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A case study of SARS-CoV-2 transmission behavior in a severely air-polluted city (Delhi, India) and the potential usage of graphene based materials for filtering air-pollutants and controlling/monitoring the COVID-19 pandemic

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1	Secondary transmission of SARS-CoV-2 through wastewater: Concerns and
2	tactics for treatment to effectively control the pandemic
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27 Abstract

The SARS-CoV-2 virus has spread globally and has severely impacted public health and 28 29 the economy. Hand hygiene, social distancing, and the usage of personal protective equipment are 30 considered the most vital tools in controlling the primary transmission of the virus. Converging evidence indicated the presence of SARS-CoV-2 in wastewater and its persistence over several 31 32 days, which may create secondary transmission of the virus via waterborne and wastewater pathways. Although, researchers have started focusing on this mode of virus transmission, limited 33 knowledge and societal unawareness of the transmission through wastewater may lead to 34 significant increases in the number of positive cases. To emphasize the severe issue of virus 35 36 transmission through wastewater and create societal awareness, we present a state of the art critical review on transmission of SARS-CoV-2 in wastewater and the potential remedial strategies to 37 effectively control the viral spread and safeguard society. For low-income countries with high 38 population densities, it is suggested to identify the virus in large scale municipal wastewater plants 39 40 before following up with one-to-one testing for effective control of the secondary transmission. Ultrafiltration is an effective method for wastewater treatment and usually more than 4 logs of 41 virus removal are achieved while safeguarding good protein permeability. Decentralized 42 43 wastewater treatment facilities using solar-assisted disinfestation methods are most economical and can be effectively used in hospitals, isolation wards, and medical centers for reducing the risk 44 of transmission from high local concentration sites, especially in tropical countries with abundant 45 solar energy. Disinfection with chlorine, sodium hypochlorite, benzalkonium chloride, and 46 47 peracetic acid have shown potential in terms of virucidal properties. Biological wastewater treatment using micro-algae will be highly effective in removal of virus and can be incorporated 48 into membrane bio-reaction to achieve excellent virus removal rate. Though promising results have 49

50 been shown by initial research for inactivation of SARS-CoV-2 in wastewater using physical, 51 chemical and biological based treatment methods, there is a pressing need for extensive 52 investigation of COVID-19 specific disinfectants with appropriate concentrations, their 53 environmental implications, and regular monitoring of transmission. Effective wastewater 54 treatment methods with high virus removal capacity and low treatment costs should be selected to 55 control the virus spread and safeguard society from this deadly virus.

56 Keywords: COVID-19, Wastewater, Disinfectants, Secondary transmission, Wastewater
57 Treatment

Abbreviations

C/N	Carbon to nitrogen loading
COVID-19	Coronavirus Disease 2019
DNA	Deoxyribonucleic acid
LRV	Log Reduction Value
MERS	Middle East respiratory syndrome
MHV	Mouse hepatitis virus
MID	Minimal infectious dose
ORF	Open reading frame
PFU	Plaque-forming units
RNA	Ribonucleic acid
RT-PCR	Real-time reverse transcription polymerase chain reaction
RT-qPCR	Reverse transcription-quantitative polymerase chain reaction
SARS-CoV	Severe Acute Respiratory Syndrome Coronavirus
SARS-CoV-1	Severe Acute Respiratory Syndrome Coronavirus 1
SARS-CoV-2	Severe Acute Respiratory Syndrome Coronavirus 2

UF	Ultrafiltration
UV	Ultraviolet;
WHO	World Health Organisation

58

59 **1. Introduction**

The newly identified coronavirus disease 'COVID-19' was first identified as a pneumonia 60 virus causing respiratory illness which is thought to have originated from a local seafood market 61 in Huanan, Wuhan, China and was named 'SARS-CoV-2' by the World Health Organization 62 (WHO) on 12th January 2020. The WHO declared COVID-19 as a worldwide health emergency 63 on 30th January, and later, it was declared a pandemic on March 11, 2020. This SARS-CoV-2 has 64 spread across 210 countries and 66,231,472 confirmed cases and 1,524,473 deaths were reported 65 by December 5, 2020 as shown in Fig. 1 (Worldometer, 2020). The SARS-CoV-2 virus is a 66 pleomorphic ribonucleic acid (RNA) virus, belonging to the coronavirus family having crown-67 shape peplomers (size - 80 to 160 nm) with positive polarity (27 - 32 kb) (Sahin et al., 2020). 68 COVID-19 virus genome sequence is 96.2%, similar to the 'BatCoV RaTG13' bat coronavirus 69 (Yan et al., 2020) and a low mortality rate of ~ 2 %. 70





Fig. 1. COVID-19 confirmed cases and their distribution country wise, as of 5th December, 2020. 72 However, the spreading rate of COVID-19 amongst humans is higher than SARs and MERS, with 73 74 an incubation time of 24 days (Yan et al., 2020). The major path of transmission of the COVID-19 virus among humans occurs through inhalation of saliva and sputum droplets along with person-75 to-person physical contacts (WHO, 2020; Kitajima et al., 2018). Recently, Doremalen et al. (2020) 76 77 compared the surface stability and aerosol transmission behavior of SARS-CoV-2 and SARS-CoV-1 and illustrated that SARS-CoV-2 can stay suspended for three hours in the air 78 (Suthar et al., 2021), with an identical drop in its rate of infections compared to SARS-CoV-1. It 79 was also revealed that the properties of SARS-CoV-2 and SARS-CoV-1 are identical in terms of 80 the formation and air particles stability. Nevertheless, human receptors affinity for the initial 81 82 variant of SARS-CoV-2 is 10 times greater than SARS-CoV-1. Several studies have shown that the COVID-19 virus can also be shed in feces from infected patients displaying acute symptoms, 83 from asymptomatic individuals, and from patients cured without any further symptoms (Dhama et 84 85 al., 2021; Pan et al., 2020; Tang et al., 2020; Xiao et al., 2020). In addition, COVID-19 viral RNA was detected in urine samples of infected patients (Ling et al., 2020). COVID-19 RNA was also 86

reported in the community wastewater and hospital sewage (Lodder and de Roda Husman, 2020). 87 Although the risk of spread of COVID-19 virus to people through water including wastewater is 88 89 still not clear, the identification of COVID-19 virus RNA in both treated and untreated wastewater (Venugopal et al., 2020) raises the alarming situation of the potential for virus transmission 90 91 through this medium, and consequent occupational exposure concerns for wastewater treatment 92 plant workers. The potential for transmission of viruses through water bodies is gaining attention recently among the research community, following the immediate response to the current 93 94 pandemic which predominantly focused on prevention of transmission from person-to-person. The 95 increasing number of testing facilities, hospitals, isolation wards and research centers developed worldwide was essential to expedite the detection of infected patients and accommodate them for 96 further testing and to carry out advanced research about this new deadly virus. It is quite obvious 97 that these facilities have increased the generation of wastewater contaminated by the virus, and 98 that if incorrectly handled this will certainly pose a threat to society. Virus transmission through 99 100 wastewater might be a major worry in regions where there is a lack of water treatment facilities and inadequate sanitation. In countries with lower income, domestic wastewater is often released 101 directly into the environment and may over time find its way towards groundwater (Omosa et al., 102 103 2012). As the majority of people fulfill their water needs using groundwater sources in rural and peri-urban areas (Kookana et al., 2020), the potential community transmission of the 104 105 SARS-COV-2 virus through infected and untreated groundwater is thus possible.

Apart from direct contact with wastewater, breathing of droplets/aerosols which are contaminated with infectious viral particles is considered as the major source of virus transmission in wastewater treatment plants. However, given that this is the first pandemic on such a global scale, very few studies have taken into consideration the risks posed to wastewater treatment plant

workers and hence, there is a tremendous need to investigate and highlight the potential of this 110 exposure route as a route of infection. Even though it is stated that the existing disinfection 111 methods can deactivate viruses in water bodies, the fate of SARS-COV-2 virus in water / 112 wastewater bodies is yet to be elucidated (Nghiem et al., 2020). In addition, there is still a 113 substantial knowledge gap regarding to what extent the early detection of virus is possible, i.e., 114 115 before the occurrence of widespread symptomatic cases, owing to the limitation in identification techniques which mostly depend on the viral load in the patient's fecal matter. Furthermore, very 116 117 few authors have reported quantitative assessments to predict the loading of virus in wastewater and its correlation to the official case statistics, although these of course are also hugely variable 118 depending on testing rates and approach. 119

With a second wave of the pandemic occurring across most parts of the world, our focus 120 here is to highlight and draw attention towards the potential transmission of the SARS-COV-2 121 virus through wastewater. In this regard, to help society fill the knowledge gap, the major objective 122 123 of this critical review is to synthesize current knowledge on approaches for treating wastewater contaminated with the virus so as to decrease COVID-19's transmission chances, and to support 124 125 prioritization of the further research needs and the current barriers to implementation of the various 126 treatment methodologies in developing countries. The methodology used for selecting the appropriate recent manuscripts, based on the objective of this work, are discussed in detail. Further, 127 the potential transmission and detection of SARS-COV-2 virus in wastewater, along with the risks 128 of infection through droplets / aerosols contaminated with infectious viral particles, and the 129 130 quantitative detection methods are discussed in detail to present a clear picture of the current state of knowledge to the readers. Finally, the various remedial approaches for wastewater treatment 131 such as decentralized wastewater treatment and different potential disinfectants for wastewater 132

treatment, are presented and their advantages and disadvantages discussed. In tropical countries with abundantly available solar energy, a sustainable low-cost approach for wastewater treatment is also highlighted. With increasing COVID-19 cases, uncertainty in transmission paths and lesssocietal knowledge and awareness, our review aims to create awareness and draw the attention of researchers and society towards the potential severity of virus transmission through wastewater and its potential remedies.

