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Routes of Transmission of SARS CoV-2 through Aquatic Environment in Developing Countries

Waled M. El-Senousy[1,]*, Mariam Abdel Rauf[2], Tarek W. M. El-Senousy[3], Seham F. Hasan[4]

1. Water Pollution Research Department, Environmental Research Division and Food-Borne Viruses Group, Centre of Excellence for Advanced Sciences, National Research Centre (NRC), Giza, Egypt.
2. Science, Technology, Engineering, and Math (STEM) Secondary School, Ismailia Branch, Egypt.
3. Manor House Language Secondary School, Dokki Branch, Giza, Egypt. tarekwaleed612007@gmail.com
4. Botany and Microbiology Department, Faculty of Science, Al-Azhar University (Girls Branch), Egypt.

***Corresponding Author: waledmorsy@hotmail.com**

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ABSTRACT

All continents across the world are being affected by the COVID-19 pandemic, even though some continents such as Africa witnessed a dramatic impact due to severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) than the others. Respiratory viruses spread from an infected individual to vulnerable people i) by contact counting coordinated person-to-person transfer of infectious secretions and indirect transfer of discharges through fomites, ii) by the ballistic spray of large droplets delivered amid coughing and sneezing (short-range transmission) and iii) by inhalation of small airborne droplets or aerosol (long-range transmission). The objective of this study was to make an overview of the route of transmission of SARS-CoV 2 especially if there is a role for water and food in virus transmission. Also, the role of water systems, and management in controlling viral frequency in developing countries. WASH is commonly known as water, sanitation, and hygiene which is currently in critical condition due to the poor sanitation systems and improper sewage disposal. These poor WASH conditions are considered one of the routes to the transmission of the Covid-19 pandemic in Africa. Generally, the unhygienic conditions, and inadequate sanitary and sewage systems cause a lot of disease outbreaks. Africa is in big need of managed wastewater treatment facilities efficiently and on the other hand, separating the sewage system and wastewater treatment facilities of healthcare centers from urban systems or treating on-site to ensure the viral removal during disinfection must be made. Also, efficient methods to eliminate face masks must be taken into consideration.

INTRODUCTION

Coronaviruses are enveloped in positive single-stranded RNA viruses which belong to subfamily *orthocoronavirinae*, family *coronaviridiae*, and order *Nidovirales*. The subfamily *orthocoronavirinae* has further classified into four genera named *Alphacoronavirus*, *Betacoronavirus*, *Deltacoronavirus*, and *Gamacoronavirus* coronaviruses genera **(AVMA, 2020)**. Genus *Alphacoronavirus* contains many animal viruses and two human coronaviruses (HCov-229E and HCov-NL63). Genus

Betacoronavirus contains the prototype mouse hepatitis virus, three human viruses (HCov-OC43, SARS-HCov, and HCov-HKU1), and the SARS-related coronavirus, Middle East respiratory syndrome (MERS) coronavirus, in addition to some animal coronaviruses. Genus *Gamacoronavirus* includes viruses of whales and birds while genus *Deltacoronavirus* includes viruses isolated from pigs and birds. According to the phylogenetic tree of coronaviruses, 2019-nCoV belongs to the genus *Betacoronavirus*, is more closely related to bat-SARS-like (SL)-CoV ZC45 and bat-SL-CoV ZXC21 and more distantly related to SARS-CoV **(Chen *et al*., 2020)**. Coronaviruses are enveloped viruses with large non-segmented positive-sense single-stranded RNA (+ssRNA) genome (~30kb) which contains at least six open reading frames (ORFs). The first ORF constitutes about two-thirds of the whole genome length and encodes 16 non-structural proteins (nsp1 to nsp16) except *Gammacoronavirus* which lacks nsp1 **(Ziebuhr *et al*., 2000; Masters, 2006)**. Other ORFs encode at least 4 major structural proteins: spike (S) protein, envelope (E) protein, transmembrane (M) protein, and nucleocapsid (N) protein in addition to special structural and accessory proteins, such as hemagglutinin-esterase (HE) protein, 3a/b protein, and 4a/b protein **(Hussain *et al*., 2005; Chen *et al*., 2020)**.

Wastewater serves as an important tool to trace the circulation of viruses in a community, providing prospects to estimate their prevalence, genetic diversity, and geographic distribution **(El-Senousy *et al*., 2020; Xagoraraki and O'Brien, 2020)**. Wastewater offers a practical approach to identifying viruses excreted in the feces of an entire region **(La Rosa and Muscillo, 2013; El-Senousy *et al*., 2020; El-Senousy *et al*., 2021)**. Thus, it becomes possible to monitor the epidemiology of virus infections even if they are not evident by clinical surveillance, mainly because traditional epidemiological approaches may be limited by the asymptomatic nature of many viral infections and under-diagnosis of clinical cases **(Johansson *et al*., 2014; Qi *et al*., 2018)**.

SARS-CoV-2 is known to cause asymptomatic or paucisymptomatic infections making it difficult to find out the actual degree of viral circulation in a community and in making comparisons with countries that have different clinical diagnostic testing capabilities with even different diagnostic methods **(Lai *et al*., 2020; Mizumoto *et al*., 2020; Nishiura *et al*., 2020; Tang *et al*., 2020)**. In the meantime, wastewater surveillance could provide a fair method of evaluating the spread of infection in different areas, indeed where assets for clinical determination are constrained and when reporting systems are inaccessible or not doable, such as in developing nations. In addition, wastewater monitoring can offer assistance to distinguish variability within the circulating strains through phylogenetic investigation, permitting for comparisons between locales and evaluation of the evolution of the virus genome over time as illustrated earlier for enteric viruses **(Lodder *et al*., 2013; La Rosa *et al*., 2014; Bisseux *et al*., 2018)**, and later for SARS-CoV-2 **(Nemudryi *et al*., 2020)**. The objective of this study was to make an overview of the route of transmission of SARS-CoV 2 especially if there is the role of water and food in virus transmission. Also, a role of water systems, and management in controlling viral frequency in developing countries.

