Review of Coronavirus transmission in urban clusters: Survival in Water and Wastewater Systems

Suzaini Zaid[1*], Muhamad Afiq Aziz[2], Raha Sulaiman[1], Khanom Simarani[2], Yohanes Totok Suyoto[3], Eric Lou[4], Masoud Esfandiari[5]

[1] *Centre for Building, Construction & Tropical Architecture, Faculty of Built Environment, University of Malaya, Kuala Lumpur, Malaysia*
[2] *Institute of Biological Science, Faculty of Science, University of Malaya, Kuala Lumpur, Malaysia*
[3] *Faculty of Humanities and Business, Pembangunan Jaya University, Bantan, Indonesia.*
[4] *Department of Engineering, Manchester Metropolitan University, Manchester, United Kingdom*
[5] *Faculty of Architecture and Urban planning, Shahid Beheshti University, Tehran, Iran*

[1*] *suzaini_zaid@um.edu.my*

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The ongoing Coronavirus Disease 2019 (COVID-19) pandemic has infected over 58 million people and claimed over 1.58 millions deaths globally (as of 11th December 2020) since its first outbreak in Wuhan, China in December 2019. Initially, the numbers of infected patients and death was largely contained in China with 98% of all confirmed infected cases. However, the increased rate of new infected cases outside of China like United States, Italy, and Spain raises questions on the virus characteristics and its routes of transmission. Although the main transmission modes of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) are through direct contact and respiratory droplet/aerosol inhalation, current studies stipulate that SARS-CoV-2 RNA is found in sewerage, suggesting the potential transmission of SARS-COV-2 through wastewater systems. This paper seeks to review potential exposure routes of SARS-COV-2 in urban environments, the survival rate of coronaviruses that pose human health risks, and to provide relevant safety recommendations to reduce the impact of ongoing COVID-19 pandemic. There is an urgent need for wastewater effluent and water treatment supply epidemiology surveillance, especially in developing countries with subpar wastewater treatment systems and infrastructure to reduce human and ecological risks to protect populations from infectious diseases outbreak.

Keywords: *COVID-19, SARS-CoV-2, coronavirus, survivability, wastewater, virus transmission, urban*

1. INTRODUCTION

The novel zoonotic Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), an etiological agent of Coronavirus Disease 2019 (COVID-19) has infected over 58 million people worldwide and continues to spread globally (WHO 2020b). This novel coronavirus (nCoV) was identified in Wuhan, China in late December 2019 and was tentatively named as 2019-nCoV (Coronaviridae Study Group of the International Committee on Taxonomy of Viruses 2020). SARS-CoV-2 is the newly re-emerging zoonotic coronavirus (CoV) that has resulted in a major outbreak after SARS-CoV in 2003 and Middle East Respiratory Syndrome Coronavirus (MERS-CoV) in 2012 (Hu et al. 2015). SARS-CoV-2 infections are responsible for causing high fever, dry cough and respiratory problems such as breathing difficulties, shortness of breath and severe pneumonia (Chen et al. 2020; Zhou et al. 2020). COVID-19 showed similar mortality risk factors to those of SARS and MERS (Lu et al. 2020a). However, the fatality rate of SAR-CoV-2 is 2.3% which is lower than other coronavirus strains such as SARS-CoV and MERS-CoV with 9.5% and 34.4%, respectively (Petrosillo et al. 2020). The basic reproduction number (R_0) represents virus transmissibility within a naïve population, indicating the average number of new infected cases produced by an infectious individual where $R_0 > 1$ shows the number of new infections is likely to increase whereas $R_0 < 1$ stipulates that virus transmission will cause less than one new infection case and the disease will eventually decline. To date, the estimate R_0 of COVID-19 is 2-2.5 people which is higher than SARS (1.7-1.9 people) and MERS (less than 1 person) (Liu et al. 2020b; Petrosillo et al. 2020).

The present COVID-19 pandemic is one of the biggest global emergency crises that does not seem to be tapering off soon, with more new infected cases are reported across the globe (WHO 2020b). Current understanding of COVID-19 transmission is mainly based on previous SARS and MERS outbreak where it has been shown to transmit from person-to-person through direct personal contact and inhalation of respiratory droplets secreted from infected individuals (Shereen et al. 2020). Intriguingly, some studies have reported that SARS-CoV-2 was detected in the stool samples collected from COVID-19-positive patients, inferring that SARS-CoV-2 may potentially transmit through faecal-oral route (Wang et al. 2020; Woelfel et al. 2020). During 2003 SARS outbreak in Hong Kong, inadequate sewage system is believed to be a platform for SARS transmission where aerosolized faecal droplets containing coronavirus re-enters into apartment complex through sewage and drainage systems with strong upward air flows, inadequate traps and non-functional water seal (Lee 2003; Hung et al. 2006; Wigginton et al. 2015). Little studies have been done on the relationship between urban clusters formation and the spread of infectious microorganisms. Therefore, enhanced environmental surveillance through wastewater system need to be addressed to reduce health burden, alert health officials to impose or withdraw control measures and inform local authorities of the potential outbreak in the near future.

2. METHODOLOGY AND DATA COLLECTION

This review article is aimed to discuss the possible exposure routes of the novel SARS-CoV-2 in urban environment and the survival rate of coronaviruses that poses human health risks. The literature analysis begins with materials collected from independent databases such as ScienceDirect, Wiley Only Library and The Lancet. In order to avoid duplication of articles, specific keyword combination were used together as advanced search such as ‘coronavirus survivalibility’, ‘covid-19 survivalibility’, ‘coronavirus transmission’, and ‘covid-19 transmission’. The database search was set to English, and articles not related to either coronavirous and covid-19 survivalibility and transmission was excluded from this review. Based on the search results, a total of 1966 articles were related to the specific keyword combination (as demonstrated in Table 1). Further exclusion were filtered to review articles focusing on transmission of coronavirus and covid-19 in the urban environment setting, particularly for water and wastewater systems. Ultimately about 89 journal articles were reviewed in this paper. Data from other medium of resources were also collected from World Health Organization, the United Nations Development Programme, Centers for Disease Control and Prevention of the United States and Ministry of Health Malaysia, to help support statistical data for this review paper.