139 **2. Methodology**

140 The articles for the present state of the art critical review were carefully selected by considering the impact of the reported research and the quality of the journals, respectively. Identification of 141 142 published work assessing the potential spread of SARS-CoV-2 virus through wastewater and the various strategies for wastewater treatment to effectively control viral spread was carried out 143 through systematic searches in the Google Scholar, Science Direct (Elsevier), Web of Science, 144 Pub Med and Scopus databases using appropriate keywords such as "SARS / SARS-CoV-2 virus 145 146 in wastewater", "secondary SARS-CoV-2 virus transmission", "advanced wastewater treatment for virus spread control". Further searches were made using keywords such as "wastewater 147 treatment" and "SARS-CoV-2 virus" for identification of the most relevant literature (up to March 148 149 2021) on SARS-CoV-2 virus transmission through wastewater and various methods to control the spread. To select the suitable literature from the so-collected manuscripts in the context to 150 wastewater treatment process exclusively to control the spread of SARS-CoV-2 virus, the 151 following key points were considered: 152

Inclusion of all studies that describe SARS / SARS-CoV-2 virus transmission by any kind
 of water sources;

155		Inclusion of manuscripts that reported a mechanism of virus transmission in water /
156		wastewater;
157	\triangleright	Inclusion of manuscripts that report detection methods for SARS-CoV-2 virus in water /
158		wastewater;
159	\triangleright	Inclusion of work that reports on impact and severity of virus spread at the social-
160		community level;
161	\triangleright	Inclusion of articles that focus on potential treatment of water / wastewater for deactivating
162		viruses;
163		Inclusion of articles on sustainable treatment strategies for viral deactivation
164		Exclusion of manuscripts that are entirely based on primary transmission of SARS-CoV-2
165		virus;
166		Exclusion of studies which don't report quantitative outcomes or merely repeat existing
167		results (i.e., review articles).
168	The n	napping of literature content and bifurcation of the selected studies were executed based on
169	the fo	llowing criteria:
170	\triangleright	What specific virus identification approach in water / wastewater was adopted?
171	\triangleright	What is the transmission mode of the virus through the water / wastewater system?
172		Is there any specific technique implemented to monitor the growth and spread of virus in
173		the water / wastewater system? If so, what are the methods to deactivate the viruses in water
174		bodies?
175		What treatment parameters were adopted to deactivate the virus?
176	\blacktriangleright	What are the sustainable approaches for treatment of wastewater?
177		What hinders implementation of the wastewater treatment method in low-income countries?

What specific conclusions are made regarding the effectiveness of the water treatment tactic
in controlling the spread of SARS-CoV-2 virus?

All the collected manuscripts were broadly classified based on the sources of virus secondary 180 transmission in water / wastewater and the individual wastewater treatment technologies were 181 further segregated depending upon the nature of treatment (decentralized, physical methods 182 183 including membrane technology and sedimentation approaches, solar assisted wastewater disinfection, ozonation, chemical based disinfectants and biological based treatment including 184 algae) and its effectiveness for virus deactivation. Under each category, the different virus 185 deactivation approaches and the advanced techniques implemented for deactivating the virus 186 spread are organized and discussed in detail. 187

188 **3.** Potential transmission and detection of COVID-19 virus in wastewater

SARS-COV-2 RNA can enter wastewater systems via various pathways, as shown in Fig. 2 189 which highlights the virus's potential transmission pathways. These include discharged wastewater 190 191 from isolation or quarantine centers, and hospitals. Urine, stool, and feces related contamination are the most common means of spreading contamination through wastewater systems. It was 192 reported that nearly 67 % of the stool samples of infected people tested positive for COVID-19 193 RNA, with counts reaching almost as high as those in sputum $(10^9 \text{ copies/mL in sputum versus})$ 194 10⁸ copies/mL in stool) (Chen et al., 2020). It is also interesting that SARS-COV-2 RNA is 195 commonly found in stool even after the respiratory infection has resolved and, in some cases, even 196 after the respiratory samples are found negative (Xiao et al., 2020). Recently, a compartmental 197 epidemic logical model using the data from Wuhan, China, showed that the fecal-oral path is 198 significant in spreading the virus (Danchin et al., 2020), which is indicative of poor hand-washing, 199 often associated with water scarcity and/or lack of access to clean water (Hannah et al., 2020). The 200

Danchin study revealed that virus replication in the gastrointestinal tract is highly possible 201 (Danchin et al., 2020). Therefore, contaminated wastewater can be supposed to carry a substantial 202 amount of infective virus. Moreover, surface waters such as lakes and streams, where 203 contaminated wastewater is often directly released without appropriate treatment in low-income 204 countries, can also be a possible carrier for the SARS-COV-2 through the water-channel into 205 206 different parts of society. Likewise, groundwater resources are also not safe, as there might be viral contamination through groundwater recharge. Fig. 2 shows the different pathways for 207 208 SARS-CoV-2 transmission through water systems. Furthermore, if the wastes from hospitals and 209 isolation wards are disposed without suitable treatment into the water bodies, this may lead to disease transmission. Hence, safeguarding the water systems is highly essential to inhibit 210 unpredictable yet preventable contamination of available water resources from SARS-COV-2 and 211 other microorganisms. 212



Fig. 2. Sources and pathways of SARS-CoV-2 in water systems (Adelodun et al., 2020). Copyright
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216 Detection of SARS-COV-2 in wastewater is highly challenging and presently different 217 approaches such as quantitative molecular methods and in vitro counts by the number of plaqueforming units (PFU) are used to detect and monitor viruses. The PFU method provides a 218 219 measurable assessment of the infectious viral-particle load; however, it is difficult and slow owing to the requirement for a suitable host for *in vitro* cultivation (Wigginton et al., 2015; Madigan et 220 221 al., 2012). Molecular methods show the ability to estimate (the COVID-19) viral RNA in 222 wastewater samples, but this method doesn't measure viral infectivity (Wigginton et al., 2015). It 223 is also important to understand that the viral identification sensitivity could be limited further by the cytotoxicity of co-contaminants usually seen in wastewater samples. Moreover, virus 224 concentrations in wastewater samples need to be high compared to the RNA detection limit (> 10^6 225 226 copies/mL) in order to distinguish infectious viral particles. Generally, real-time reverse 227 transcription polymerase chain reaction (RT-PCR) is considered the gold standard for determining SARS-CoV-2 using a direct assay of human extraction, where the samples are collected from the 228 upper respiratory system using swabs. In real-time RT-PCR, the limit of detection is ~100 copies 229 230 of viral RNA/mL of the transport medium; however, the RNA detection limit is $>10^6$ copies/mL in the case of wastewater. Therefore, the wastewater measurement method needs to be more 231 232 accurate with higher sensitivity for detecting the virus than that needed for clinical samples detection. In order to achieve this, intact virions are concentrated on a cell-free substrate coated 233 234 with the analogous receptors after the enzyme treatment to eliminate the broken virions. Later, the 235 bound virions are amplified and measured by reverse transcription-quantitative polymerase chain

reaction (RT-qPCR). This method was used in recent studies to identify the SARS-COV-2 in water
samples (Medema et al., 2020).

Reference	Region of study	Genes analyzed	Outcomes
Kumar et al. (2020)	Ahmedabad, India ORF1ab, N and S		2/2 influent water samples - Positive
			2/2 effluent water samples - Negative
Sherchan et al. (2020)	Louisiana, USA	N1 and N2	2/15 raw wastewater samples - Positive
			All effluent water samples - Negative
Randazzo et al. (2020)	Valencia, Spain	N1, N2 and N3	35 /42 influent water samples - Positive
			2/18 secondary treated water samples - Positive
			0/12 tertiary effluent water samples - Positive
Nemudryi et al. (2020)	Bozeman, Montana,	N1 and N2	7/7 samples - Positive in March/April 2020
	USA		
Wu et al. (2020)	Massachusetts, USA	N1, N2 and N3	10/10 raw wastewater samples - Positive
	Istanbul, Turkey	RdRp	9/9 sludge samples – Positive
Haramoto et al. (2020)	Yamanashi	N1 and N2	0/5 influent samples – Positive
	Prefecture, Japan		1/5 secondary effluent samples – Positive
			0/3 river water samples – Positive

238	Table 1. Recent studies ass	essing the prea	sence of SARS-CoV-2 i	n wastewater samples
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Table 1 presents the recently conducted studies on detection of SARS-CoV-2 in different wastewater samples globally through different targeted genes like ORF1ab, N1, N2, and N3 using RT-qPCR. Very few studies reported on whether the genetic material was present in free nucleic acids or in intact virus particles. It was seen that the majority of the samples tested at multiple different locations globally (per 100,000 people) had demonstrated the presence of SARS-CoV-2
in untreated wastewater through RT-qPCR. Although RT-qPCR shows good outcomes in detecting
SARS-CoV-2 in wastewater, other methods must be developed in order to accurately determine
the infection in wastewater samples even under low virus load concentration. Presently, the
minimal infectious dose (MID) of the COVID-19 virus is unknown for humans (Kitajima et al.,
2020). However, this novel virus's rapid transmission shows that its MID is lower than or identical
to those of other enveloped viruses (Watanabe et al., 2020; Lindsley et al., 2020).