DISCUSSION

To achieve the objective of this study, some points will be discussed including cornavirus transmission routes, swimming activities and some kinds of foods as sources for virus transmission, role of water systems management in controlling SARS CoV-2 in developing countries, persistence and elimination of SARS CoV-2 in wastewater, and regular remedial measures of SARS-CoV-2 transmission in African water systems.

1. Routes of transmission

Based on the coronavirus species, coronaviruses may be transmitted from one host to some other host, via way of means such as an aerosol, fomite, or fecal-oral route **(Decaro, 2011)**. Human coronaviruses infect the epithelial cells of the respiratory tract, whereas animal coronaviruses normally infect the epithelial cells of the digestive tract **(de Groot *et al*., 2012)**.

MERS-CoV was transmitted by adjacent person-to-person contact. Even though primary cases of infection have been linked to contact with infected dromedary camels, the transmission of the virus happened through respiratory discharges discharged by the infected individuals when coughing and sneezing **(Peeri *et al*., 2020)**. Moreover, droplets from coughing and/or sneezing have been the cruel way by which the transmission of SARS-CoV happened, through person-to-person contact. Although much less common, fecal transmission, fomites, and managing of animals also resulted in the transmission of the virus **(Chan-Yeung and Xu, 2003)**. Also, asymptomatic individuals may transmit the virus and thus play a chief role in the spread of the disease **(Shen *et al*., 2020)**.

In recent times, the prospect of fecal-oral transmission of SARS-CoV-2 has been raised since the virus has been detected in the feces of COVID-19 patients **(Holshue *et al*., 2020)**. This shows that the virus can exist and replicate in the digestive tract, but it is not clear whether consuming SARS-CoV-2-contaminated food causes infection **(Van Doremalen *et al*., 2020)**.

Coronaviruses can be introduced into sewage by a variety of sources, such as hand washing, sputum, vomiting, and mostly by viral shedding in the feces of infected persons **(Bhowmick *et al*., 2019; Adelodun *et al*., 2020; Han *et al*., 2020; Wang *et al*., 2020a; Wei *et al*., 2020)**. Furthermore, urine samples from infected individuals were reported to contain SARS-CoV in 2003 **(Xu *et al*., 2005)**, MERS-CoV in 2012 **(Drosten *et al*., 2013)**, and SARS-CoV-2 in 2020 **(Nomoto *et al*., 2020)**. Moreover, infectious viral particles were also isolated from feces, sputum, nasal- and oropharyngeal swabs, and urine of COVID-19 patients **(Xiao *et al*., 2020; Kujawski *et al*., 2020; Wölfel *et al*., 2020; Sun *et al*., 2020)**. Consequently, the viruses may enter the water systems through numerous pathways, mostly from sewage discharged from hospitals and quarantine centers, but also from houses and other buildings inhabited by infected persons, whether symptomatic or not **(Adelodun *et al*., 2020; Gandhi *et al*., 2020; Nabi *et al*., 2020; Zhang *et al*., 2020)**.

Several studies have quantified SARS-CoV-2 RNA in sewage samples from different countries by reverse transcription-quantitative polymerase chain reaction (RT-qPCR), and the virus was found up to 10^4 copies/Liter (L) in Montana **(Nemudryi *et al*., 2020)**, from 10^4 to 10^5 copies/L in Detroit **(Brijen *et al*., 2020)**, up to 10^6 copies/L in Massachusetts **(Schmidt 2020; Wu *et al*., 2020)**, and up to 10^7 copies/L in Virginia in the USA **(Gonzalez *et al*., 2020)**, 60–350 copies/L in Ahmedabad in India **(Kumar *et al*., 2020a)**, up to 3.4×10^4 copies/L in the United Arab Emirates **(Hasan *et al*., 2020)**, 10^6 copies/L in Murcia in Spain **(Randazzo *et al*., 2020b)**, and during the epidemic peak, up to 10^7 copies/L were found in the sewage from Paris in France **(Wurtzer *et al*., 2020)**. Moreover, **Gallardo-Escárate *et al*. (2020)** found up to 10^4 copies/L in sewage samples from a penitentiary and health care facilities in Chillan, a city in Southern Chile, while **Gonçalves *et al*. (2020)** found up to 10^7 copies/L in hospital wastewater in Ljubljana, Slovenia. The variations reported in viral concentrations in sewage may be related to the level of infections and other specific sewage conditions, such as the area served and the resulting balance between industrial, stormwater, domestic, and healthcare facilities inputs **(Pecson *et al*., 2020)**. There are also studies reporting the presence of SARS-CoV-2 RNA in sewage samples before records of the COVID-19 cases. **La Rosa *et al*. (2021)** re-analyzed the stored samples of raw sewage that were collected between October 2019 and February 2020 in five wastewater treatment plants (WWTPs) in northern Italy and found viral loads of 1.2×10^3, 4.1×10^3, and 2.9×10^4 copies/L in Turin, Milan, and Bologna, respectively, on 10–18 December 2019. Interestingly, the first autochthonous Italian case of COVID-19 was documented just on 21 February 2020. Also, **Martin *et al*. (2020)** detected SARS-CoV-2 RNA in sewage samples collected at a WWTP in South East England On 11 February 2020, i.e., three days before the first case was reported in that area. Moreover, it was observed that the presence of SARS-CoV-2 RNA in WWTPs from the metropolitan locale of Valencia, Spain, in late February, when affirmed COVID-19 cases in that locale were just beginning **(Randazzo *et al*., 2020a)** These results robustly suggest that the virus was undergoing community transmission earlier than previously believed, and suggest that wastewater analysis could be a sensitive and cost-effective strategy for COVID-19 epidemiological surveillance **(Randazzo *et al*., 2020a)**. Routine implementation of this surveillance tool would significantly improve awareness against new or recurrent viral outbreaks **(Randazzo *et al*., 2020a)**. Likewise, **Lodder and de Roda Husman (2020)** detected SARS-CoV-2 RNA in sewage at Schiphol airport in Tilburg, the Netherlands, on 17 February 2020, i.e. four days after the first case of COVID-19 was confirmed in the country. Additionally, **Medema *et al*. (2020)** detected SARS-CoV-2 RNA in sewage from Amersfoort, in the Netherlands, on 5 March 2020, i.e. six days before the announcement of the first case in the city. Raw wastewater samples collected from April to June 2020, in 33 WWTPs of the Czech Republic, in districts with a higher occurrence of COVID-19, affirmed that SARS-CoV-2 RNA was present in greater than 27.3% of the samples from WWTPs **(Mlejnkova *et al*., 2020)**. Briefly, reports from Australia **(Ahmed *et al*., 2020)**, the United Arab Emirates **(Albastaki *et al*., 2020)**, the United States **(Peccia *et al*., 2020; Sherchan *et al*., 2020)**, Brazil **(Prado *et al*., 2020)**, Canada **(D'Aoust *et al*., 2021)**, Sweden **(Saguti *et al*., 2021)**, and Germany **(Westhaus *et al*., 2021)** have shown the feasibility of detecting viral RNA in sewage and WWTP sludge, and the possibility of using these data for monitoring the prevalence of infections among the populace by wastewater-based epidemiology.

