domestic wastewater from urban and rural settlements

It has been reported that during SARS outbreak in 2004 in China, SARS-CoV RNA was detected in 100% (10/10) of untreated and 30% (3/10) of disinfected wastewater samples collected from a hospital in Beijing, China receiving SARS patients (Wang et al., 2005d). Meanwhile, as mentioned earlier, during the ongoing COVID-19 pandemic, a number of recent studies has reported the molecular detection of SARS-CoV-2 in wastewater in the Australia, France, Japan, the Netherlands, Spain, Pakistan and USA (Ahmed et al., 2020; Haramoto et al., 2020; Medema et al., 2020; Nemudryi et al., 2020; Rimoldi et al., 2020; Sharif et al., 2020; Wurtzer et al., 2020a), highlighting the potential for fecal–oral transmission of the virus if this SARS-CoV-2 contaminated wastewater is not properly managed and treated before discharged into receiving water bodies. In case of developing Asian countries, it may pose a major risk to wider environment, since most of domestic wastewater and septage (generated sludge from septic tank) is only partly treated by simple and ineffective onsite sanitation systems such as septic tank (normally without disinfection process), before being discharged directly into receiving water bodies or infiltrated into the soil, which may contaminate shallow groundwater sources.

In addition, faulty sewage pipelines and ventilation systems can also contribute to the spread of SARS-CoV through aerosols, as mentioned in a case reported at Hong Kong's Amoy Gardens private housing estate almost two decades ago, where more than 300 residents caught severe acute respiratory syndrome (SARS), partially due to faulty sewage pipelines, and 42 residents died (Lee, 2003).

Considering this huge potential health risks of infection, it is strongly recommended that all domestic wastewater must be properly managed and treated, either by centralized or decentralized wastewater treatment systems, and disinfected before releasing into receiving water bodies or environment. Besides, precautionary measures for protecting the health of sanitation workers of water and wastewater treatment facilities and water/wastewater service providers must be followed. Workers/operators working in water and wastewater services, particularly at the sewage treatment plants, should wear appropriate personal protective equipment, which includes protective outerwear, gloves, boots, a face shield, and a mask. It is also recommended that workers should frequently perform hygienic practices like washing hands frequently, avoid touching eyes, nose and mouth with unwashed hands.

10.3.3 Risks associated with the direct contact with of SARS-CoV-2 contaminated sewage overflows during flooding events

Urban flood incidents triggered by heavy rainfall observed in many Asian cities nowadays often cause flooding of combined sewer systems as well. Prolonged and high frequency of flooding events are often associated with a number of waterborne pathogens like Campylobacter, Cryptosporidium, Giardia, norovirus and enterovirus, which can cause gastrointestinal diseases to people, exposed to these pathogens in the inundated areas. In order to evaluate the microbial risks associated with sewer flooding incidents, Veldhuis et al. (2010) took a number of samples from three sewer flooding incidents and measured the concentrations of Escherichia coli, intestinal enterococci and Campylobacter in the urban floodwater. The results indicated fecal contamination: fecal indicator organism concentrations were similar to those found in crude sewage under high-flow conditions and Campylobacter was detected in all samples. Meanwhile, in another study, Man et al. (2014) used quantitative microbial risk assessment to assess the risks of infection from exposure to urban floodwater in Netherland during 23 events in 2011 and 2012. The results showed a mean risk of infection per event for children in the community, who are exposed to the floodwater coming out of combined sewer overflows, stormwater and from the surface runoff generated due to rainfall, was 33%, 23%, and 3.5%, respectively. However, for the adults, the corresponding mean risk of infection was 3.9%, 0.58%, and 0.039%, respectively, mainly due to noroviruses and enteroviruses present in floodwater. Thus, the risk factors of COVID-19 should never been compromised because there is a high possibility that it will be spread through SARS-CoV-2 contaminated wastewater from combined sewer overflows and flooding sewers, especially during heavy rains and flooding events. Meanwhile, public should be announced and made aware that floodwater might be contaminated by enteric pathogens and virus, including SARS-CoV-2 (especially during COVID-19 outbreaks). Thus, people should avoid direct exposure to or contact with floodwater, as much as possible, and hence good hygiene practices should be regularly implemented.