251 It is interesting to note that a range of factors affects the virions of SARS-COV-2 in water bodies such as organic content, water temperature, and water pH. The survival time of the 252 253 SARS-COV-2 is estimated from the time needed for 90 % inactivation (T90) (Bogler et al., 2020). Under different environmental conditions, the virus can remain infective for many days. However, 254 the method through which the virus translates into severe infection risk is still unknown, especially 255 256 as human activities on, and exposure to, water varies across seasons and regions. Lower 257 temperatures support longer persistence of SARS-CoVs infectivity; at 4 °C it has been shown to remain infective for 14 days in wastewater whereas it remained viable for only two days at 25 °C 258 259 (Wang et al., 2020). Therefore, lower ambient temperatures under cold climatic conditions support 260 a higher survival of the SARS-COV-2. In view of the possible transmission of the SARS-COV-2 through water and wastewater, precautionary measures must be taken to manage wastewater 261 effectively. During winter or cold climatic conditions, hospitals located in the middle/high 262 latitudes can increase the wastewater treatment temperature by between 20 °C to 25 °C to reliably 263 and rapidly inactivate the SARS-COV-2. 264

4. Risk of infection through droplets / aerosols contaminated with infectious particles and
 its quantitative analysis

With increasing threat of secondary transmission, the major exposure risk is associated with 267 the wastewater treatment plant worker, who can be directly exposed to the sewage through faults 268 269 or leaks in plumbing or sewer networks. In addition, water treatment workers could also be prone to inhaling aerosols / droplets which are contaminated with the infectious viral-particles and there 270 is very high chance of such cases. Gholipour et al. (2021) examined and reported the detection of 271 272 Covid-19 virus RNA in about 40% of the air samples (6/15) of wastewater treatment plants, when the prevalence of SARS-CoV-2 virus was very high in the region. Covid-19 virus RNA was 273 274 identified in the range of 5 to 188 genomic copies / liter of air and the maximum concentration 275 was investigated at the wastewater pumping station. However, very few occupationally exposed cases of this indirect transmission risk through the wastewater aerosols / droplet have been studied 276 or reported as yet, and thus there is a lack of knowledge and reported literature regarding this kind 277 of possible infection. In view of societal equality and generalized safety, it is very important to 278 safeguard wastewater plants workers, who played a pivotal role for society during the lockdown. 279 280 Various factors affect the probability of infections arising in wastewater plant workers through the inhalation of aerosols which are contaminated with corona virus, as follows: 281

Climatic conditions: Wind velocity and its direction along with turbulence and deposition are
 the major factors which determine the transmission of virus through aerosols. These factors
 can critically impact the generated aerosols height and the distance covered before they settle.
 It is also expected that high wind velocity may lead to enhanced exposure of aerosols to the
 populations living downwind of wastewater plants.

Volume of the infectious viral-particles inhaled: Volume of lung, inhalation rate and viral particle size and density are crucial factor in view of infection likelihood (Wilkinson et al., 2012). Generally, males have bigger nasal-cavities and higher, longer and narrower nasal floors

than females with similar body size (García-Martínez et al., 2016). This could result in males
breathing a higher volume of infectious viral-particles than female workers, which could result
in greater risk of contracting the SARS-COV-2 virus infection.

Health response of workers: The most critical factor for assessing the potential for infection 293 of the workers are the host response to the inhaled particles. With the available data, critical 294 295 infections of SARS-COV-2 virus are predominantly seen in patients with underlying health conditions such as chronic-lung disease, diabetics, and cardiovascular disease (Bonow et al., 296 2020). Previous studies of health effects in wastewater treatment workers have shown 297 298 enhanced prevalence of cardiovascular and breathing related conditions compared to control populations (Albatanony et al., 2011). Nevertheless, healthy persons are also infected by 299 particle exposure and therefore, all wastewater plants workers regardless of their health 300 conditions are at risk of infection, especially during severe outbreaks where viral loading may 301 be very elevated. 302

4.1 Quantitative analysis: Aerosols emitted from wastewater plants possess higher risk and
therefore, must be assessed. A human-fecal shedding technique was used for determination of the
concentration of SARS-CoV-2 in wastewater (Barker, 2014; Zaneti et al. 2021).

Exposure assessment – The aerosols generated in aeration tanks and pumping stations are predominantly of diameter $\leq 10 \,\mu\text{m}$, which are considered to be respirable and could deposit in the respiratory tract and reach the alveolar region of the lungs (USEPA, 2011).

The daily dose (dd, TCID₅₀ / day) of SARS-COV-2 aerosols inhaled by the wastewater treatment workers can be calculated using an equation developed by (Barker, 2014) for other airborne microbes:

$$dd = C_c \cdot PC_{w-ar} \cdot AIR.t_{exp} \cdot ARR$$
(1)

where, C_c is the SARS-COV-2 concentration in wastewater (TCID₅₀ / L), PC_{w-ar} is the microbial 'water to air' partitioning coefficient (L / m³), *AIR* is the average rate of inhalation (m³ / h), t_{exp} is everyday exposure time (8 h for professional exposure), and *ARR* is the retention rate of aerosol in lungs, determined using the following equation (Schoen et al., 2011):

$$ARR = FF_i^1 \cdot FF_i^2 \tag{2}$$

where, FF_i^1 is the fraction of aerosols with size range of 'i' and FF_i^2 is the fraction of size range i which were deposited onto the lower respiratory tract.

320 The virus concentration in wastewater is determined using the following equation (Barker, 2014).

$$C_c = \frac{C_i \cdot PR_{fs} \cdot S_d \cdot S_r \cdot FP}{dt \cdot Q_f \cdot CF \cdot 1000}$$
(3)

where, C_i is the cumulative number of COVID-19 cases, PR_{fs} is the % of people with fecal-322 shedding of SARS-COV-2. Sr and Sd are the shedding rate (copy / gram) and shedding duration 323 (d) of SARS-COV-2 in the feces of patients, respectively, FP is the everyday production of fecal 324 matter by patients (gram feces / person / day), dt is the time period of study, Qf is the flow-rate of 325 wastewater in the plant and CF is the conversion factor of genomic copy number to TCID₅₀. When 326 327 determining viral concentration through quantitative analysis, care must be taken to account for uncertainty and variability inherent in the biological systems as suitable for the investigated 328 conditions. 329

5. Potential wastewater treatment options for COVID-19 inactivation

Different precautionary measures have been suggested by the WHO to effectively control the spread of COVID-19, such as face masking at indoor and outdoor gatherings, social distancing, and frequent hand washing with alcohol-based sanitizer or soap. Although the precautionary

measures are effective in controlling the transmission, the fear of potential community 334 transmission is very high, particularly in the countries with lower income where several families 335 share (often limited) water systems and sanitation faciliites. Hence, extensive measures are needed 336 to effectively control the spread from wastewater through effective treatment techniques. These 337 treatment approaches include physical, chemical and biological treatment methods, which are 338 339 focused on removal of suspended solids and bio-degradable organics (Crini et al., 2019, (Fu et al., 2010). The efficiency of pathogen removal from water-treatment processes is characterized by the 340 Log Reduction Value (LRV), expressed as the relative number of live-microbes removed from the 341 system through any removal procedure and is represented as: 342

$$Log Reduction = log_{10} (C_{mb}) - log_{10} (C_{ma})$$
(4)

where, C_{mb} and C_{ma} signify the viable microbe numbers before and after the treatment. Various
wastewater treatment processes and potential remedial approaches such as decentralized
wastewater treatment, sedimentation and membrane technology (physical treatment processes),
chemical and biological processes including microalgae based treatment techniques are discussed
in the following section.

5.1 Decentralized wastewater treatment for preventing virus spread

The COVID-19 pandemic has created huge stress on the availability of clean water for maintaining hygiene and contaminated wastewater treatment in order to safeguard communities and reduce exposure. In general, the dedicated COVID-19 isolation wards and health centers to monitor and treat the patients share the same sewerage systems with nearby societies. People living in the same society are likely to use common water resources, especially in low-income countries, and they may potentially be exposed to the SARS-COV-2 virus through shared water resources.

Furthermore, the inappropriate dumping of wastewater from hospitals without any treatment or 356 disinfection approach may cause community health risks and may spread the infection. As there is 357 358 a potential for the SARS-COV-2 virus spread in a centralized wastewater treatment systems, the decentralized wastewater treatment strategies with affordable and low maintenance cost could play 359 a significant role (Matto and Singhal, 2020) during COVID-19. Design and development of small-360 361 scale wastewater treatment plants can be viable alternatives to the centralized treatment plants in COVID hotspots, such as isolation wards and quarantine centers, which are a high potential source 362 for spreading the virus through wastewater. In a decentralized treatment system, utilization of UV 363 radiation and some promising ecofriendly virucidal alternatives, such as performic acid, peracetic 364 acid and sodium dichloro isocyanurate, appear to be effective in disinfecting the Covid-19 virus 365 and thus combatting any potential contamination through wastewater transmission. Decentralized 366 wastewater treatment facilities that consist of light emitting diode (LED) based UV could be highly 367 useful (Naddeo and Liu, 2020). In low-income countries, where the infrastructure is not good, and 368 369 construction of a complete wastewater treatment plant is not possible in a short time span, the usage of mobile wastewater treatment services with disinfection devices could be a better and more 370 feasible option. Rural solar toilets can also be a viable alternative as they can easily achieve water 371 372 temperatures up to 44 °C, which helps in the removal of pathogens (Moe and Izurieta, 2003). Additionally, sanitary landfills/wetlands or ponds are also an effective method of discharging the 373 374 wastewater, and they can be treated with economic disinfectants like sodium hypochlorite. It has 375 been inferred from the above discussion that a cost effective method for controlling the viral spread can be achieved through decentralized treatment of wastewater, and various dimensions should be 376 377 taken into consideration while designing this system, particularly the local issues related to the 378 suitability and availability while selecting this technology.