Although coronaviruses remain infectious in sewage for some hours–days (**Barcelo, 2020; Hart and Halden, 2020; Heller *et al*., 2020; Michael-Kordatou *et al*., 2020; Randazzo *et al*., 2020a)**, they may persist for up to fourteen days, depending on the environmental conditions **(Wang *et al*., 2005)**. **Zaneti and co-workers (2021)** used a quantitative microbial risk assessment approach to analyze the potential health risks of SARS-CoV-2 in sewage to WWTPs workers for three COVID-19 pandemic conditions (moderate, aggressive, and extreme). Their work confirmed a viral RNA load in the raw sewage inflowing the WWTPs ranging from 4.14×10^{4} to 5.23×10^{6} copies/L, resulting in estimated risks for aggressive and extreme conditions (2.63×10^{-3} and 1.3×10^{-2}, respectively) exceeding the derived bearable infection risk for SARS-CoV-2 of 5.5×10^{-4} per person per year. On the other hand, **Dada and Gyawali (2020)** found that the average disease risks for low-grade, moderate, and aggressive outbreak conditions, are 0.036, 0.32, and 3.21 cases of disease per 1000 exposed WWTP workers, respectively, using a quantitative microbial risk assessment approach to evaluate the disease risks for WWTP labors, and expecting that 0.03%, 0.3%, and 3% of the wastewater-generating population is infected with SARS-CoV-2.

2. Is there a role of swimming activities for SARS-CoV-2 transmission?

Swimming in a pool or a lake involves proximity among people and a high frequency of touching common surfaces. These factors would increase the risk of virus transmission. **Carraturo *et al*. (2020)** reported the spread of SARS-CoV-2 through droplets and potentially airborne transmission. Water-borne transmission is still not confirmed. A well-publicized event was a Fourth of July celebration in a Michigan lake, where people contracted COVID-19 **(Jones *et al*., 2020)**. **Termansen and co-workers (2020)** attempted to explore the extent of transmission of SARS-CoV-2 in Danish swimming clubs during indoor swimming activities between August and December 2020. They collect data from an official contact person from each swimming club using an electronic-based questionnaire. A SARS-CoV-2 positive subject in a swimming activity was considered a risk case. Out of a total of 162 risk cases that occurred, eight (4.9%) led to the transmission of SARS-CoV-2 that affected 23 people. Also, they noted 23 SARS-CoV-2 infections among swimmers from the same club in a training camp. Remarkably, participants of other clubs training in the same swimming pool during the same period were unaffected, thereby suggesting that the transmissions may be due to other exercises within the training camp like dining, sleeping in dormitories, and socializing. Also, they evaluated the efficiency of the safety strategies. To this end, no relationship between the implementation of safety measures and the risk of SARS-CoV-2 transmission for indoor swimming was noted. However, this study was biased and provided inconclusive evidence. **Bao *et al*. (2020)** investigated the epidemiology of a COVID-19 outbreak at an entertainment location, containing a floor for public bathing. They showed an infected person who had used a public bath for 2 consecutive days. The infected person has belonged to 12 bath-related infections, of which 10 among bathers, and two among workers at the location. Afterward, one of these bathers infected 19 colleagues and family individuals at successive meals, and one of the two laborers infected 41 people, of which seven individuals were among the bathers. Also, they noted a significantly lower secondary transmission rate at the entertainment location than outside the location (like colleagues and family clusters). Also, it was noted that nine infected COVID-19 persons who were hospitalized in the Jiangsu Province of China had all used the same bath center **(Luo *et al*. 2020)**. The center contained a swimming pool, showers, and sauna. Their study accounted that the first patient showered in the center, while the following seven patients took showers, used a sauna, and went swimming in the pool, and the ninth case was among workers. They disagreed with those of Bao *et al*., and transmissibility of COVID-19 showed no signs of weakening in warm (25-41 °C) and humid conditions (60%). Thus, evidence from the three studies was inconclusive and did not address the confounding factors **(Yaacoub *et al*., 2021)**.