Table 1 Online Database Keywords Search Results

	ScienceDirect	Wiley Online Library	The Lancet
Search keywords results	960	565	441
Total	1966		
Reviewed	89		

3. CHARACTERISTICS OF SARS-COV-2 AND ITS POTENTIAL TRANSMISSION ROUTES

SARS-CoV-2 belongs to the *Coronaviridae* family in the the *Nidovirales* order (Fan et al. 2019). There are four genera of coronaviruses namely α-CoV and β-CoV which are known to infect gastrointestinal tract, respiratory tract and central nervous system to cause diseases in human and mammals while γ-CoV, and δ-CoV primarily target birds (Perlman and Netland 2009; Fehr and Perlman 2015). SARS-CoV-2 is a novel β-CoV which forms distinct clade in lineage B of Sarbecovirus subgenus (Lu et al. 2020b). The genome of SARS-CoV-2 is comprised of positive-sense single-stranded RNA with approximately 79% and 50% similar to SARS-CoV and MERS-CoV, respectively (Chen et al. 2020; Lu et al. 2020b). The origin of SARS-CoV-2 is still controversial. However, phylogenetic analysis of complete viral genome sequence of SARS-CoV-2 from early outbreak patients in China revealed that this novel coronavirus may have originated from bat with 96% nucleotide similarity to bat coronavirus (Zhou et al. 2020) and 91.02% identical to Malayan pangolin coronavirus , implying that pangolin may serve as intermediate host of SARS-CoV-2 associated with the COVID-19 pandemic (Tsan-Yuk Lam et al. 2020; Zhang et al. 2020). Like other coronavirus strains, SARS-CoV-2 is an enveloped RNA virus which comprised of spikes that protrude from its viral surface with crown-like appearance, hence its name corona which means crown in Latin (Figure 1) (Li 2016).

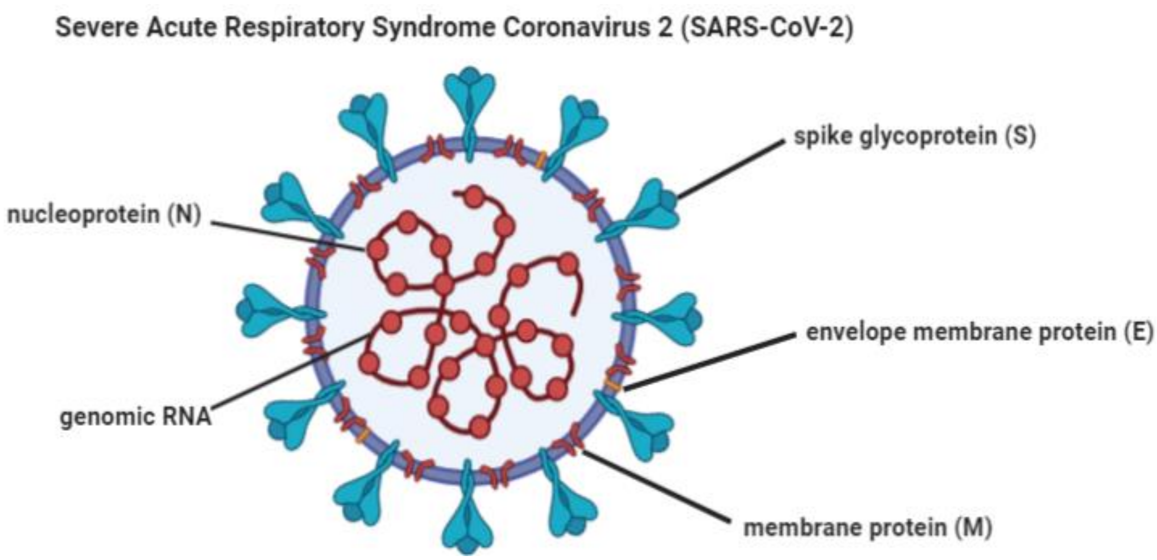

Figure 1. Schematic representation of SARS-CoV-2 virus particle. The virion of SARS-CoV-2 consists of four main proteins namely spike protein (S), nucleocapsid protein (N), envelope protein (E) and membrane protein (M). (Acknowledgement: The image was created using BioRender scientific illustration program).

The main mode of SARS-CoV-2 transmission is via respiratory droplets secreted when an infected individual sneezes, coughs and talks, which means that this virus can be transmitted air-borne (Wang et al., 2021). Therefore, SARS-CoV-2 transmission is likely to happen when susceptible persons are in close proximity to COVID-19 infected individuals or by touching virus-contaminated inanimate objects or surfaces (Sahin 2020). Although SARS-CoV-2 is generally thought to be transmitted via respiratory routes, new evidence suggests that it may also infect gastrointestinal tract and its viral RNA was detected in the stool of SARS-CoV-2 infected hospitilized patients, indicating the possibility of this respiratory virus to spread through faecal-oral route(Xiao et al., 2020). Previous research indicates that toilet water containing SARS coronavirus could generate aerosol droplets from toilet flushing, highlighting the potential spread of infectious particles in the indoor environment such as home and office as shown in Figure 2 (Barker & Jones, 2005; Knowlton et al., 2018; La Rosa et al., 2013; Lockhart et al., 2020; Yu et al., 2004).