5.2 Prevention of virus spread through wastewater by utilizing membrane technology

Membrane filtration technology is considered to be a robust, non-invasive and non-toxic 380 381 technique. It is highly preferred for removing virus and considered as the most advanced method 382 for wastewater treatment. In this technology, ultrafiltration (UF) is an effective method for removing viruses, macromolecules, pyrogens, and bacteria. UF utilizes membranes with 1000 kilo-383 384 Dalton molecular weight cut-off that are explicitly designed to retain viruses, and usually more than 4 logs of virus removal are attained while safeguarding good protein permeability. In 385 386 filtration, viruses of size less than the pore-size are carried with the fluid and pass through the pores of membranes, while if the size of the pore is less than that of the virus, the virus get retained. 387 388 Size exclusion is the key mechanism of clearance by filtration. UF has potential to provide a complete barrier to COVID-19 virus spread, as it can easily remove the virus whose diameter is 389 100 nm. 390

Filtration capability can be further enhanced using different surface characteristics of the 391 filtration membrane such as hydrophobic and charged regions which attract groups on the viral 392 envelope, leading to the removal of sizes beyond exclusion owing to the electrostatic and 393 hydrophobic interactions (Chaudhry et al., 2015; Bodzek et al., 2019). The usage of UF membranes 394 in bioreactors has further improved the virus removal capability through the combination of three 395 distinct mechanisms: steric removal, adsorption, and inactivation during treatment (Bodzek et al., 396 397 2019). Owing to the advanced features of UF membrane in bioreactors, they removed bacteriophage MS2 (virus) with high efficiency (4–7 log). Moreover, nano-filtration (pore size <398 399 2 nm) with high pressure, using a tight and dense membrane system along with forward and reverse 400 osmosis membranes, can completely remove SARS-CoVs (Pendergast et al., 2011). These filtration technologies are most efficient when used in tangential flow or cross flow mode, and are 401

being exploited in various virus removal and wastewater purification processes as they are cheaper 402 than other methods such as chromatography and also easier to implement. Nano-filtration 403 possesses features for separating the COVID-19 virus from wastewater, however extensive 404 experimental studies are needed prior to design and execution especially for wastewater 405 applications. Various effective experimental methods for predicting flux exist, but still there is a 406 407 lack of theoretical studies, predominantly those targeting the calculation of filtration efficiency related to log reduction value, and hence, filtration efficiency should be considered for advanced 408 design and efficient operation of UF in terms of virus separation. 409

In addition to filtration, sedimentation is also reported to remove viruses (Verbyla et al.,
2105; Shin et al., 2015). Viral adsorption onto large-size settleable solids followed by
sedimentation is considered to be the main removal mechanism in many treatment plants (Verbyla
et al., 2105). The terminal velocity (V) of the dispersed solid settling due to gravity is represented
by the following equation:

415
$$V = \sqrt{\frac{4.D.g\left(\rho_p - \rho_w\right)}{3.C_D.\rho_w}} \tag{5}$$

where D is diameter of the solid particle (m), g is acceleration due to gravity (m / s), ρ_p is the density of the solid particle (kg / m³), ρ_w is density of water (kg / m³), and C_D is the drag coefficient. Drag coefficient is calculated using the Reynolds's number (Re), which is expressed as:

419
$$Re = \frac{D.\rho_w.u}{\mu} \tag{6}$$

420 where μ denotes the viscosity of water and u denotes the relative velocity, respectively.

It can be seen from these equations that increased settling velocity will be achieved by increasing 421 422 the diameter or volume of the particles (Mohammed et al., 2013) and similar concepts have been 423 used for removal of viruses in wastewater. As the virus attaches to the suspended-solids, the combined agglomerated particles exhibit a larger size diameter with greater density, which in turn 424 leads to enhanced sedimentation and consequently to removal of the virus. LRV of 0.65-2.85 were 425 426 achieved for eleven different viruses during conventional activated sludge processes and similarly, LRVs of 1.4–1.7 were achieved for noroviruses, rotaviruses and enteroviruses (Kitajima et al., 427 428 2014; Zhou et al., 2015). Therefore, sedimentation is the main mechanism to reduce the viral 429 concentration in wastewater. However, only selected strains of rotavirus and norovirus were removed by this process (Da Silva et al., 2008) and hence, further studies are required to make this 430 technology more effective and to assess its suitability for removal of the COVID-19 virus from 431 432 wastewater.

433 **5.3** Potential disinfectant strategies for prevention of virus spread

434 5.3.1 Solar assisted wastewater disinfection

Solar assisted wastewater disinfection is a highly feasible and applicable option in several 435 types of aquatic environments (Nelson et al., 2018). Solar based drinking water disinfection is a 436 sustainable approach for disinfecting water, and it is widely promoted (Thakur et al., 2021a; 437 Thakur et al., 2021b; Thakur et al., 2021c; Thakur et al., 2020a; Thakur et al., 2020b; Thakur et 438 439 al., 2021d; Thakur et al., 2018a; Thakur et al., 2018b; Kumar et al., 2017). It mainly depends on the intensity of solar radiation, the optical, physical, and chemical properties of the wastewater, 440 and the type of virus (Verbyla et al., 2015). Solar energy has abundant availability with yearly 441 442 solar irradiance higher than 2000 kWh/m²/y in most places on earth except Russia, Canada, Japan, 443 and South Korea. Tropical countries like India have plenty of sunshine, and average daily solar

radiation varies between 4-7 kWh/m² for different parts of the country. With an average of 250-444 300 clear sunny days in a year, India receives about 5000 TWh of solar insolation per year, and it 445 shows excellent potential for solar assisted wastewater disinfection facilities. Various mechanisms 446 are used for the disinfection of wastewater by solar radiation such as the direct mechanism, which 447 needs photon absorption directly by the virus or an endogenous component such as proteins, 448 449 nucleic acids and other biomolecules. They absorb the UV-B fraction of solar radiation that leads to structural change and thus, inactivates the virus. Recently, Sagripanti et al. (2020) examined 450 451 and explored the role of virus inactivation by the UV-B in sunlight in various populated cities 452 across the world. The results showed comparatively faster inactivation of COVID-19 virus (than influenza A) during the summer time, demonstrating the important role of solar radiation on its 453 occurrence and spread. The authors concluded that more than 90% of COVID-19 virus was 454 inactivated by exposure to mid-day solar radiation after 11-34 min in the majority of US cities and 455 world cities during their respective summer. Ratnesar-Shumate et al. (2020) explored the role of 456 457 simulated solar radiation on the survival of COVID-19 virus dispersed in simulated saliva or culture medium (Vero cells 'ATCC CCL-81' cultured at 37°C and under 5% CO₂ in complete 458 growth medium 'gMEM'). A solar simulator was designed to produce natural sunlight, specifically 459 460 in the range of ultraviolet. It was observed that solar radiation had a direct effect on survival of the virus with 90% of the infectious virus being inactivated in 6.8 min in simulated saliva under the 461 462 simulated conditions; however, for culture medium, the time taken was around 14.3 min. Under 463 all simulated conditions, the virus's inactivation rate was greater when dispersed in simulated saliva than in the culture medium. Fisher et al. (2011) examined the role of simulated solar 464 465 radiation on the inactivation of a single-stranded RNA bacteriophage 'MS2' and a double-stranded 466 DNA bacteriophage 'PRD1' in clear water (no exogenous sensitizers). It was observed that UVA

467 (320–400 nm) and UV-B (280–320 nm) could inactivate 'PRD1'; however 'MS2' was inactivated
468 only by the UVB light. It is inferred from the above discussion that solar based disinfection is the
469 most sustainable way of wastewater treatment as well as being a cost-effective approach, which
470 has potential for treating contaminated water and deactivating the COVID-19 coronavirus.

471

5.3.2 Ozonation for wastewater disinfection

Ozone (O₃) is an oxidizing agent that can effectively inactivate viruses by oxidative 472 damage due to free radicals. As the viruses multiply only within their host cell, they transform host 473 474 cell protein into their own protein. O₃ inactivates the virus by diffusing through its protein coat into the nucleic acid core, leading to the viral RNA damage. Once O₃ interacts with a virus, protein 475 476 is converted into protein hydroxides and protein hydroperoxides, resulting in the creation of oxidative stress, against which viruses have no self-protection mechanisms. Recently, Tizaoui 477 (2020) proposed that usage of O_3 can be effective for SARS-CoV-2 virus as O_3 can disorder the 478 lipids and proteins of the virus's spikes. O_3 acts on the cytoplasmic membrane through breaking 479 the lipid molecules, thereby inactivating the virus (Kataki et al., 2020). In general, an initial dose 480 of O₃ (3–10 mg/L) with 10 min contact time demonstrates Ct values (the product of the 481 482 concentration of the disinfectant and the contact time with the water being disinfected) of 30-100 mg/min, which has been suggested is the requirement for successful ozonation (Paraskeva and 483 484 Graham 2002). Ozone is also considered as a significantly stronger disinfectant (10 times) than 485 chlorine in wastewater treatment (Hajiali et al., 2018). Even after dissolving in water, it did not irritate skin, nor did it form a chemical film. It is a stronger disinfectant where the oxidation 486 reaction takes place several time faster than chlorine to inactivate viruses, bacterial and water-487 488 borne pathogens. However, for wastewater treatment, ozonation's major issue is the increasing acidity level in the treated water (Zaied et al., 2020) and it needs further investigation. 489

490 5.3.3 Chemical based disinfectants for wastewater disinfection

Chlorine-based disinfectants are widely used for water disinfection. Inactivation of 491 492 microorganisms by chlorine is mainly governed by various factors such as the oxidation of 493 sulfhydryl enzymes and amino acids, reduced nutrient uptake, loss of intracellular contents, reduced oxygen uptake, inhibited protein synthesis, and decreased ATP production. Various 494 495 literature has shown the efficiency of chlorine towards the virus, but greater tolerance of the virus can be seen for chlorine disinfectants (compared to ozonation or solar assisted disinfection) owing 496 497 to the absence of a metabolic enzyme system as compared to bacteria, which means that in viruses there are less targets upon which the chlorine can act. Previous research revealed that 0.2 to 0.5 498 499 mg/L of free chlorine residual is sufficient to disinfect the SARS virus in municipal wastewater (Wang et al., 2005). Engelbrecht et al. (1980) investigated the chlorine (0.1% available chlorine) 500 effectiveness against six enteric viruses and revealed a broader range of susceptibility of viruses 501 towards chlorine disinfection. pH is considered as the most important factor for achieving 502 503 inactivation of viruses in wastewater; the deactivation rate is greater at lower pH (6) than at higher pH (10), yet also with a deviation in the relative sensitivity in respect of different viruses. pH is 504 505 the regulating factor which controls the dissociation of hypochlorous acid to the less microbicidal 506 form OCl⁻. With increasing pH, transformation of undissociated hypochlorous acid to OCl⁻ takes place and the disinfecting ability of Cl⁻ reduces. Therefore, at pH higher than 7, the time needed 507 508 to achieve the same degree of inactivation increases, requiring from 1.5-6 fold longer (Clarke et al., 1956; Weidenkopf, 1958). Recently, Zhang et al. (2020) evaluated the existence of 509 510 SARS-CoV-2 RNA in septic tanks of Wuchang Cabin Hospital, and Fig. 3 shows the schematic arrangement for the disinfection process of the septic tanks of hospital. 511



Fig. 3. Schematic illustration of the disinfection process occurring in septic tanks of the Wuchang
Cabin Hospital. Copyright 2020 Elsevier.