3. Is there a role of some kinds of foods for virus transmission?

Currently, there may be no evidence that SARS-CoV-2 can be transmitted through foods, and did now no longer anticipate those positive foods needed to be withdrawn **(CDC 2020; FDA, 2020; FSS, 2020; WHO, 2020a)**. Even though no coordinate interface has been established between SARS-CoV-2 infection and foodborne transmission, later occurrences highlighted frozen foods as carriers for the long-range transport of SARS-CoV-2 during the current pandemic. SARS-CoV-2 was detected on a cutting board used for processing imported salmon on 12 June 2020 in the Xinfadi agricultural produce wholesale marketplace in Beijing. A total of 256 instances have been affirmed over the other two weeks, with 98.8% of those associated with the Xinfadi marketplace wherein a salmon cutting board was tried positive for SARS-CoV-2 **(Xinhua, News 2020)**. Genome sequencing of the SARS-CoV-2 infection examined from the Xinfadi marketplace identified a European coronavirus strain, giving solid proof that the re-emergent COVID-19 cases in Beijing may be caused by imported causes **(CCDC, 2020)**. Though later studies did not find distinct proof of its origin, this particular incident raised awareness of frozen foods as possible SARS-CoV-2 carriers. At least nine cases of contamination of food have been described across the country since the start of July 2020, when SARS-CoV-2 was identified on packaging materials of imported foods. The majority of those incidents have been traced to frozen shrimps imported from Ecuador, where SARS-CoV-2 became located on their packaging materials, and in one case, it was also detected on the interior of a shipping container. Remarkably, in the latest incident in Shenzhen, Guangdong province on August 12, 2020, SARS-CoV-2 was found on the surface of a frozen chicken wing sample originating from Brazil, which became the first known case where the novel coronavirus was detected on actual food samples **(SMHC, 2020)**.

Frequent detection of SARS-CoV-2 in frozen foods suggested that food-borne transmission may present a systematic risk in the ongoing pandemic. Food contamination may happen through respiratory beads, contact, or other means, during the cultivating, processing, storing, transport, and retailing process where foods may contact with diverse labors and surrounding conditions. Before the re-emergence of the first COVID-19 case on June 11, 2020, there had been no local transmission reported for 56 consecutive days in Beijing **(China Daily 2020)**.

Ceylan *et al*. (2020) pointed out that foodborne illnesses caused by viral contamination are common, and viruses can contaminate food by contaminated water in which shellfish develops or utilized for fruit washing after harvest, poor hand hygiene practices, and the ingestion of animal-based products containing zoonotic viruses. Afterward, **Rizou *et al*. (2020)** discussed safety measures required in the food supply chain during the COVID-19 pandemic and hypothesized that transmission may happen through frozen foods or packaging, even though the probability would be lower after days of shipment. However, none of those researches has accounted for any real proof **(Ceylan *et al*., 2020; Rizou *et al*., 2020)**.

4. Role of management of water systems in developing countries in controlling SARS CoV-2 taking Africa as a model study

All continents across the world are being affected by the COVID-19 pandemic, even though some continents as Africa witness a more dramatic impact due to SARS-CoV-2 than others. Regarding this, each government is taking all the possible precautionary instructions and rules to tackle this issue and eliminate its fatal effects on humans and the surroundings. Recent clinical experiments have shown SARS-CoV-2 abundance in urine samples, hospitals, and urban sewage **(Lescure *et al*., 2020; Ling *et al*., 2020)**. Also, recent studies show that SARS-CoV-2 has been detected in stool samples of COVID-19 cases **(Medema *et al*., 2020)**. This proves that wastewater has become an important pathway for SARS-CoV-2 in wastewater systems, which alleviates the pandemic transmission. Hence, the resilient policies, poor sanitation, and water systems problems in most developing countries ease the spread of COVID-19 among people. Africa's death toll on 12 July 2020 was 12,996 with more than 280,000 recoveries **(Africa Centres for Disease Control and Prevention 2020)**. According to the BBC September 2021, most covid-19 cases were found in the USA, Brazil, India, Mexico, and Peru which has the biggest mortality rate of 620.5 people per 100,000 **(BBC News, 2021)**.

Wastewater management systems and sanitary systems in Africa are currently in critical conditions; by which pit latrines and groundwater systems can be found close to each other which eases the cross-contamination between the pit latrines and the groundwater organs **(Sunkari *et al*., 2021)**. Thus, this increases the risk of being infected with SARS-CoV-2 by people who transmit the virus through their stool to the drinking water sources. Shared toilets, a common tradition in Africa, may also higher the exposure to Covid-19; as the virus may remain in the air droplets due to the limited aeration **(Sunkari *et al*., 2021)**. On 2 July 2020 in Ghana, medical officers observed the presence of unusual symptoms of Covid-19 such as diarrhea, vomiting, and stomach upset because it was detected that the virus attacks the gastro intestines not only the respiratory system. Altogether, African people mainly depend on groundwater and surface water for their consumption, causing a dramatic risk for SARS-CoV-2 infection through contaminated water. Consequently, sources and routes of SARS-CoV-2 transmission through the water must have been adhered **(Sunkari *et al*., 2021)**.