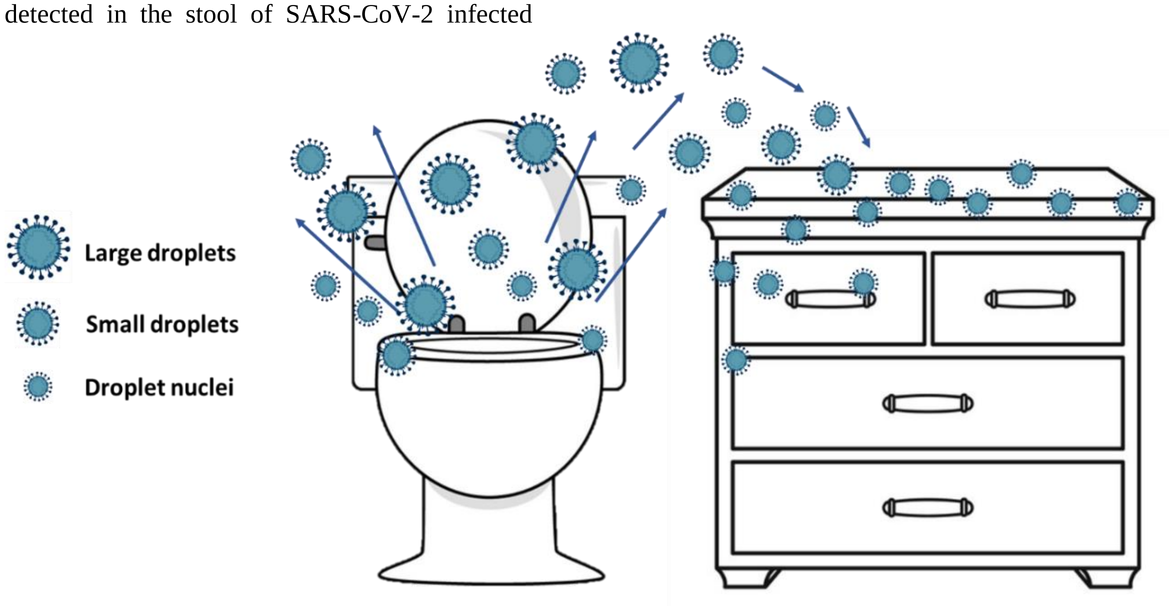

Figure 2. Schematic illustration of potential spread of aerosolized viral particles generated during toilet usage. Large infectious particles are generally regarded as > 60 µm in diameter whereas small infectious particles are usually 10 - 60 µm (Gralton et al. 2011). Infectious airborne particles, also termed as droplet nuclei are less than 10 µm in diameter (Tellier et al. 2019). Droplets (5 – 10 µm) are able to settle on adjacent surfaces (person or fomites) within 2 metres from its source (La Rosa et al. 2013).

The specific characteristics of viral particles can be vary depending on the sources but according to the World Health Organisation (WHO), droplets are defined as > 5 µm in diameter whereas airborne particles are < 5 µm in diameter (WHO 2020a). Respiratory droplets secrected from infected person are stable in the air for several amount of time before settling on the grounds or surfaces due to gravity (van Doremalen et al. 2020). The bioaerosols generated by the toilet flush are generally smaller than the threshold for respirable particle size (diameter 10 µm) with the greater portion of the mean particle sizes reported to be 5 µm or less in size based on an evaluation of commonly cited studies describing toilet bioaerosol particle sizes (Darlow & Bale, 1959; Johnson et al., 2013; O'Toole et al., 2009).

Large particles (diameter >10 µm) can possibly become droplet splatter, while other particles measured (10 µm <diameter <100 µm) are still inhalable through the mouth or aerosolized respirable particles (diameter <10 µm) inhaled through the nose ((Chattopadhyay & Taft, 2018). Additionally, the WHO Guideline on Water, Sanitation, Hygiene and Waste Management for

COVID-19 prescribes that toilets should be flushed with the lid down to prevent droplet splatter and aerosol clouds (WHO, 2020b). According to the UNESCO World Water Development Report 2019, it is estimated that over 80% of wastewater worldwide is released into the environment without proper treatment and in developing countries that figure is over 95% (UNESCO, 2019). This has led to over 800,000 deaths worldwide in 2012 caused by contaminated drinking water, inadequate handwashing facilities and inappropriate sanitation systems, which consequently also caused de-oxygenated dead zones in the oceans from the untreated wastewater discharge (UNESCO, 2019).

Previously, several studies have reported the ability of coronaviruses to survive on multiple surfaces at different temperatures (see Table 2). More recently, the stability of SARS-CoV-2 on different surfaces in different environmental settings was investigated (Table 2) (Chin et al., 2020; Van Doremalen et al., 2013). SARS-CoV-2 was is highly stable at low temperature (4°C) and susceptible to heat and common disinfectants such as 70% ethanol and household bleach (Chin et al., 2020). These findings suggest the indirect transmission of SARS-CoV-2 through contamined surface and airborne particles, and highlight the importance of frequent disinfection of touched surfaces or objects.

Table 2. The time for coronaviruses inactivation on different inanimate surfaces at variable temperature conditions.