512

515 It was found that utilization of sodium hypochlorite for a contact period of 1.5 h at a dose of 800-6700 g/m³ effectively deactivated the SARS-CoV-2 in the hospital's septic tanks. It was also 516 517 suggested to revise the present WHO recommended disinfection scheme (freely available chlorine \geq 0.5 mg/L for at least 30 min) and the China Center for Disease Control and Prevention's current 518 guidance (freely available chlorine above 6.5 mg/L for 1.5 h) in order to completely remove the 519 COVID-19 viral RNA using a decentralized disinfection system. Kampf (2020) reported that usage 520 of sodium hypochlorite (0.21%) solution could be highly efficient for 4 log reduction of 521 COVID-19 in 1 min. Wang et al. (2005) illustrated that a free chlorine residual '0.2 to 0.5 mg/L' 522 in the municipal wastewater is enough to sterilize the SARS virus. Dellanno et al. (2009) showed 523

a reduction of 3 log in surrogate of the coronavirus mouse hepatitis virus (MHV) using 0.21% sodium hypochlorite as a common disinfectant for a contact period of 30 s. Similarly, Ansaldi et al. (2004) found that utilization of 0.05% hypochlorite solution can completely inactivate the SARS-CoV with a contact time of < 1 min.

Quaternary ammonium-based compounds, being eco-friendly disinfectants, are also 528 529 recommended for wastewater treatment. For example, benzalkonium chloride (BKC), a quaternary ammonium compound, can be an effective disinfectant for water treatment. The hydrophilic 530 531 cationic section of benzalkonium chloride generates electrostatic interfaces with a pathogen's 532 surface (negatively charged components), leading to the destabilization of the germs (McDonnell and Russel, 1999). 1% benzalkonium chloride '1000 ppm' was used by Ansaldi et al. (2004) for 533 SARS-CoV, and outcomes showed that the virus lost viability after 30 min exposure. Rabenau et 534 al. (2005) revealed that BKC inactivated SARS-CoV under the limit of detection with a reduction 535 factor >4. However, owing to the restricted action of ammonium compounds with the viruses, it is 536 537 required to use it in combination with other disinfectants to achieve optimal results. WHO also recommends peracetic acid (PAA) for virucide of SARS-CoV-2. It is reliable and possesses 538 excellent disinfectant characteristics with extensive anti-microbicidal activity (Antonelli et al., 539 540 2013). Ansaldi et al. (2004) revealed that SARS-CoV-1 was disrupted using 35 ppm PAA with a contact period of <2 min, while there was no effect after 30 min with the same concentration and 541 542 further investigation is thus needed. Although chemical-based disinfectants are preferred for 543 wastewater treatment, their role in the deactivation of SARS-CoV-2 is less explored. In addition, 544 optimization of the disinfectant concentration and their reduced efficiency in high organic loaded 545 wastewater needs to be further explored.

546 **5.4 Biological wastewater treatment**

Biological wastewater treatment techniques rely on microorganisms' (such as bacteria, algae or fungi) cellular activity under aerobic / anaerobic conditions in order to achieve the oxidation of the organic matter present in wastewater (Samer, 2015). Biological wastewater treatment methods include membrane bio-reactors, activated sludge, bio-chemical systems, biological contactors and anaerobic digesters. Since the majority of studies assessing the removal of viruses have concentrated on membrane bio-reactors and granular reactors, these are described in greater detail.

554 5.4.1 Membrane bio-reactors: These consist of a combined arrangement of membrane based filtration with a suspended-growth biological reactor. This approach is a suitable alternative 555 556 method for achieving virus removal from wastewater owing to the excellent features like a reduced ecological footprint and high effluent quality (Marti et al., 2011). The principal mechanism of 557 pathogenic bacteria removal is the process of size exclusion, whereas the mechanism of virus 558 removal is less studied and not fully understood. Sepehri et al. (2018) highlighted that membrane 559 560 fouling in membrane bio-reactors mainly depends on microbial cell density and their population structure. The authors concluded that suitable organic carbon to nitrogen (C/N) loading ratio could 561 562 control the microbial population and benefit the nitrifiers, considerably mitigating the fouling. 563 Various studies have highlighted the role of mixed liquor suspended solids and backwashed membranes in the inactivation of viruses (Xagoraraki et al., 2014; Miura et al., 2015). Da Silva et 564 al. (2007) determined an LRV for norovirus of 5.2–5.5 in a membrane bio-reactor. Similarly, LRVs 565 of 4.8, 6.3, and 6.8 were achieved in a membrane bio-reactor for noroviruses, adenoviruses, and 566 enteroviruses, respectively (Simmons et al., 2011). In contrast, Zhou et al. (2015) concluded that 567 568 complete removal of several viruses, including rotaviruses, noroviruses and enteroviruses could 569 not be achieved by this method. This discrepancy could be attributed to the fact that the membrane

bio-reactor method mainly focusses on physical removal of viruses, whereas the removal is greatly governed by the virus structure, mixed liquor suspended solids, solids and hydraulic retention time along with frequent cleaning of the membrane in order to achieve effective removal. In addition, this method is energy intensive, has a high operational cost, and requires proper disposal of the virus-contaminated sludge produced. The aforementioned drawbacks of this technology can be overcome by utilizing microalgae-based process either alone or coupled with the membrane technology to generate safe biologically treated water.

5.4.2 Microalgae-based wastewater treatment: The usage of macro / micro algae is gaining 577 enormous attention in removal of pollutants including viruses from wastewater in recent years 578 579 (Prajapati et al., 2014). Several researchers have studied the cultivation of microalgae in membrane bio-reactors, oxidation ponds and biofilm reactors to estimate their efficacy for wastewater 580 disinfection. Recently, Delanka-Pedige et al. (2020) demonstrated that utilization of microalgae in 581 wastewater treatment through employment of extremophile Galdieria sulphuraria leads to high 582 583 removal rates of noroviruses (1.49 ± 0.16) and enteroviruses (1.05 ± 0.32) . Scalable and sustainable filter paper made from Pithophora cellulose were studied for drinking water 584 585 purification purposes. Results showed that all types of bacterial and infectious viruses were 586 successfully removed from sample water by this filter paper. Sepehri et al. (2020) demonstrated that the aeration system in conventional nitrification processes can be substituted by a microalgae 587 based cleaning process which will result in less metabolite generation, improved carbon capture, 588 augmented nutrient removal, and decreased sludge production. Similarly, Sepehri et al. (2019) 589 590 found that a nitratation intensification strategy and nitrite-oxidizing bacterial enrichment using a zero C/N ratio reduced microbial metabolites by 50% as compared to the conventional process and 591

improved the nitrification efficacy in the activated sludge involved process. This improvedefficiency should also lead to increased effectiveness of viral deactivation.

594 5.5 Large scale community wise monitoring and testing of COVID-19 RNA in wastewater

The countries with lower income, determined according to GDP per capita, have in general 595 conducted lower testing for COVID-19 compared to the developed nations, as shown in Fig. 4 (till 596 December 2nd 2020). There is presently a substantial gap in COVID-19 testing in various low-597 income nations, with only 779,708 persons tested so far in Nigeria as of December 4, 2020, out of 598 599 about 200 million population, which is Africa's most populated country (NCDC, 2020). 600 Unfortunately, the transmission of the Covid-19 virus in these nations has been ascribed to the 601 incompetence of quickly detecting the infected people before the virus transmits to others and thus spreads the COVID-19 virus (Mehtar et al., 2020). As the initial identification of the virus could 602 be made through faeces (Orive et al., 2020) rapid testing and monitoring of the virus in the 603 municipal/societal wastewater might be an effective technique to control the spread. This method 604 will be more suitable for low-income countries where the virus testing in communities is still 605 limited. Initial surveillance should be done for the pervasiveness of the COVID-19 infection in the 606 populace by observing the abundance of COVID-19 virus in wastewater, and then, the currently 607 applied inspection of symptomatic and/or likely exposed individuals should be carried out for 608 episodic analysis. Recently, Daughton (2020) emphasized the significance of large-scale 609 610 community wide testing as an economical method for monitoring the status and development of COVID-19 infections. Moreover, improved water quality and adequate sanitation are also essential 611 to effectively prevent the unexpected spread of the COVID-19 and other potential human enteric 612 613 related viruses that might originate from an infected person's feces.



Fig. 4. Total COVID-19 tests per 1,000 population vs. GDP per capita (Our world in data, 2020)

617 6. Viewpoint and conclusion

The present effort of public health experts and medical professionals dealing with the COVID-618 19 pandemic is understandably focused on controlling its direct human-to-human spread and the 619 620 care of infected individuals. Nevertheless, the potential spread of the virus through secondary transmission must not be underrated. Evidence for the existence of COVID-19 viral RNA in 621 wastewater systems is seen globally, and the risks associated with waterborne transmission should 622 be considered as severe. This needs to be quickly evaluated, especially in low-income countries 623 where higher population density, poor sanitation infrastructure, lack of appropriate wastewater 624 625 treatment facilities and direct exposure to aerosolized wastewater are major concerns, and may damage the hard-won achievements of the present control measures to reduce individual contacts, 626

leading to a huge spike in COVID-19 cases. Various studies have confirmed the existence of 627 viruses at sewage plants, however, there is no data related to the effectiveness of current 628 629 disinfection approaches as utilized on real wastewater in the treatment facilities against Covid-19. Therefore, extensive research should be carried out urgently to identify the prevalence of SARS-630 CoV-2 viral particles in wastewater in order to gain the crucial information related to the virus's 631 632 abundance in raw and treated wastewater, in order to (1) evaluate the effectiveness of existing disinfection methods for inactivation of SARS-COV-2 and where additional disinfection regimes 633 634 are needed temporarily to deal with this new challenge; (2) ensure the reduction of potential secondary exposures by appropriately treating wastewater, and ensuring effluents are virus-free; 635 and (3) facilitate monitoring and early-warning of potential hot-spots of infection, enabling local 636 preventative responses to be implemented in a timely manner. Further, the requirement for 637 disinfectants and application regimes should be evaluated according to the loading of the virus. 638 Thus, surveillance should be a core aspect of policymaking and wasterwater treatment modalities 639 640 in order to effectively monitor and control the spread of SARS-CoV-2 infections in society.