In 2017, it was surveyed that out of two billion people who lack basic sanitation facilities in the world, 709 million (35 % of the whole number) are living in Africa **(WHO, 2019)**. Thus, there is the usage of contaminated water and poor sewage systems in Africa **(Street *et al*., 2020)**. This contributes to the rising levels of open defecation existing in all of sub-Saharan Africa **(WHO 2019; Street *et al*., 2020)**. These fragile conditions may indirectly increase the percentage of covid-19 transmission among water systems. By 2030, the (SDG 6) sustainable development goals aim to eradicate the issue of open defecation and ease the accessibility of clean water and developed sewage systems **(WHO, 2014)**. Even so, this target is quite difficult to be achieved with the current state of the continent **(Sunkari *et al*., 2021)**. For instance, only 21% of Ghana has improved sanitary systems; although it's considered to be one of the strongest economies in Africa **(Appiah-Effah *et al*., 2019)**. This is besides the logistic restrictions that prevent most of the wastewater released in the whole 16 regions of Ghana to be subjected to any filtration or recycling systems **(Sunkari *et al*., 2021)**. Population growth also is one of the significant factors that attributes to the slow progress of achieving the SDGs goals, especially if the number of sub-Saharan African residents is expected to triple by the year 2050 **(Adams *et al*., 2019; Dos Santos *et al*., 2017)**. Furthermore, Nigeria (the giant of Africa), as it has over 200 million inhabitants, includes many states that suffer from dysfunctional management systems, like Plateau, Niger, Kwara, Kogi, and Benue, correspondingly some other states don't have any sanitary systems at all **(Adesogan 2013; Adewumi and Oguntuase 2016; Omole *et al*., 2019)**. Without a doubt, this proves the information that the wastewater in these states is being released into the surface water sources without passing through pre-treatment plants or disinfection facilities **(Azizullah *et al*., 2011; Afzal *et al*., 2019; Arslan *et al*., 2020)**. In South Africa, about 37% of the population lacks wastewater management systems, this results in an overreliance on pit latrines, bucket toilets, and chemical toilets **(Street *et al*., 2020)**. The situation is much worse in case ground or surface water sources are present close to these toilets, which eases the cross-contamination to happen. Despite all the fatal effects and disease outbreaks caused by these problems and the fragile management of the sewage systems; it's not yet reported that SARS-CoV-2 may be transmitted through the fecal-oral route **(Sunkari *et al*., 2021)**. **Nhamo *et al*., (2019)** indicated, using a composite index method, that SDGs targets are far from being reached in Africa by the year 2030 depending on three important determinants; the proportion of the population using well-managed drinking facilities, the proportion using secured sanitation amenities, and the level of water stress. These results showed that all the African countries are at various levels of accomplishing the SDGs goals whereas a great percentage are in a declining state of water, sanitation, and hygiene (WASH) **(Nhamo *et al*., 2019)**.

Many routes and methods can indirectly lead SARS-CoV-2 to be transmitted in the water systems. For example, discharging wastewater from hospitals, quarantine houses, and isolation centers **(Wang *et al*., 2020b)**. In some cases, this contaminated water is directly released into groundwater and surface water without proper treatment; consequently, these water sources serve as a potential route for Covid-19 **(Sunkari *et al*., 2021)**. The domestic water supply's reliance on surface water makes the situation much riskier especially if this wastewater contains SARS-CoV-2 fragments the causative virus of Covid-19 **(Sunkari *et al*., 2021)**. Likewise, Groundwater can also be a route for SARS-CoV-2 in case some of the contaminated water that includes the virus fragments is introduced to the aquifer or the reservoir. There is a majority of waterborne diseases that are related to groundwater specific, such as rotavirus, hepatitis A and E viruses, astrovirus, enteric adenovirus, and caliciviruses (norovirus and Sapporo virus) **(Sunkari *et al*., 2021)**. This mentioned accumulation of disease has many fatal consequences like paralysis, encephalitis, myocarditis, gastroenteritis, diarrhea, hepatitis, insulin-independent diabetes, aseptic meningitis, and conjunctivitis **(Fong and lipp, 2005; Gerba, 2009)**. This clarifies that most disease outbreaks happen because of wells used in industrial and domestic practices **(Borchardt *et al*., 2003, Fong *et al*., 2007**). Groundwater microbial state is not continuously monitored which requires much concern to improve the water quality **(Sunkari *et al*., 2021)**. Up till now, the transmission of

SARS-CoV-2 through drinking water has not been proved **(Sunkari *et al*., 2021)**. However, **Sbaoui *et al*. (2021)** documented that caliciviruses, rotaviruses, adenoviruses, astroviruses, and coronaviruses can also use the enteric tract as a course of passage to the human, animal, or avian host. Consequently, these viruses could be detected in drinking water in case a failure in treatment processes happens.

5. SARS CoV-2 in wastewater persistence and elimination:

The survival period of the virus in groundwater is not clear yet; however, few researchers suggested that it can survive in groundwater for weeks **(Gundy *et al*., 2009)**. On the fact that SARS-CoV-2 can be transmitted to groundwater through the stool, due to cross-contamination **(lai *et al*., 2005)**. In general, the organic matter in the patients' stool can protect the virus from the disinfection process **(Zhang *et al*., 2020)**. Recently, some authors reported that coronavirus can survive a longer duration in the primary water than in the secondary water; for instance, it can survive 11 days in the primary water and only 6 days in the second one **(Tran *et al*., 2021)**. **Chin *et al*. (2020)**, investigated the survival state of the virus under various environmental conditions and found that SARS-CoV-2 is extremely stable at pH ranges from 3 to 10 at room temperature. On the whole, the duration in which the virus can survive in water is strongly dependent on the water properties, pH level, and organic matter present in this water. Temperature is a principal factor in the virus disinfection process; hence it's widely used in the food industry. Recent studies proved that SARS-CoV-2 tend to survive in low temperature, 14 days at 4 ℃ and 2 days at 25 ℃. In contrast, it was analyzed that total inactivation of SARS-CoV and SARS-CoV-2 was achieved at 56 ℃ for 30 and 90 minutes respectively. Recent researchers analyzed whether SARS-CoV-2 can exist in the wastewater after the disinfection process or not, stating that there isn't any available evidence of any fragments of the virus present in both drinking water and wastewater after the disinfection process **(WHO 2020b)**. This assumption is also consistent with the recent study by **Sherchan *et al*. (2020)**. Also, the United States environmental protection agency reported that after the disinfection process there wasn't any available evidence for SARS-CoV-2 in drinking water supplies **(USEPA, 2020)**. However, **Sbaoui *et al*. (2021)** proposed that inactivation and control of pathogens trials do not ensure 100 % removal of the virus. SARS-CoV-2 genetic material can be inactivated and destroyed using the following devices: gravity-based ultrafilter, zero-valent iron filter, iron-oxide bio-sand filter, nitrocellulose-based filter, and many more **(Bradley *et al*., 2011; Shi *et al*., 2012; Chaidez *et al*., 2016; Mautner 2020)**. Furthermore, Ultraviolet (UV) disinfection, chlorination, ozonation, and sodium hypochlorite are found to be successful techniques for eliminating the virus from water systems **(La Rosa *et al*., 2020; Quevedo-león *et al*., 2020; Wang *et al*., 2020c)**.