Type of Surface	**Virus***	**Virus Survival**	**Temperature**	**Reference**
Steel	SARS-CoV-2	7 days	22°C	(Chin et al. 2020)
		2 days	21-23°C	(van Doremalen et al. 2020)
	MERS-CoV (HCoV-EMC/2012)	3 days	20°C	(van Doremalen et al. 2013)
		2 days	30°C	
	TGEV	> 28 days	4°C	(Casanova et al. 2010)
		3 – 28 days	20°C	
		4 – 96 hours	40°C	
	MHV	> 28 days	4°C	
		4 – 28 days	20°C	
		4 – 96 hours	40°C	
	HCoV (229E strain)	5 days	21°C	(Warnes et al. 2015)
Plastic	SARS-CoV-2	7 days	22°C	(Chin et al. 2020)
		3 days	21-23°C	(van Doremalen et al. 2020)
	MERS-CoV (HCoV-EMC/2012)	3 days	20°C	(van Doremalen et al. 2013)
		2 days	30°C	
	SARS-CoV (P9 strain)	4 days	RT	(Duan et al. 2003)
	SARS-CoV (FFM1 strain)	6 – 9 days	RT	(Rabenau et al. 2005) (Rabenau et al. 2005)
	HCoV (229E strain)	2 – 6 days	RT	

Cooper	SARS-CoV-2	4 hours	21-23°C	(van Doremalen et al. 2020)
Cardboard	SARS-CoV-2	24 hours	21-23°C	
Metal	SARS-CoV (P9 strain)	5 days	RT	(Duan et al. 2003)
Paper	SARS-CoV (P9 strain)	4 – 5 days	RT	(Duan et al. 2003)
	SARS-CoV (GVU6109 strain)	24 hours	RT	(Lai et al. 2005)
	SARS-CoV-2	3 hours	22°C	(Chin et al. 2020)
Glass	SARS-CoV (P9 strain)	4 days	RT	(Duan et al. 2003)
	HCoV (229E strain)	5 days	21°C	(Warnes et al. 2015)
	SARS-CoV-2	4 days	22°C	(Chin et al. 2020)
Banknote	SARS-CoV-2	4 days	22°C	
Wood	SARS-CoV-2	2 days	22°C	
Clothes	SARS-CoV-2	2 days	22°C	
Silicon Rubber	HCoV (229E strain)	5 days	21°C	(Warnes et al. 2015)
Surgical Glove (Latex)	HCoV (229E & OC43 strain)	8 hours	21°C	(Sizun et al. 2000)
Disposable Gown	SARS-CoV (GVU6109)	2 days	RT	(Lai et al. 2005)
Surgical Mask (Inner layer)	SARS-CoV-2	7 days	22°C	(Chin et al. 2020) (Chin et al. 2020)
Surgical Mask (Outer layer)	SARS-CoV-2	7 days**	22°C	

*CoV = coronavirus; MERS = Middle East Respiratory Syndrome; HCoV = human coronavirus; TGEV = transmissible gastroenteritis virus; MHV = mouse hepatitis virus; SARS = Severe Acute Respiratory Syndrome; RT = room temperature
** SARS-CoV-2 is still present after 7 days of incubation (titre: 10^3 Log $TCID_{50}$/ml).

4. SURVIVABILITY OF CORONAVIRUSES IN AQUATIC ENVIRONMENT

Human viruses enter the municipal wastewater systems and wastewater treatment plants (WWTP) through faeces, urine or vomit of infected persons (Jones et al., 2020). Wastewater contains a wide range of pathogenic viruses that provides important information about virus circulation, introduction of newly emerged virus strains and community health (Martínez-Puchol et al., 2020; Shaheen & Elmahdy, 2019). The vast majority of studies on enteric viruses (pathogens that infect gastrointestinal tract and transmit primarily through fecal-oral pathway) mostly focus on non-enveloped viruses such as polioviruses, enteroviruses, rotaviruses, and noroviruses (Hellmér et al. 2014). Since the emergence of COVID-19, many countries have increasingly implemented their wastewater survelience as SARS-CoV-2 RNA was detected in the stool of infected individuals (Woelfel et al., 2020; Xiao et al., 2020). Enveloped viruses such as coronavirus is generally considered to be less stable and more readily inactivated in environment than non-enveloped viruses (La Rosa et al., 2013).

However, several studies have reported that SARS-CoV and its surrogate viruses can persist in water environments for several days depending on temperature, pH and salinity (Brown et al., 2007; Stallknecht et al., 1990; Wigginton et al., 2015a). It has been reported that SARS-CoV can survive longer at 4°C than 20°C in faecal samples (Wang et al., 2005). Additionally, research by Gundy et al. (2009) demonstrated that 229E strain of human coronavirus (HCoV) survived longer in filtered tap water at 4°C compared to 23°C (Table 3). Other findings using transmissible gastroenteritis virus (TGEV) and mouse hepatitis virus (MHV) also showed that these surrogate coronaviruses are also stable for lengthy period of time at lower temperature of 4°C than higher temperature of 25°C (Table 3).

Based on the previous observations, it is possible that enveloped viruses like SARS-CoV that are excreted from faeces and urine could survive longer in aqueous environments such as wasterwater, drinking water and surface water especially during winter season where the temperature is very low (Wigginton et al., 2015a). During SARS outbreak in Hong Kong, faecal samples of infected person were still tested positive for SARS-CoV up to 73 days following the onset of symptoms (Leung et al., 2003). Similarly, SARS-CoV-2 was also detected in faecal samples of COVID-19 patients (Wang et al., 2020; Xiao et al., 2020), and viral shedding in faecal ranged from several hours to 47 days even after the respiratory samples were tested negative for COVID-19 (Cheung et al., 2020; Gupta et al., 2020; Liu et al., 2020) (Cheung et al. 2020; Gupta et al. 2020; Liu et al. 2020a). The persistence of SARS-CoV-2 in faecal samples has intrigued many scientists to determine the presence of SARS-CoV-2 RNA fragments in wastewater systems which have been reported in a number of locations such as The Netherlands (Medema et al. 2020), Australia (Ahmed et al. 2020), United States (Nemudryi et al., 2020; Wu et al., 2020), France (Wurtzer et al., 2020), Pakistan (Sharif et al., 2020), Spain (Randazzo et al., 2020), Italy (Rimoldi et al., 2020) and Japan (Haramoto et al., 2020).