To minimize human exposure to the Covid-19 virus via waterborne transmission, contaminated 641 642 wastewater from isolation wards, hospitals, testing centers, and quarantine centers should be 643 disinfected and treated correctly before being discharged into the main sewerage systems. In lowincome countries with inadequate centralized wastewater plants, decentralized wastewater 644 treatment with solar energy utilization can be incorporated to efficiently inactivate the virus 645 locally. Figure 5 presents a summary of the major considerations for determination of the optimal 646 647 treatment to implement locally depending on local conditions (e.g., UV availability, volume or 648 wastewater to be treated, current waste infrastructure capabilities etc.).



Selection of suitable disinfectant method
 Optimal contact period of disinfectants with wastewater
 Efficient dispersal of disinfectants in wastewater
 Residual degradation in environment post treatment

649

Fig. 5. Various potential wastewater treatment strategies and concerns during Covid-19

651 pandemic.

In tropical countries like India, where there is abundant solar energy availability, a solar-based 652 disinfectant solution can be a viable option for wastewater treatment. Simple wastewater 653 654 treatments such as wetlands, ponds, or lagoons could be a superior choice for viral inactivation under the joint effect of solar radiation, comparatively long retention time, high pH, and microbial 655 action. The usage of chemical disinfectants such as the widely available chlorine, sodium 656 657 hypochlorite, benzalkonium chloride, peracetic acid etc. have shown potential in terms of virucidal 658 properties. Biological treatments including microalgae can be a viable solution for viral removal from wastewater. Fig. 5 presents the different strategies towards the treatment of wastewater and 659 some major concerns that must be considered during the selection of the most appropriate 660 661 treatment in the view of the SARS-CoV-2 virus.

Nevertheless, further technical evidence is needed to confirm the effectiveness of viral 662 disinfection policies in wastewater, and the impact of different viral loadings on the treatment 663 efficiency. In conclusion, there is a pressing need for improved monitoring and risk assessment 664 along with the implementation of management policies for controlling the spread of COVID-19 665 via wastewater. To effectively control the spread of the novel coronavirus, policymakers should 666 667 emphasize systematic testing of the disinfectants' efficiency and concentration ranges under different environmental conditions (e.g., different organic loadings, different water quality 668 scenarios, etc.). Beyond SARS-CoV-2 infections, these methods will also be helpful in improving 669 670 the identification, response, and inactivation of future viral disease outbreaks, and indeed in controlling other enteric viruses responsible for diarrhea and other intestinal conditions. 671

- 672 Declaration of Competing Interest
- 673 The authors declare no conflicts of interest.

674 **References**

- Albatanony, M.A., El-Shafie, M.K., 2011. Work-related health effects among wastewater
 treatment plants workers. Int J Occup Environ Med. 2(4):237-244.
- Ansaldi, F., Banfi, F., Morelli, P., Valle, L., Durando, P., Sticchi, L., Contos, S., Gasparin, R.,
- 678 Crovari, P., 2004. SARS CoV, influenza A and syncitial respiratory virus resistance against
- 679 common disinfectants and ultraviolet irradiation. J. Prev. Med. Hyg. 45, 5–8.
- Antonelli, M., Turolla, A., Mezzanotte, V., Nurizzo, C., 2013. Peracetic acid for secondary effluent
- disinfection: a comprehensive performance assessment. Water. Sci. Technol. 68, 2638–2644.

682	Arslan, A., Topkaya, E., Özbay, B., Özbay, I., Veli, S., 2017. Application of O ₃ /UV/H ₂ O ₂
683	oxidation and process optimization for treatment of potato chips manufacturing wastewater.
684	Water Environ. J. 31, 64–71.

- Barker, S.F., 2014. Risk of norovirus gastroenteritis from consumption of vegetables irrigated with
- highly treated municipal wastewater-evaluation of methods to estimate sewage quality. RiskAnal. 34, 803-817.
- 688 Bashir Adelodun, Fidelis Odedishemi Ajibade, Rahmat Gbemisola Ibrahim, Hashim Olalekan
- Bakare, Kyung-Sook Choi, 2020. Snowballing transmission of COVID-19 (SARS-CoV-2)
- 690 through wastewater: Any sustainable preventive measures to curtail the scourge in low-income
- 691 countries?. Sci. Total Environ. 140680.
- Bodzek, M., Konieczny, K., Rajca, M., 2019. Membranes in water and wastewater disinfection –
 review. Arch. Environ. Prot. 45, 3–18.
- Bonow, R.O., Fonarow, G.C., O'Gara, P.T., Yancy, C.W., 2020. Association of coronavirus
- disease 2019 (covid-19) with myocardial injury and mortality. JAMA Cardiol.
- Burns, N., Hunter, G., Jackman, A., Hulsey, R., Coughenour, J., Walz, T., 2007. The return of
 ozone and the hydroxyl radical to wastewater disinfection. Ozone Sci. Eng. 29, 303–306.
- 698 Bushmaker, T., Morris, D.H., Holbrook, M.G., Gamble, A., Williamson, B.N., Tamin, A.,
- Harcourt, J.L., Thornburg, N.J., Gerber, S.I., Lloyd-Smith, J.O., de Wit, E., Munster, V.J.,
- 7002020. Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1. N Engl701116, 1564, 1567
- 701 J Med 16, 1564-1567.
- 702 Chaudhry, R. M., Nelson, K. L., Drewes, J. E., 2015. Mechanisms of pathogenic virus removal in
- a full-scale membrane bioreactor. Environ. Sci. Technol. 49, 2815–2822.

- 704 Chen, Y., Chen, L., Deng, Q., Zhang, G., Wu, K., Ni, L., Yang, Y., Liu, B., Wang, W., Wei, C.,
- Yang, J., Ye, G., Cheng, Z., 2020. The presence of SARS-CoV-2 RNA in feces of COVID-19
 patients. J. Med. Virol. 92, 833–840.
- Clarke, N.A., Stevenson, R.E., Kabler, P.W., 1956. The inactivation of purified type 3 adenovirus
 in water by chlorine. Am. J. Hyg. 64, 314–319.
- Crini, G., Lichtfouse, E., 2019. Advantages and disadvantages of techniques used for wastewater
 treatment, Environ. Chem. Lett. 17, 145–155.
- Danchin, A., Wai Ng, P.T., Turinic, G., 2021. A new transmission route for the propagation of the
 SARS-CoV-2 coronavirus. Biology 1, 10.
- 713 Da Silva, A.K., Le Guyader, F.S., Le Saux, J.C., Pommepuy, M., Montgomery, M.A., Elimelech,
- M., 2008. Norovirus removal and particle association in a waste stabilization pond, Environ.
 Sci. Technol. 42, 9151–9157.
- 716 Da Silva, A.K., Le Saux, J.C., Parnaudeau, S., Pommepuy, M., Elimelech, M., Le Guyader F.S.,
- 2007. Evaluation of Removal of Noroviruses during Wastewater Treatment, Using Real-Time
 Reverse Transcription-PCR: Different Behaviors of Genogroups I and II, Appl. Environ.
- 719 Microbiol. 73, 7891–78.
- Daughton, C., 2020. The international imperative to rapidly and inexpensively monitor
 community-wide Covid-19 infection status and trends. Sci. Total Environ. 726, 138149.
- Delanka-Pedige, H.M.K., Cheng, X., Munasinghe-Arachchige, S.P., AbeysiriwardanaArachchige, I.S. A., Xu, J., Nirmalakhandan, N., Zhang, Y., 2020. Metagenomic insights into
- virus removal performance of an algal-based wastewater treatment system utilizing Galdieria
- sulphuraria, Algal Res. 47. 101865, https://doi.org/10.1016/j.algal.2020.101865.

- Dellanno, C., Vega, Q., Boesenberg, D., 2009. The antiviral action of common household
 disinfectants and antiseptics against murine hepatitis virus, a potential surrogate for SARS
 coronavirus. Americ. J. infec. Con. 37, 649–652.
- 729 Dhama, K., Patel, S. K., Yatoo, M. I., Tiwari, R., Khan, S., Dhama, J., Natesan, S., Malik, Y.S.,
- Singh, K.P., Harapan, H., 2021. SARS-CoV-2 existence in sewage and wastewater: A global
 public health concern. J. Environ. Manage. 280, 111825.
- Fisher, M.B., Love, D.C., Schuech, R., Nelson, K.L., 2011. Simulated sunlight action spectra for
 inactivation of MS2 and PRD1 bacteriophages in clear water. Environ. Sci. Technol. 45, 9249–
 9255.
- Fu, C.Y., Xie, X., Huang, J.J., Zhang, T., Wu, Q.Y., Chen, J.N., Hu, H.Y., 2010. Monitoring and
 evaluation of removal of pathogens at municipal wastewater treatment plants, Water Sci.
 Technol. 61, 1589–1599.
- 740 García-Martínez, D., Torres-Tamayo, N., Torres-Sanchez, I., García-Río, F., Bastir, M., 2016.
- 741 Morphological and functional implications of sexual dimorphism in the human skeletal thorax.
- Am. J. Phys. Anthropol. 161, 467–477.
- 743 Gholipour, S., Mohammadi, F., Nikaeen, M., Shamsizadeh, Z., Khazeni, A., Sahbaei, Z., Mousavi,
- S.M., Ghobadian, M., Mirhendi, H., 2021. COVID-19 infection risk from exposure to aerosols
 of wastewater treatment plants. Chemosphere 273, 129701.
- Haramoto, E., Malla, B., Thakali, O., Kitajima, M., 2020. First environmental surveillance for the
 presence of SARS-CoV-2 RNA in wastewater and river water in Japan. Sci. Total Environ.
- 748 737, 140405.