6. Regular remedial measures of SARS-CoV-2 transmission in African water systems

6.1. Improved hygienic, sanitation services and public awareness

WASH is currently in critical condition due to poor sanitation systems and improper sewage disposal **(Sunkari *et al*., 2021)**. These poor WASH conditions are considered one of the routes to the transmission of the Covid-19 pandemic in Africa. Generally, the unhygienic conditions, and inadequate sanitary and sewage systems cause a lot of disease outbreaks. It was reported that WASH-related diseases have caused about 829,000 deaths annually worldwide **(Prüss-Ustün *et al*., 2019)**. Even so, the death mortality in Africa was four times the mentioned number due to the same reason, WASH-related disease **(Sunkari *et al*., 2021)**. The best solution for this dilemma is to provide households with sufficient funds for better WASH facilities and proper sanitation systems. In addition, encouraging WASH-related activities and public awareness campaigns to improve people's behaviors and widen their thinking about adequate personal protective equipment (PPE) disposal and hygiene tips would also be a good solution. Improper disposal of PPE can also be one of the routes to the transmission of the virus **(Kumar *et al*., 2020b)**. The intensive use of face masks in African countries is an indicator of a dramatic problem since the proper disposal of these masks is being neglected **(Nzediegwu and Chang, 2020)**. The increasing production of face masks adds a lot to the existing concern resulting in a potential impact on the water and air quality. Multiple guidelines and various recommendations have been announced by the World Health Organization (WHO), the US Centers for Disease Control and Prevention, the National Centers for Disease Control, and even the media about the proper discharge of PPE related to Covid-19 **(Sangkham, 2020)**. However, a lot of face masks were found littered in the streets, public places, roads, gardens, hospitals, and beaches in Piura, Ancash, La Libertad, and Lima Regions **(Fig. 1) (Torres and De-la-Torre, 2021)**. The failure of the adequate disposal of these masks may ease them to become one of the transmission routes of SARS-CoV-2 instead of being a preventive tool for the virus spread. Also, mismanagement of face masks and PPE waste would result in a negative impact on people like health workers, sanitary workers, animals, and crops **(Mejjad, 2021)**.

Moreover, the method of using the face masks and their incorrect removal could higher the risk of transmission. From 28 October 2014 to 31 March 2015 a study was conducted to address the risk of contamination on skin and clothing; it was found that the risk is especially high during the removal of the PPE **(Tomas *et al*., 2015)**. This clarifies that the improper removal of face masks higher the risk of infection especially if they are in close contact with infected patients. In consequence, discarding this PPE waste and using face masks in an open bin is dangerous to the environment and it results in transmitting the virus to sanitary workers and stray animals **(Chin *et al*., 2020)**. **Chin *et al*. (2020)** stated that the persistence duration of the virus on the surface of the surgical mask is 7 days. The presented risk is still in increase with the increasing number of face masks sustainably generated as a measure for SARS-CoV-2 control. For instance, mask production in China reached 468.9 tons per day **(Peng *et al*., 2020)**. These solid medical wastes are harmful because they may involve any substance suspected of containing a pathogen (bacteria, virus, parasite, or fungus) in sufficient concentration or amount to cause disease in a susceptible host **(Sangkham, 2020)**. The case is much worse in developing countries such as Cambodia, Philippines, Thailand, India, Malaysia, Indonesia, Bangladesh, Vietnam, and Palestine which are widely known to dump solid waste in poorly managed and open landfills **(Ferronato and Torreta, 2019)**. Hence, one of the many problems that will inevitably occur is contagious waste, which, if not overseen legitimately, may stay the root cause of severe infections and environmental problems.

Fig. 1. Face masks discarded in the streets and beaches of Piura, La Libertad, and Lima regions **(Torres and De-la-Torre, 2021)**.

6.2. Improving management of wastewater treatment facilities

Africa is in big need of managed wastewater treatment facilities. Wastewater is not treated above the secondary stage in the majority of African countries **(Adewumi and Oguntuase, 2016)**. Thus, the risk related to the existence of SARS-CoV-2 in surface water makes people vulnerable to the virus. In most African countries there is a huge amount of wastewater being directly released into surface water without previous treatment which is unacceptable. As mentioned before, Ghana is a good example of this practice; the discharge of raw sewage in surface water resources seriously calls for an investigation. The various effects of this practice on public health are dramatically fatal. **Adelodun *et al*. (2020)** reported that sewage from hospitals and quarantine centers used to treat suspected and confirmed patients with covid-19 is common in the sewage of communities and cities. They suggested that the best solution for this problem is to separate the sewage system and wastewater treatment facilities of healthcare centers from urban systems to ensure viral removal during disinfection **(Adelodun *et al*., 2020)**. Peracetic acid (blended with ethanol), chlorine disinfectant (trichloroisocyanuric acid, blended with ethylene glycol) with two concentrations, and quaternary ammonium salt (DNC, blended with ethanol) can inactivate SARS-CoV-2 on the cold chain's surface. The RNA of SARS-CoV-2 remained detectable in 2–3 h disinfection, even if disinfectants fully inactivated the virus in 5 min **(Wu *et al*., 2022)**. **Gautret and co-workers (2020)** suggested that public spitting in China may have played a significant role in encouraging the transmission of SARS-CoV-2. However, this bad custom is very frequent in a lot of developing countries.

CONCLUSION

Poor sanitation systems and improper sewage disposal in developing countries may play an effective role in the frequency of SARS-CoV 2, however, till now, there is no confirmation about the direct role of food and water in viral transmission by the fecal-oral route. Africa as a model for developing countries is in a big need of managed wastewater treatment facilities efficiently and on the other hand, separating the sewage system and wastewater treatment facilities of healthcare centres treat on-site before discharging. Also, efficient methods of getting rid of or recycling the used face masks must be developed. Additionally, getting rid of bad customs like public spitting must be done.