Table 3. The survival of coronaviruses in various incubation conditions at different

Virus	Aqueous conditions	Temperature	Virus survival[1,2]	Reference
SARS-CoV	Serum-free culture media	21-25°C	9 days	(Rabenau et al. 2005)
	Wastewater, domestic sewage and dechorinated tap water	20°C	2 days	(Wang et al. 2005)
	Feces		3 days	
	Phosphate- buffered saline		14 days	
	Urine		17 days	
	Wastewater	4°C	14 days	
	Urine and Feces		17 days	
HCoV 229E	Serum-free culture media	21-25°C	< 1 day	(Rabenau et al. 2005)
	Filtered tap water[3]	4°C	588 days (projected values)	(Gundy et al. 2009)
		23°C	10 days	

[1] Infectious virus titres were determined as 50% tissue culture infective doses (TCID50) in confluent cells in 96-well plates

[2] Time required for virus titre to decrease by 99% and 99.9% is expressed as T99 and T99.9 respectively (Gundy et al., 2009).

[3] Tap water filtered through a 0.2-lm pore size filter

	Unfiltered tap water	23°C	12 days	
	Filtered primary effluent[4]	23°C	2 days	
	Unfiltered primary effluent	23°C	3 days	
TGEV	Reagent-grade water[5]	25°C	33 days	(Casanova et al. 2009)
		4°C	330 days	
	Pasteurized settled sewage[6]	25°C	14 days	
		4°C	73 days	
MHV	Reagent-grade water	25°C	26 days	
		4°C	> 365 days	
	Pasteurized settled sewage	25°C	10 days	

[4] Collected in sterile polypropylene bottles from the Roger Road Wastewater Treatment Plant in Tucson, AZ, USA. Primary effluent was collected after settling. Primary effluent is biological oxygen demand (BOD) and suspended solids of 110–220 mg/l.

[5] Reagent-grade water (pH 6.0, turbidity 0.1 NTU)

[6] Settled sewage is raw sewage that has undergone an initial settling step after entry into the plant to separate large solids from the liquid. The resulting liquid (pH 7.6, turbidity 17.6 NTU) was pasteurized in a water bath at 70 °C for 3 h to inactivate other microorganisms that would interfere with cell culture infectivity assays of coronaviruses

4.1 Water and Wastewater Systems in Building as Coronavirus Transmission Route

To date, there is no report of SARS-CoV-2 transmission from sewage and human excretion. However, during 2003 SARS outbreak in Hong Kong, the transmission from person-to-person via respiratory droplets and aerosolised particles from feces through air ventilation was reported (Casanova et al., 2009; WHO, 2003). There were reported cases of virus spreading from passenger to passenger on an airplane (Olsen et al., 2003) and from patients to healthcare workers and visitor in hospitals (Seto et al., 2003). However, the community outbreak in a high-density Hong Kong apartment led to a faecal droplet-respiratory route of transmission, and this method of virus transmission is still poorly understood (Wigginton et al., 2015b). It is believed that the combination of faulty drain traps and powerful exhaust fans resulted in virus loaded liquid droplets drawn from the wastewater systems into living spaces via floor drains (Figure 3) (Casanova et al., 2009). During the SARS outbreak at Amoy Gardens apartment complex, the U-pipes connected to the floor drains were dried up without water and that allowed virus-laden droplets coming down from the pipes to other apartments to collect in the U-trap bend (Figure 3) (Regan, 2020). These dried up U-trap could have emitted the SARS virus from the discharge coming out of the toilet or water closet through the air vent pipe into other indoor environments in the building (Regan, 2020). This air vent is one of the main parts of a building's plumbing system, and is also known as a vent stack that regulates the air pressure in the plumbing system through the roof of a building vertically (New York Engineers, 2020). The drain and soil pipe physically remove water and sewage (wastewater) from a building, while plumbing air vent pipes remove gas and odour of the waste from a building (New York Engineers, 2020). The air vent pipes are attached to the drainpipe line and releases pressure to help water flow smoothly through the drainpipes by providing fresh air into the plumbing system (New York Engineers, 2020).

Another possibility and risk of transmission from wastewater is when an infected person has used the toilet and flushes it without closing the toilet seat cover or lid, this action can generate concentration of virus-laden aerosols into the air (Figure 2) (Wenhong, 2020). The flushing of toilet produces bioaerosol with a range of particle sizes, between 14−700 nm using a scanning mobility particle sizer and between 0.5−20 µm using an aerodynamic particle size spectrometer (Chattopadhyay & Taft, 2018). Based on a study by Lin and Marr (2017) that measured two commercial auto-flush mechanism toilets for the aerosolization of Ebola virus surrogate in wastewater, a total particle number of 1.7 to 2.6 million per flush and the total volume of aerosols generated in the range of 10−9 to 10−8 mL were reported. The study found that the size distribution across a particle size range (e.g., 1 µm to 20 µm, large droplets) and the distribution peaks over the particle size range of approximately 10 nm to 1,000 nm (i.e., 10-2 µm to 1 µm) (Lin & Marr, 2017).