10.3.4 Risks associated with treatment facilities for water supply using raw water sources contaminated with SARS-CoV-2

Water treatment plants are vulnerable to the impacts of SARS-CoV-2 contaminated wastewater; however, receiving surface water sources with upstream wastewater impacts are the most susceptible to SARS-CoV-2 contamination during and after the COVID-19 outbreak. However, up to date, there is no infectious SARS-CoV-2 case detected from drinking water supplies, thus it can be assume that the health risk for drinking water supplies is low. There are a number of factors that may help to inactivate the virus in surface waters, including sunlight, oxidative chemicals, chlorination and disinfection with ultraviolet (UV) light, predation by microorganisms, etc. Although, there is no evidence to date about the survival of SARS-CoV-2 in drinking water; and conventional centralized water treatment plants with filtration and disinfection techniques which most likely inactivate the COVID-19 virus WHO and UNICEF (2020). For effective disinfection, a residual concentration of free chlorine $\geq$0.5 mg/L after at least 30 minutes of contact time at pH $<$8.0 is required (WHO and UNICEF, 2020). In addition, a chlorine residual should be maintained throughout the distribution system until reaching the end-use taps. In rural areas, especially in the places where centralized/decentralized drinking water treatment plants are not operating or not available, common household water treatment practices including boiling should be regularly used (e.g., SARS-CoV-2 can be completely inactivated when heated at 92°C for 15 minutes (Pastorino et al., 2020), or using high-performing ultrafiltration or nanofiltration filters, solar irradiation, and, in nonturbid waters, UV irradiation and appropriately dosed free chlorine", should be used (WHO and UNICEF, 2020).

10.4 Regular virus surveillance in wastewater for COVID-19

Regular virus surveillance in wastewater (also known as wastewater-based epidemiology) is a proven concept in public health, which has been used for decades to assess the success of vaccination campaigns against poliovirus. Such practice can be replicated as a useful tool to understand the circulation and prevalence of other pathogenic viruses in a human community. Viral pathogens can be shed in the stool of infected individuals at high concentrations and found to be relatively stable in wastewater (Fong and Lipp, 2005). Thus, sampling and analyzing wastewater can be an alternative approach to study the epidemiology of virus infection in a human community served by the wastewater system. This approach can overcome the limitation of traditional clinical surveillance, which is time-consuming, laborious, and expensive. In addition, the clinical test cannot identify asymptomatic patients and so can underestimate the real scale of the virus infection. Wastewater surveillance has a long history of use in public health, particularly for investigating the infection of enteric viruses (e.g., poliovirus, norovirus, enterovirus) and their genetic diversity in the human population (Kazama et al., 2016; Nakamura et al., 2015; Prevost et al., 2015).

In the current COVID-19 pandemic, the occurrence of SARS-CoV-2 has been commonly found in the feces of COVID-19 patients (Foladori et al., 2020). This has triggered research to detect noninfective RNA fragments of SARS-CoV-2 in untreated domestic and hospital wastewater, and sludge. SARS-CoV-2 has been widely detected in raw wastewater of wastewater treatment plants served for the human population infected by COVID-19 around the world (Kitajima et al., 2020; Rosa et al., 2020). Medema et al. (2020) investigated the concentration of noninfective RNA fragments of SARS-CoV-2 in the wastewater of six cities in the Netherlands and compared to the reported COVID-19 cases in the same cities during the study period. This study found that an increase in the SARS-CoV-2 RNA concentration was observed as the number of reported COVID-19 cases increased in these cities. Further studies conducted in France and the United States also demonstrated a correlation between the concentration of SARS-CoV-2 RNA in wastewater and the number of confirmed COIVD-19 cases in infected areas (Peccia et al., 2020; Wu et al., 2020a; Wurtzer et al., 2020a). Moreover, a recent study reported that the positive copy numbers of SARS-CoV-2 in wastewater could be used to estimate the number of infected individuals in a catchment via Monte Carlo simulation (Ahmed et al., 2020). The simulation estimated a median range of 171–1090 infected people in the catchment in Australia (population of 600,000), which is in reasonable agreement with clinical observations. These are important evidence to indicate the potential application of wastewater surveillance of SARS-CoV-2 to detect the infection of COVID-19 in the human population.

Several recent studies have also reported the information on the sensitivity of wastewater surveillance for SARS-CoV-2. In a study conducted in Japan, SARS-CoV-2 was detected in wastewater when the 36 cumulative COVID-19 cases were reported, corresponding to only 4.4 cases per 100,000 inhabitants. Similar findings were also observed in a study conducted in the Netherlands since positive wastewater samples were detected when the number of reported cases reached 5–10 cases per 100,000 inhabitants (Medema et al., 2020). Similarly, a study conducted in Spain, positive signals of SARS-CoV-2 were found in areas with low COVID-19 prevalence, ranging from 16.69–21.18 cases per 100,000 inhabitants (Randazzo et al., 2020). These studies suggest that monitoring of wastewater for SARS-CoV-2 could be sensitive enough to detect the low prevalence of COVID-19 cases in the local communities. Notably, recent studies conducted in France and the United States have reported the presence of SARS-CoV-2 in wastewater several days before the detection of COVID-19 in clinical surveillance (Wu et al., 2020a; Wurtzer et al., 2020b). In addition, SARS-CoV-2 can be detected in wastewater 12–16 days before first confirmed COVID-19 cases in the study conducted in Spain (Randazzo et al., 2020). Thus, there is potential to use wastewater surveillance as an early warning tool for the occurrence of COVID-19 in communities, monitoring the status of COVID-19 infection in local communities, and evaluating the trends and tracking hotspots. Early warning of infection would provide a valuable time to implement actions to control the spread of COVID-19.