REFERENCES

Adams, E.A.; Sambu, D. and Smileym, S.L. (2019). Urban water supply in Sub-Saharan Africa: historical and emerging policies and institutional arrangements. Int. J. Water Resour. Dev., 35(2): 240–263. https://doi.org/10.1080/07900627.2017.1423282

Adelodun, B.; Odedishemi, F.; Gbemisola, R.; Olalekan, H. and Choi, K. (2020). Snowballing transmission of COVID-19 (SARS-CoV-2) through wastewater: any sustainable preventive measures to curtail the scourge in low-income countries? Sci. Tot. Environ., 742: 140680. https://doi.org/10.1016/j.scitotenv.2020.140680

Adesogan, S. (2013). Sewage technology in Nigeria: a pragmatic approach. Sci. J. Environ. Eng. Res., 1–9. https://doi.org/10.7237/sjeer/266

Adewumi, J.R. and Oguntuase, A.M. (2016). Planning of wastewater reuse programme in Nigeria. J. Sustain. Dev., 15 (1): 1–33. https://doi.org/10.7916/consilience.v0i15.4666

Africa Centres for Disease Control and Prevention COVID-19 dashboard. (2020). https://africacdc.org/covid-19

Afzal, M.; Arslan, M.; Müller, J.A.; Shabir, G.; Islam, E.; Tahseen, R.M.; Anwar-ul-Haq, M.; Hashmat, A. J.; Iqbal, S. and M. Khan, Q. M. (2019). Floating treatment wetlands as a suitable option for large-scale wastewater treatment. Nat. Sustain., 2(9): 863–871. https://doi.org/10.1038/s41893-019-0350-y

Ahmed, W.; Angel, N.; Edson, J.; Bibby, K..; Bivins, A.; Brien, J.W.O.; Choi, P.M.; Kitajima; M. Simpson; S.L.; Li, J.; Tscharke, B.; Verhagen, R.; Smithg, W.J.M.; Zaugg, J.; Dierens, L.; Hugenholtz, P.; Thomas, K.V. and Mueller, J. F. (2020). First confirmed detection of SARS-CoV-2 in untreated wastewater in Australia: a proof of concept for the wastewater surveillance of COVID-19 in the community. Sci. Total. Environ., 728(138764): 1–8. https://doi.org/10.1016/j.scitotenv.2020.138764

Albastaki, A.; Naji, M.; Lootah, R.; Almeheiri, R.; Almulla, H., Almarri, I.; Alreyami, A.; Aden, A. and Alghafri, R. (2020). First confirmed detection of SARS-COV-2 in untreated municipal and aircraft wastewater in Dubai, UAE: the use of wastewater based epidemiology as an early warning tool to monitor the prevalence of COVID-19. Sci. Total. Environ., 760: 143350. https://doi.org/10.1016/j.scitotenv.2020.143350

Appiah-Effah, E.; Duku, G.A.; Azangbego, N.Y.; Aggrey, R.K.A.; Gyapong-Korsah, B. and Nyarko, K.B. (2019). Ghana’s Post-MDGs Sanitation Situation: An Overview. J. Water Sanit. Hyg. Dev., 9: 397–415. https://doi.org/10.2166/washdev.2019.031

Arslan, M.; Xu, B.; El-Din, M.G. (2020). Transmission of SARS-CoV-2 via fecal-oral and aerosols–borne routes: environmental dynamics and implications for wastewater management in underprivileged societies. Sci. Total. Environ., 743: 140709. https://doi.org/10.1016/j.scitotenv.2020.140709

Azizullah, A.; Khattak, M.N.K..; Richter, P. and Häder, D.P. (2011). Water pollution in Pakistan and its impact on public health—a review. Environ. Int., 37(2): 479–497. https://doi.org/10.1016/j.envint.2010.10.007

Bao, C.; Pan, E.; Ai, J.; Dai, Q.; Xu, K.; Shi, N.; Gao, Q.; Hu, J.; Peng, Z.; Huang, H.; Jin, H. and Zhu, F. (2020). COVID-19 outbreak following a single patient exposure at an entertainment site: an epidemiological study. Transbound. Emerg. Dis., 68: 773–781. https://doi.org/10.1111/tbed.13742

Barcelo, D. (2020). An environmental and health perspective for COVID-19 outbreak: meteorology and air quality influence, sewage epidemiology indicator, hospitals disinfection, drug therapies and recommendations. J. Environ. Chem. Eng., 8(4): 104006. https://doi.org/10.1016/j.jece.2020.104006

Bhowmick, G.D.; Dhar, D.; Nath, D.; Ghangrekar, M.M.; Banerjee, R., Das, S. and Chatterjee, J. (2019). Coronavirus disease 2019 (COVID-19) outbreak: some serious consequences with urban and rural water cycle. NPJ. Clean. Water, 3(32): 1–8. https://doi.org/10.1038/s41545-020-0079-1

Bisseux, M.; Colombet, J.; Mirand, A.; Roque-Afonso, A.M.; Abravanel, F.; Izopet, J.; Archimbaud, C.; Peigue-Lafeuille, H.; Debroas, D.; Bailly, J. and Henquell, C. (2018) Monitoring human enteric viruses in wastewater and relevance to infections encountered in the clinical setting: a one-year experiment in Central France, 2014 to 2015. Euro. Surveill., 23(7): 1–11. https://doi.org/10.2807/1560-7917.ES.2018.23.7.17-00237

Borchardt, M.A.; Bertz, P.D.; Spencer, S.K. and Battigelli, D.A. (2003). Incidence of enteric viruses in groundwater from household wells in Wisconsin. Appl. Environ. Microbiol. 69(2): 1172–1180. https://doi.org/10.1128/AEM.69.2.1172-1180.2003