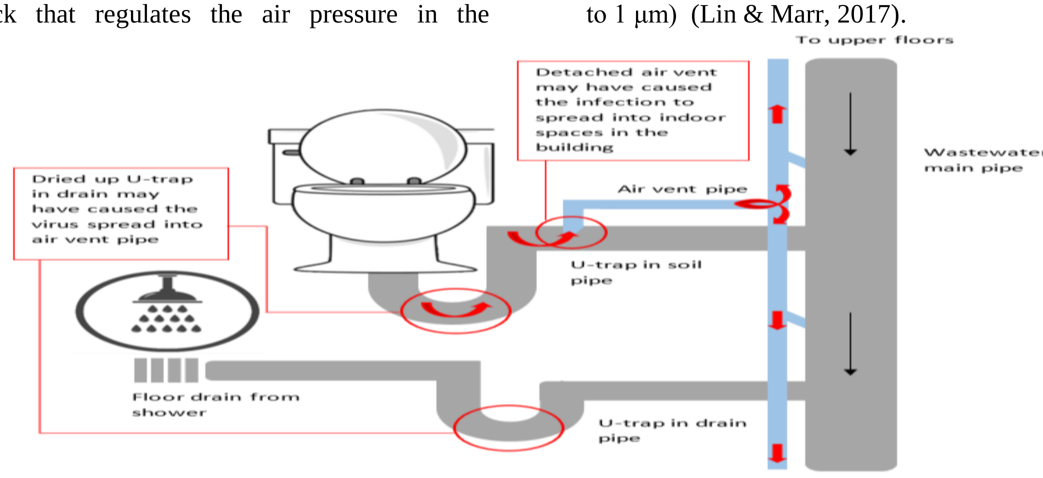

Figure 3: Representation of building plumbing system. Viral particles that are released into drainage could get trapped in the piping system. If the viral particles become aerosolised, the piping system could be the mode of transmission for virus spread within the closed building area.

5. GUIDELINE ON DISCHARGE PIPE

The wastewater discharge pipe should be kept minimum in distance, fewer bends and adequate gradients to prevent the transmission of foul air into the building, by using water trap at all sanitary appliances. The foul air may contain contamination that may cause nuisance or health hazard. The water traps come together as part of the integrated molded sanitary appliances such as the water closets (wc) or the gullies. To smaller fittings such as sinks and basins, they will be fitted with either a trap ‘P’, ‘S’ or ‘Q’ as (Figure 4) (Hall & Greeno, 2009)

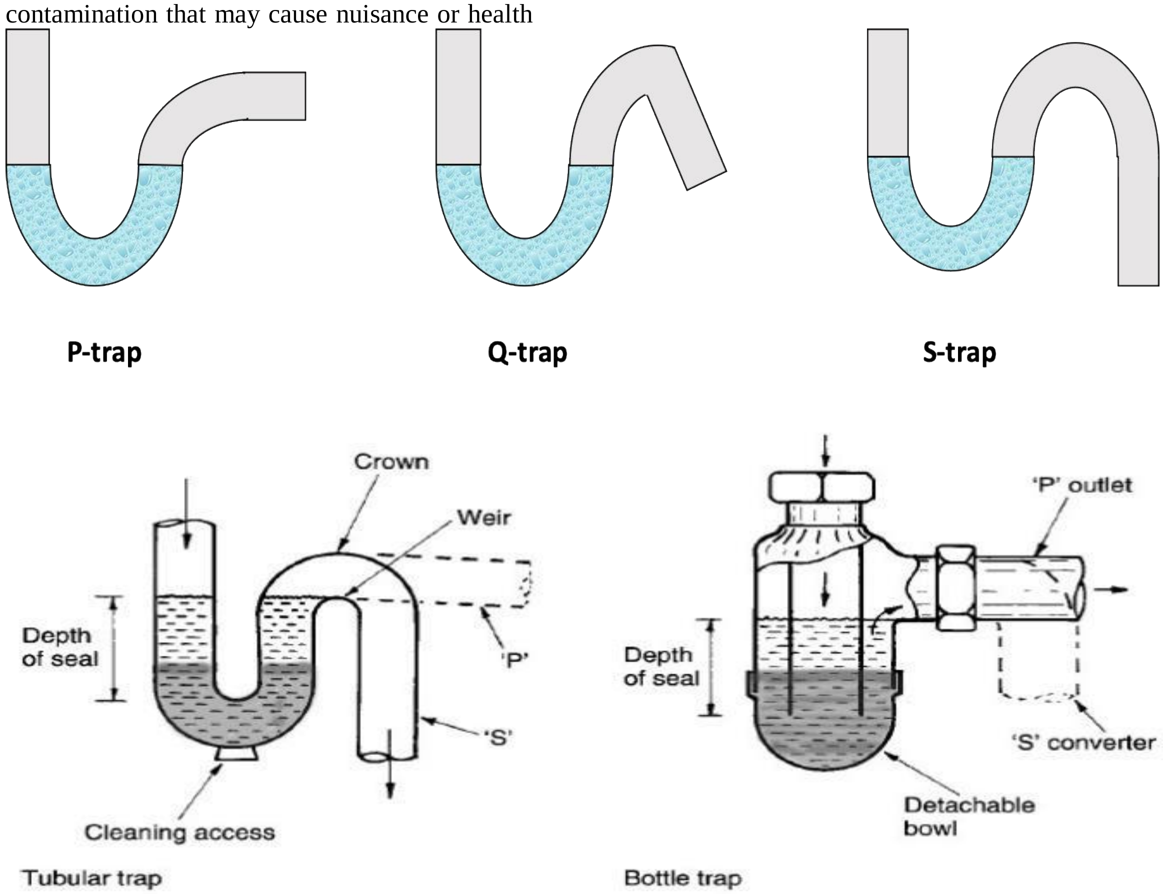

Figure 4: (a) Types of traps connected to sanitary appliances, and (b) technical guideline on seal depth between normal seal depth and seal loss when the height is reduced (situation in grey water level) (Source: adopted from Hall and Greenor, 2009)

The U-trap is one of the common water traps used at sanitary appliances to avoid foul air into the buildings with certain depth and height of the seal (JKR, 2017). The depth of seal must be retained at no less than 25mm for a typical wash down water closet (WC) or for tubular trap at 75mm seal depth (Hall & Greeno, 2009). The occurrence of water seal loss may happen at 19mm (tubular trap) and 25mm (WC) (Department of Standard Malaysia, 2006) (JKR, 2017), which may lead to self-siphonage, induced siphonage, back pressure, capillary action and wavering out (Hall & Greeno, 2009). Adequate ventilating pipes within sanitary plumbing system are needed to prevent the loss of water seal in the traps (Singapore’s National Water Agency, 2019), as shown in previously Figure 3, the vent-pipes are connected to the traps and directly to a discharge pipe.