Although the findings of current studies have supported the technical viability of wastewater surveillance for SARS-CoV-2, challenges are remaining. Calculating the actual number of cases in a community based on the SARS-CoV-2 concentrations in wastewater is one of the biggest challenges since it can be affected by many factors such as the amount and dynamics of viral shedding in feces, viral stability in the sewer network and variation in wastewater flow due to climate (Farkas et al., 2020). In addition, there is no standardized protocol for concentrating SARS-CoV-2 in wastewater. The current concentration methods used for SARS-CoV-2 were originally developed for the recovery of nonenveloped human enteric viruses, such as norovirus, rotavirus and adenovirus, which are major causes of waterborne diseases (Kitajima et al., 2020). Thus, little is known about the recovery efficiencies of SARS-CoV-2 from the viral concentration methods, which are important to determine the accurate number of SARS-COV-2 in wastewater. Moreover, most studies to date on wastewater surveillance of SARS-CoV-2 have been conducted in developed countries, where majority of population is connected to wastewater collecting system. It is necessary to investigate whether this approach can be applied in developing countries with poor infrastructure for wastewater collection and treatment.

10.5 Conclusions and recommendations

Under the ongoing coronavirus outbreak 2019, a number of scientific evidences have showed that SARS-CoV-2 was detected and spreading through human feces; and gradually ended up in sewage/wastewater treatment plants. SARS-CoV-2 could maintain their viability (e.g., in raw sewage, hospital wastewater, raw wastewater discharges from quarantine buildings/spots, SARS-CoV-2 contaminated floodwater, and water bodies that was originated from fecal discharge of infected patients) for several days in vitro after leaving the feces; thus posing a potential risk to public health, if it is not properly handled and treated. Therefore, precautionary measures, effective interventions and control strategies should be taken to stop the spread of SARS-CoV-2 infections from these possible routes, especially from aerosol transmission in above mentioned hotspot areas. Meanwhile, workers working for water and wastewater services, particularly at the sewage treatment plants, must be equipped with appropriate personal protective equipment, frequently perform handwashing and respiratory hygiene using alcohol hand rub or hand sanitizer, and avoid touching eyes, nose, and mouth with unwashed hands.

It is also recommended that COVID-19 pandemic response plans should also be quickly prepared by each local government for the period until SARS-CoV-2 is under control, possibly a year or more.

In addition, it has been showed that regular wastewater surveillance for viral loads, including in the areas replying on nonsewered on-site sanitation systems, is considered a useful early-warning and complementary tool to clinical surveillance of COVID-19, which may help to monitor the changes in the quantity of SARS-CoV-2 over time; therefore, it can facilitate to forecast new possible outbreaks. This is also considered a "cost-effective" measure in the community, as well as effective tool to identify potential hotspots of COVID-19 infection in early stage. If SARS-CoV-2 can be effectively monitored in a community at an early stage through wastewater-based epidemiology, together with results from clinical diagnostic testing, effective interventions can be proposed and taken as early as possible to restrict the movements of infected population, as well as to minimize the pathogen spread and threat to public health.

However, in order to replicate and scale up the regular virus surveillance in wastewater for COVID-19 in developing Asian countries, a number of challenges or gaps have been identified (GWOPA, 2020; UN Habitat and GIZ, 2020) and these challenges must be overcome for effective utilization of this early warning tool for stopping the spread of COVID-19 infections, including: (i) lack of access to testing facilities or laboratories for detection of SARS-CoV-2 in water/wastewater/sludge samples; (ii) lack of knowledge and scientific evidence on how SARS-CoV-2 behave in wastewater and fecal sludge; (iii) unavailability of detailed technical guidance on monitoring in both sewered and nonsewered areas; (iv) lack of protocols or standard methodologies for sampling, collection, treatment, and examining the wastewater for the presence of SARS-CoV-2; (v) prohibitive costs; (vi) and finally inadequate collaboration between water/wastewater utilities and health authorities.

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