- Kampf, G., 2020. Potential role of inanimate surfaces for the spread of coronaviruses and their
 inactivation with disinfectant agents. Infect. Prev. Pract. 2, 100044.
- 751 Kitajima, M., Ahmed, W., Bibby, K., Carducci, A., Gerba, C.P., Hamilton, K.A., Haramoto, E.,
- Rose, J.B., 2020. SARS-CoV-2 in wastewater: state of the knowledge and research needs. Sci.
- 753 Total Environ. 739, 139076.
- Kitajima, M., Iker, B.C., Pepper, I.L., Gerba, C.P., 2014. Relative abundance and treatment
 reduction of viruses during wastewater treatment processes Identification of potential viral
 indicators, Sci. Total Environ. 488–489, 290–296.
- Kitajima, M., Sassi, H.P., Torrey, J.R., 2018. Pepper mild mottle virus as a water quality indicator.
 npj Clean Water 1,19.
- Kumar Thakur A., Kumar Pathak S., 2017. Single basin solar still with varying depth of water:
 optimization by computational method. Iran J Energy Environ (IJEE) 8(3):216–223
- 761 Kumar, M., Kumar Patel, A., Shah, A.V., Raval, J., Rajpara, N., Joshi, M., Joshi, C.G., 2020. First
- proof of the capability of wastewater surveillance for COVID-19 in India through detection of
 genetic material of SARS-CoV-2. Sci. Total Environ. 746, 141326.
- Lindsley W. G., Pearce T. A., Hudnall J. B., Davis K. A., Davis S.M., Fisher M. A., Khakoo R,
- 765 Palmer J. E., Clark K. E., Celik I, Coffey C. C., Blachere F. M., Beezhold D. H., 2012. Quantity
- and size distribution of cough-generated aerosol particles produced by influenza patients
 during and after illness. J Occup Environ Hyg. 9, 443-449.
- 768 Ling, Y., Xu, S.B., Lin, Y.X., Tian, D., Zhu, Z.Q., Dai, F.H., Wu, F., Song, Z.H., Huang, W.,
- 769 Chen, J., Hu, Bi.J., Wang, S., Mao, E.Q., Zhu, L., Zhang, W.H., Lu, H.Z., 2020. Persistence
- and clearance of viral RNA in 2019 novel coronavirus disease rehabilitation patients. Chin.
- 771 Med. J. 9, 1039-1043.

- Lodder, W., de Roda Husman, A.M., 2020. SARS-CoV-2 in wastewater: potential health risk, but
 also data source. lancet. Gastroenterol. Hepatol. 1253, 30087.
- Madigan, M.T., Martinko, J.M., Parker, J., Brock, T.D., 2012. Brock Biology of Microorganisms
 thirteenth ed. Pearson, London.
- 776 Marti, E., Monclús, H., Jofre, J., Rodriguez-Roda, I., Comas, J., Balc´azar, J.L., 2011. Removal
- of microbial indicators from municipal wastewater by a membrane bioreactor (MBR).
 Bioresour. Technol. 102, 5004–5009.
- Matto, M., Singhal, S., 2020. COVID-19: the need is to decentralise how we manage wastewater.
- Available at: <u>https://www.downtoearth.org.in/blog/water/covid-19-the-need-is-to-</u>
 decentralise-how-we-manage-wastewater-70991
- McDonnell, G., Russell, A.D., 1999. Antiseptics and disinfectants: activity, action, and resistance.
 Clinic. Microbiol. Rev. 12, 147–179.
- Medema, G., Heijnen, L., Elsinga, G., Italiaander, R., Brouwer, A., 2020. Presence of SARS
 Coronavirus-2 in sewage and correlation with reported COVID-19 prevalence in the early
 stage of the epidemic in the Netherlands. Environ. Sci. Technol. Lett. 7, 511–516.
- 787 Mehtar, S., Preiser, W., Lakhe, N.A., Bousso, A., TamFum, J.-J.M., Kallay, O., Seydi, M., Zumla,
- A., Nachega, J.B., 2020. Limiting the spread of COVID-19 in Africa: one size mitigation
 strategies do not fit all countries. Lancet Glob. Heal. 0, 2019–2021.
- Miura, T., Okabe, S., Nakahara, Y., Sano, D., 2015. Removal properties of human enteric viruses
 in a pilot-scale membrane bioreactor (MBR) process, Water Res. 75, 282–291.
- Moe, C.L., Izurieta, R., 2003. Longitudinal study of double vault urine diverting toilets and solar
- toilets in El Salvador. Proceedings of the Second International Symposium on Ecological
- Sanitation, Lubeck, Germany, 295–302.

- Mohammed, M.A.R., Halagy, D.A.E., 2013. Studying the factors affecting the settling velocity of
 solid particles in non-newtonian fluids, Al-Nahrain J. Eng. Sci. 16, 41–50.
- 797 Naddeo, V., Liu, H., 2020. Editorial Perspectives: 2019 novel coronavirus (SARS-CoV-2): what
- is its fate in urban water cycle and how can the water research community respond? Water Res.
- 799 Technol. Environ. Sci. 6, 1213-1216.
- NCDC, 2020. Nigeria Centre for Disease Control on Coronavirus COVID-19 update 2020.
 https://covid19.ncdc.gov.ng/ (Accessed 5th December 2020).
- Nelson, K.L., Boehm, A.B., Davies-Colley, R.J., Dodd, M.C., Kohn, T., Linden, K.G., Nguyen,
- T.H., Parker, K.M., Rodriguez, R.A., Sassoubre, L.M., Silverman, A.I., Wigginton, K.R.,
- 804 Zepp, R.G., 2018. Sunlight-mediated inactivation of health-relevant microorganisms in water:
- a review of mechanisms and modeling approaches. Environ. Sci. Processes Impacts 20, 1089–
 1122.
- Nemudryi, A., Nemudraiam, A., Surya, K., Wiegand, T., Buyukyoruk, M., Wilkinson, R.,
 Wiedenheft, B., 2020. Temporal detection and phylogenetic assessment of SARSCoV- 2 in
 municipal wastewater. Cell Rep Med. 1, 100098.
- Nghiem, L.D., Morgan, B., Donner, E., Short, M.D., 2020. The COVID-19 pandemic:
 considerations for the waste and wastewater services sector. Case Studies in Chem. Environ.
 Eng., 100006.
- 813 Omosa, I.B., Wang, H., Cheng, S., Li, F., 2012. Sustainable tertiary wastewater treatment is
- required for water resources pollution control in Africa. Environ. Sci. Technol. 46, 7065–7066.
- 815 Orive, G., Lertxundi, U., Barcelo, D., 2020. Early SARS-CoV-2 outbreak detection by sewage-
- 816 based epidemiology. Sci. Total Environ., 183135

- 817 Our world in data, 2020 <u>https://ourworldindata.org/grapher/tests-of-covid-19-per-thousand-</u>
- 818 people-vs-gdp-per capita? Tab=chart&stackMode=absolute&time=latest&country=&
 819 region=World (Accessed 5th December 2020).
- Pan, X., Chen, D., Xia, Y., 2020. Viral load of SARS-CoV-2 in clinical samples. Lancet Infect.
- 821 Dis. 20, 411–412.
- Paraskeva, P., Graham, N.J., 2002. Ozonation of municipal wastewater effluents. Water environ.
 Res. 74, 569–581.
- Pendergast, M. M., Hoek, E.M.V., 2011. A review of water treatment membrane
 nanotechnologies. Energy Environ. Sci. 4, 1946–1971.
- Prajapati, S.K., Choudhary, P., Malik, A., Vijay, V.K., 2014. Algae mediated treatment and
 bioenergy generation process for handling liquid and solid waste from dairy cattle farm,
 Bioresour. Technol. 167, 260–268.
- Rabenau, H., Kampf, G., Cinatl, J., Doerr, H., 2005. Efficacy of various disinfectants against
 SARS coronavirus. J. Hosp. Infect. 61, 107–111.
- 831 Randazzo, W., Truchado, P., Cuevas Ferrando, E., Simon, P., Allende, A., Sanchez, G., 2020.
- 832 SARS-CoV-2 RNA titers in wastewater anticipated COVID-19 occurrence in a low prevalence
- area. Water Res. 181, 115942.
- Ratnesar-Shumate, S., Williams, G., Green, B., Krause, M., Holland, B., Wood, S., Bohannon, J.,
- Boydston, J., Freeburger, D., Hooper, I., Beck, K., 2020. Simulated sunlight rapidly inactivates
 SARS-CoV-2 on surfaces. J. Infect. Dis. 222, 214–222.
- 837 Sagripanti, J.L., Lytle, C.D., 2020. Estimated Inactivation of Coronaviruses by Solar Radiation
 838 With Special Reference to COVID-19. Photochem. Photobiol. 96, 731-737.

- 839 Sahin, A.H., Aysegul, E., Pelin, M.A., Yeliz, D., Ahmet, Y.C., Mahmut, E.S., Ramazan, A.O., Ali
- Muhittin, T., 2020. 2019 novel coronavirus (COVID-19) outbreak: a review of the current of
 the current literature. EJMO 4 (1), 1–7.
- 842 Samer, M., 2015. Biological and chemical wastewater treatment processes. Wastewater Treat.
- 843 Eng., InTech. https://doi.org/10.5772/61250.
- Schoen, M.E., Ashbolt, N.J., 2011. An in-premise model for Legionella exposure during
 showering events. Water Res. 45, 5826-5836.
- 846 Sepehri, A., Sarrafzadeh, M-H., Avateffazeli, M., 2020. Interaction between Chlorella vulgaris
- and nitrifying-enriched activated sludge in the treatment of wastewater with low C/N. J. Clean.
 Prod. 247, 119164.
- Sepehri, A., Sarrafzadeh, M-H., Avateffazeli, 2019. Activity enhancement of ammonia-oxidizing
 bacteria and nitrite-oxidizing bacteria in activated sludge process: metabolite reduction and
 CO2 mitigation intensification process. Appl. Water Sci. 9,131.
- Sepehri, A., Sarrafzadeh, M-H., Avateffazeli, 2018. Effect of nitrifiers community on fouling
 mitigation and nitrification efficiency in a membrane bioreactor. Chem Eng Process CHEM
 ENG PROCESS 128, 10–18
- 855 Sherchan, S.P., Shahin, S., Ward, L.M., Tandukar, S., Aw, T.G., Schmitz, B., Ahmed, W.,
- 856 Kitajima, M., 2020. First detection of SARS-CoV-2 RNA in wastewater in North America: a
- study in Louisiana, USA. Sci. Total Environ. 743, 140621.
- Shin, G.A., Sobsey, M.D., 2015. Removal of norovirus from water by coagulation, flocculation
 and sedimentation processes. Water Sci. Technol. Water Supply. 15, 158–163.
- 860 Sigmon, C., Shin, G.A., Mieog, J., Linden, K.G., 2015. Establishing surrogate–virus relationships
- for ozone disinfection of wastewater. Environ. Eng. Sci. 32, 451–460.