6. URBAN WATER AND WASTEWATER TREATMENT

The human health risk of enteroviruses such as E.Col, Salmonella typhi, and Shigella spp. is greater than bacterial pathogens in urban surface waters (that can be the source of drinking water) and would require greater removal or treatment processes (Zhang & Wang, 2012). Water treatment can be defined by as the processes used to purify, disinfect and protect water against recontamination, and is highly dependent on around the clock energy supply (usually electricity) (UNESCO, 2019). This high energy dependency for clean water remains a challenge for developing countries, and as a result low-tech and nature-based filtration process is used that does not guarantee safe drinking water quality for its population (UNESCO, 2019). Safe drinking water quality persist in both developed and developing countries alike, and several water-related diseases such as cholera and schistosomiasis are widespread across many developing countries as majority of the domestic and urban wastewater is not treated before its release into the environment (UN-Water, 2018).

A study in Gothenburg analysed untreated sewage samples from Ryaverket wastewater treatment plant found seven (7) different enteric viruses such as norovirus, astrovirus, rotavirus, adenovirus, Aichi virus, hepatitis A virus and hepatitis B virus (Hellmér et al., 2014). When these viruses are detected in sewage, it is evident that there are several persons infected in the community, and these viruses are circulating in the population (Hellmér et al., 2014). Another study in South Africa collected effluent samples from five wastewater treatment plants in Eastern Cape of South Africa detected rotavirus, faecal coliform bacteria and E.coli (Osuolale & Okoh, 2017). Antibiotic resistant bacteria were also detected in China coastal water samples (bacterial genera of Acidovorax, Acinetobacter, Brachymonas and Pseudomonas), where affluence from wastewater treatment were discharged (Zhang et al., 2020). The overuse and abuse of antibiotics in preventing/treating bacterial diseases and promoting animal growth has promoted antibiotic resistance genes (ARGs) in bacteria, which poses tremendous risk to human population as these ARG bacteria are more difficult to control and kill (Bouki et al., 2013; Zhang et al., 2020) . Latest findings from Netherlands found the COVID-19 virus in wastewater at Amsterdam Schiphol Airport and the wastewater treatment plant in Kaatsheuvel – servicing the town where the first reported COVID-19 patient in Netherlands lives (National Institute for Public Health and the Environment, 2020).

These studies illustrate the importance of monitoring and identifying typing strains in sewage and wastewater for viruses in order to provide an early warning for possible outbreaks (Hellmér et al., 2014; Osuolale & Okoh, 2017), and there is potential public health risk for infectious disease to infect a population through improper wastewater treatment systems. Generally, the wastewater or sewage treatment process is categorized in four (4) different phases: preliminary, primary, secondary and tertiary (Figure 5) (CDC, 2015a; IWK, 2019). The preliminary sewage treatment process (or coagulation) includes screening, grit removal, pre-aeration and removal of rubbish, grit, oil and grease (IWK, 2019). The primary treatment includes sedimentation, floatation and removal of suspended solids and organic matter; while the secondary treatment is directed to filter biodegradable organic and suspended solids using biological unit processes, filters (sand, gravel and charcoal) and disinfection (CDC, 2015a; IWK, 2019). Finally, in the tertiary phase includes biological and chemical treatment to remove nutrients and pathogens, toxic substances including heavy metals and further removal of suspended solids and organic matter, through filtration and disinfection processes (chlorin or chloramine) (CDC, 2015a; IWK, 2019).

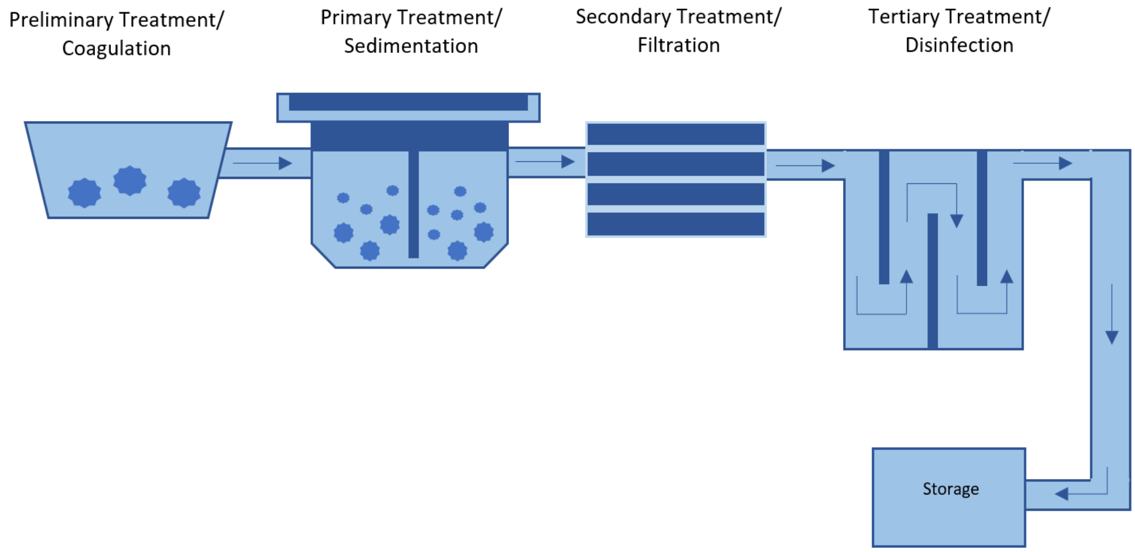

Figure 5: Wastewater treatment process.
Source: Adapted from IWK (2019), CDC (2015a)