- Silverman, A.I., Peterson, B.M., Boehm, A.B., McNeill, K., Nelson, K.L., 2013. Sunlight
 inactivation of human viruses and bacteriophages in coastal waters containing natural
 photosensitizers. Environ. Sci. Technol. 47, 1870–1878.
- 865 Simmons, F., Kuo, D., Xagoraraki, I., 2011. Removal of human enteric viruses by a fullscale
 866 membrane bioreactor during municipal wastewater processing, Water Res. 45 (9), 2739–2750.
- 867 Suthar, S., Das, S., Nagpure, A., Madhurantakam, C., Tiwari, S.B., Gahlot, P., Tyagi, V.K., 2021.
- Epidemiology and diagnosis, environmental resources quality and socio-economic
 perspectives for COVID-19 pandemic. J. Environ. Manage. 280, 111700.
- 870 Tang, A., Tong, Z., Wang, H., Dai, Y., Li, K., Liu, J., Wu, W., Yuan, C., Yu, M., Li, P., Yan, J.,
- 2020. Detection of novel coronavirus by RT-PCR in stool specimen from asymptomatic child,
 China. Emerg. Infect. Dis. J. 26, 1337-1339.
- Thakur, A.K., Agarwal, D., Khandelwal, P., Dev, S., 2018a. Comparative study and yield
 productivity of nano-paint and nano-fluid used in a passive-type single basin solar still,
 Advances in Smart Grid and Renewable Energy. Springer, pp. 709-716.
- Thakur, A.K., Chandramohan V.P., 2020a. Productivity enhancement of passive type solar still
 using copper and aluminum based absorber plate with Al2O3 nanofluid in water basin. In: In
 Advances in Energy Research, 2nd edn. Springer, Singapore, pp 273–281.
- Thakur, A.K., Khandelwal, P., Sharma, B., 2018b. Productivity comparison of solar still with
 nano fluid and phase changing material with same depth of water. In: Anand G, Pandey J, Rana
- 881 S (eds) Nanotechnology for Energy and Water. ICNEW 2017. Springer. Proceedings in
- Energy. Springer, Cham. https://doi.org/10.1007/978-3-319-63085-4_17.

883	Thakur A.K., Sathyamurthy, R., Sharshir, W.S., Ahmed, M.S., Hwang, J.Y., 2021a. A novel
884	reduced graphene oxide based absorber for augmenting the water yield and thermal
885	performance of solar desalination unit. Mater Lett 286, 128867.

- 886 Thakur A.K., Sathyamurthy, R., Sharshir, W.S., Kabeel, A.E., Elkadeem, Ma, Z., Manokar, A. M.,
- Arıcı, M., Pandey, A.K., Saidur, R., 2021c. Performance analysis of a modified solar still using
 reduced graphene oxide coated absorber plate with activated carbon pellet. Sustain. Energy

889 Technol. Assess. 45, 101046.

- 890 Thakur A.K., Sharshir, S.W., Ma, Z., Thirugnanasambantham, A., Christopher, S.S., Vikram,
- M.P., Li, S., Wang, P., Zhao, W., Kabeel, A.E., 2021b. Performance amelioration of single
 basin solar still integrated with V- type concentrator: energy, exergy, and economic analysis.
 Environ Sci Pollut Res 28, 3406–3420.
- Thakur, A.K., Sathyamurthy, R., Sharshir, S.W., Kabeel, A.E., Manokar, A.M., Zhao, W., 2021d.
 An experimental investigation of a water desalination unit using different microparticle-coated
 absorber plate: yield, thermal, economic, and environmental assessments. Environ Sci Pollut
 Res Int. doi: 10.1007/s11356-021-12837-6.
- Thakur, A.K., Vikrama, M.P., Christopher, S., 2020b. Augmented yield productivity of solar still 898 899 using energy storage materials: experimental investigation under the climatic conditions of Rajasthan. In: Bhoi A, Sherpa K, Kalam A, Chae GS (eds) Advances in Greener Energy 900 Singapore. 901 Technologies. Green Energy and Technology. Springer, 902 https://doi.org/10.1007/978-981-15-4246-6_51.
- Tizaoui, C., 2020. Ozone: a Potential Oxidant for COVID-19 Virus (SARS-CoV-2). Ozone Sci
 Eng. 42, 378-385.
- 905 USEPA, 2011. Exposure Factors Handbook 2011 Edition. Final Report, Washington, DC.

- 906 Venugopal, A., Ganesan, H., Sudalaimuthu Raja, S.S., Govindasamy, V., Arunachalam, M.,
- 907 Narayanasamy, A., Sivaprakash, P., Rahman, P.K.S.M., Gopalakrishnan, A.V., Siama, Z.,
- 908 Vellingiri, B., 2020. Novel wastewater surveillance strategy for early detection of coronavirus
- disease 2019 hotspots. Curr. Opin. Environ. Sci. Heal. 17, 8–13.
- 910 Verbyla, M.E., Mihelcic, J.R., 2015. A review of virus removal in wastewater treatment pond
 911 systems. Water Res. 71, 107–124.
- 912 Wang X.W., Li J.S., Jin M, Zhen B, Kong Q.X., Song N, Xiao W.J., Yin J, Wei W, Wang G.J., Si
- B.Y., Guo B.Z., Liu C, Ou G.R., Wang M.N., Fang T.Y., Chao F.H., Li J.W., 2005. Study on
- 914 the resistance of severe acute respiratory syndrome-associated coronavirus. J Virol Methods.
- 915 126,171-77.
- Watanabe, T., Bartrand, T.A., Weir, M.H., Omura, T., Haas, C.N., 2010. Development of a doseresponse model for SARS coronavirus. Risk Anal. 30, 1129–1138.
- 918 Weidenkopf, S.J., 1958. Inactivation of type I poliomyelites virus with chlorine. Virol 5,
- 919 56–67.
- Wigginton, K.R., Kohn, T., 2012. Virus disinfection mechanisms: the role of virus composition,
 structure, and function. Curr. Opinion Virol. 2, 84–89.
- 922 Wigginton, K.R., Ye, Y., Ellenberg, R.M., 2015. Emerging investigators series: the source and
- fate of pandemic viruses in the urban water cycle. Environ. Sci. Water Res. Technol. 1, 735–
 746.
- Wilkinson, D.M., Koumoutsaris, S., Mitchell, E.A., Bey, I., 2012. Modelling the effect of size on
 the aerial dispersal of microorganisms. J. Biogeogr. 39, 89–97.
- 927 World Health Organization, 2020a. Modes of transmission of virus causing COVID-19:
 928 implications for IPC precaution recommendations. https://www.who.int/news-

- 929 <u>room/commentaries/detail/modes-of-transmission-of-virus-causing-covid-19-implications-</u>
- 930 <u>for-ipcprecautionrecommendations</u>. (Accessed 5 December 2020).
- Worldometer graph, <u>https://www.worldometers.info/coronavirus/worldwide-graphs/</u> (accessed as
 on 5th December 2020)
- 933 Wu, Y., Guo, C., Tang, L., Hong, Z., Zhou, J., Dong, X., Yin, H., Xiao, Q., Tang, Y., Qu, X.,
- Kuang, L., Fang, X., Mishra, N., Lu, J., Shan, H., Jiang, G., Huang, X., 2020a. Prolonged
 presence of SARS-CoV-2 viral RNA in faecal samples. Lancet Gastroenterol. Hepatol. 5, 434–
 435.
- Yagoraraki, I., Yin, Z., Svambayev, Z., 2014. Fate of viruses in water systems. J. Environ. Eng.
 140, 04014020.
- Xiao, F., Tang, M., Zheng, X., Liu, Y., Li, X., Shan, H., 2020. Evidence for gastrointestinal
 infection of SARS-CoV-2. Gastroenterology 158, 1831–1833.
- Xu, Y., 2020. Unveiling the Origin and Transmission of 2019-nCoV. Trends. Microbiol. 28, 239
 240.
- 943 Yan, Y., Shin, W.I., Pang, Y.X., Meng, Y., Lai, J., You, C., Zhao, H., Lester, E., Wu, T., Pang,
- 944 C.H., 2020. The first 75 Days of novel coronavirus (SARS-CoV-2) outbreak: recent advances,
 945 prevention, and treatment. Inter. Environ. Res. Public Health 17, 2323.
- Zaied, B.K., Rashid, M., Nasrullah, M., Zularisam, A.W., Pant, D., Singh, L., 2020. A
 comprehensive review on contaminants removal from pharmaceutical wastewater by
 electrocoagulation process. Sci. The Tot. Environ. 138095.
- 949 Zaneti, R.N., Girardi, V., Spilki, F.R., Mena, K., Westphalen, A.P.C., da Costa Colares, E.R.,
- 950 Pozzebon, A.G., Etchepare, R.G., 2021. Quantitative microbial risk assessment of SARS-CoV-
- 2 for workers in wastewater treatment plants. Sci. Total Environ. 754, 142163.

952	Zhang, D., Ling, H., Huang, X., Li, J., Li, W., Yi, C., Zhang, T., Jiang, Y., He, Y., Deng, S., Zhang,
953	X., 2020. Potential spreading risks and disinfection challenges of medical wastewater by the
954	presence of severe acute respiratory syndrome Coronavirus 2 (SARS-CoV-2) viral RNA in
955	septic tanks of fangcang hospital. Sci. The Tot. Environ. 140445.
956	Zhou, J., Wang, X.C., Ji, Z., Xu, L., Yu, Z., 2015. Source identification of bacterial and viral
957	pathogens and their survival/fading in the process of wastewater treatment, reclamation, and

environmental reuse, World J. Microbiol. Biotechnol. 31, 109–120.

959