In urban water and wastewater treatment, chlorine treatment or chlorination is the most common method to treat and disinfect drinking water for safe consumption (CDC, 2015b; EPA, 2002). Disinfection is the process to kill or inactivate most microorganism in wastewater such as bacteria, viruses or spores that causes illness to the human and animal population (CDC, 2015b). Chlorine is used either in compressed elemental gas, in solution (sodium hypochlorite – NaOCl, or in solid form (calcium hypochlorite – $Ca(OCl)_2$ and added to water to kill harmful microorganism (CDC, 2015b). Therefore, for developed and most modern developing countries with high technology wastewater system that includes chlorination will be effective in provided safe water to its population. However, for least developed countries, the COVID-19 pandemic poses a real threat where untreated wastewater remains common practice, and without proper wastewater infrastructure, technical and institutional capacity and financing (UNESCO, 2019).

7. DISCUSSION

Multiple studies that have found coronaviruses survivability in water and wastewater (Casanova et al., 2009; Gundy et al., 2008; Wigginton et al., 2015b; Wolff et al., 2005) long enough for it to be a possible transmission method. Gastroenteritis (TGEV) and mouse hepatitis (MHV) viruses are able to survive up to 14 days in pasteurized settled sewage at 25° C, and up to 105 days at 4°C (Casanova et al., 2009). The high risk of potential rapid and mass infection is when contaminated water or wastewater with coronavirus becomes aerosolized (Casanova et al., 2009). Contaminated water and wastewater systems will defeat any quarantine or isolation measures as the virus remains infectious within then contaminated systems even after the infected individuals have been removed from the area (Casanova et al., 2009). It is very worrying as the COVID-19 pandemic SARS-CoV-2 virus might have the same survivability rate as the SARS-CoV virus since they belong to the same Coronaviridae family, and the SARS-CoV virus is able to survive up to 9 days in culture media at room temperature (Rabenau et al., 2005). Research also need to be done in testing the SARS-CoV-2 virus's survivability in water, as other human coronavirus HCoV 229E is predicted to survive up to 588 days at 4°C, and tested to survive up to 10 days in 23°C in tap filtered water (Gundy et al., 2008).

SARS-CoV-2 virus transmission route is mainly through respiratory droplets, it is also important to review viruses survivability on fomites or inanimate surfaces. Previous research shows that the SARS-CoV virus is able to survive on metal, paper and plastic surfaces up to 5 days in room temperature (Duan et al., 2003; Rabenau et al., 2005). Similarly, looking at gastroenteritis (TGEV) and mouse hepatitis (MHV) viruses, it was found that they are able to survive on steel surfaces for more than 28 days at 4°C (Casanova et al., 2010). More importantly for health care providers, some studies have found that the HCoV 229E virus can survive up to 5 days on silicon rubber (Warnes et al., 2015) and up to 8 hours on surgical latex gloves at 21°C (Sizun et al., 2000). Equally important, Lai et al. (2005) found that the SARS-CoV GVU6109 virus is able to survive up to 2 days on disposable gowns in room temperature conditions.

However, methods of disinfection and rendering the virus inactive is quite simple and low cost. The coronaviruses can easily be efficiently inactivated by disinfection procedures with 60-70% ethanol, 0.5% hydrogen peroxide or 0.1% sodium hypochlorite within one (1) minute (Kampf et al., 2020). Guidelines by WHO and CDC recommends avoiding physical contact, frequently washing hands with soap for at least 20 seconds or using alcohol-based hand sanitizers, wear a facemask, and avoid sharing personal household items such as dishes, eating utensils and towels (CDC, 2020; WHO, 2020a). Disinfecting and cleaning "high-touch" surfaces such as doorknobs, countertops, keyboards and phones daily by using household disinfectant and diluted chlorine solution (CDC, 2020). The common household disinfectant brand Dettol (with active ingredient Chloroxylenol) claims that their products are able to kill other coronavirus such as (SARS-CoV, MERs-CoV and HCoV) (99.9% inactivation) and therefore would be also be an effective disinfectant for the emerging coronavirus, SARS-CoV-2 (Dettol, 2019).

8. CONCLUSION

This review paper has highlighted the significant gap in the potential role of water and wastewater treatment spreading the COVID-19 pandemic virus, following previous research on different coronaviruses such as SARS-CoV, MERS-CoV, gastroenteritis (TGEV) and mouse hepatitis (MHV). New findings from Netherlands have proven that the novel SARS-CoV-2 virus is able to also survive in wastewater. There is an urgent need to conduct testing on wastewater effluent and water treatment supply to curb further outbreak in communities, especially in developing countries with subpar wastewater treatment systems and infrastructure to reduce human and ecological risks. Human coronaviruses can also remain infectious on fomites or inanimate surfaces up to 9 days and this data is especially important to health care providers so they do not become infected and infect others surrounding them as the virus can survive up to 2 days on their protective gowns and 8 hours on surgical latex gloves. Constant monitoring and testing of water and wastewater effluent is needed for epidemiology surveillance to protect populations from infectious diseases outbreak. Similarly, routine surface disinfectant using 60% alcohol-based solutions or ethanol will significantly reduce coronavirus infectivity and survivability, and the same should be expected for the novel SARS-CoV-2 virus.

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10. DATA AVAILABILITY STATEMENT

All data, models, and code generated or used during the study appear in the submitted article.

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