Bradley, I.; Straub, A.; Maraccini, P.; Markazi, S. and Nguyen, T.H. (2011). Iron oxide amended biosand filters for virus removal. Water Res., 45: 4501–4510. https://doi.org/10.1016/j.watres.2011.05.045

Brijen, M.; Xavier, F.; John, N.; Anna, M. and Irene, X. (2020). SARS-CoV-2 in Detroit wastewater. J. Environ. Eng., 146(11): 6020004-1–6020004-6. https://doi.org/10.1061/(ASCE)EE.1943-7870.0001830

Carraturo, F.; Del Giudice, C.; Morelli, M.; Cerullo, V.; Libralato, G.; Galdiero, E. and Guida, M. (2020) Persistence of SARS-CoV-2 in the environment and COVID-19 transmission risk from environmental matrices and surfaces. Environ. Pollut., 265: 115010. https://doi.org/10.1016/j.envpol.2020.115010

CCDC. (2020). Notes from the field: reemergent cases of COVID-19—Xinfadi Wholesales Market, Beijing municipality, China, June 11, 2020. http://weekly.chinacdc.cn/ en/article/doi/10.46234/ccdcw2020.132. Accessed 2 September 2020

CDC. (2020). Food and coronavirus disease 2019 (COVID-19). https://www.cdc. gov/coronavirus/2019-ncov/daily-life-coping/food-and-COVID-19.html. Accessed 2 September 2020

Ceylan, Z.; Meral, R. and Cetinkaya, T. (2020). Relevance of SARS-CoV-2 in food safety and food hygiene: potential preventive measures, suggestions and nanotechnological approaches. VirusDis., 31(2): 154–160. https://doi.org/10.1007/s13337-020-00611-0

Chaidez, C.; Ibarra-Rodríguez, J. R.; Valdez-Torres, J.B.; Soto, M.; Gerba, C.P. and Castro-del Campo, N. (2016) Point-of-use unit based on gravity ultrafiltration removes waterborne gastrointestinal pathogens from untreated water sources in rural communities. Wilderness. Environ. Med., 27: 379–385. https://doi.org/10.1016/j.wem.2016.05.006

Chan-Yeung, M. and Xu, R.H. (2003). SARS: epidemiology. Respirology, 8: S9–S14. https://doi.org/10.1046/j.1440-1843.2003.00518.x

Chen, Y.; Liu, Q. and Guo, D. (2020) Emerging coronaviruses: Genome structure, replication, and pathogenesis. J. Med. Virol., 92(4): 418–423. https://doi.org/10.1002/jmv.25681

Chin, A.W.H.; Chu, J.T.S.' Perera, M.R.A.; Hui, K.P.Y.; Yen, H.L.; Chan, M.C.W.; Malik Peiris, M. and Leo L M Poon, L.L.M. (2020). Stability of SARS-CoV-2 in different environmental conditions. Lancet Microbe 1: e10. https://doi.org/10. 1016/S2666-5247(20)30003-3

China Daily. (2020). Editorial: Beijing's quick lockdown of market vicinity shows no quarter will be given to virus. https://www.chinadaily.com.cn/a/202006/13/WS5ee4e567a 310834817252d5d. html. Accessed 2 September 2020

AVMA. (2020). Coronavirus: Detailed taxonomy. https://www.avma.org/sites/default/ files/2020-02/AVMA-Detailed-Coronoavirus-Taxonomy-2020-02-03.pdf. Accessed 3 February 2020

BBC News. (2021). Covid map: Coronavirus cases, deaths, vaccinations by country https://www.bbc.com/news/world-51235105. Accessed 21 September 2021

Dada, A.C. and Gyawali, P. (2020). Quantitative microbial risk assessment (QMRA) of occupational exposure to SARS-CoV-2 in wastewater treatment plants. Sci. Total. Environ., 763: 142989. https://doi.org/10.1016/j.scitotenv.2020.142989

D'Aoust, P.M.; Mercier, E.; Montpetit, D.; Jia, J.J.; Alexandrov, I. and Neault, N. (2021). Quantitative analysis of SARS-CoV-2 RNA from wastewater solids in communities with low COVID-19 incidence and prevalence. Water Res 188: 116560. https://doi.org/10.1016/j.watres.2020.116560

de Groot, R.J.; Baker, S.C.; Baric, R.; Enjuanes, L.; Gorbalenya, A.E.; Holmes, K.V.; Baig, A.T.; Mayne, J.; Zhang, X.; Alain, T., Langlois, M.; Servos, M. R.; MacKenzie, M.; Figeys; D.; MacKenzie, A.; Tyson E Graber, T.E. and Delatolla, R. (2012). Family Coronaviridae. In: " Virus taxonomy: ninth report of the International Committee on Taxonomy of Viruses." King, A.M.; Lefkowitz, E.; Adams, M.J.; Carstens, E.B. & International Committee on Taxonomy of Viruses & International Union of Microbiological Societies (Eds.). Elsevier Academic Press, San Diego, CA, pp. 806–828. https://doi.org/10.1016/B978-0-12-384684-6.00068-9

Decaro, N. (2011). Alphacoronavirus. In: " The springer index of viruses " Tidona, C. & Darai, G. (Eds.). Springer, New York, pp. 371–383. https://doi.org/10.1007/978-0-387-95919-1_56

Dos Santos, S.; Adams, E. A.; Neville, G.; Wada, Y.; De Sherbinin, A.; Bernhardt, E.M.; and Adamo, S.B. (2017). Urban growth and water access in Sub-Saharan Africa: progress, challenges, and emerging research directions. Sci. Total Environ., 607: 497–508. https://doi.org/10.1016/j.scitotenv.2017.06.157

Drosten, C.; Seilmaier, M.; Corman, V.M,; Hartmann, W.; Scheible, G.; Sack, S.; Guggemos, W.; Kallies, R.; Muth, D.; Junglen, S.; Müller, M.A.; Haas, W.; Guberina, H.; Röhnisch, T.; Schmid-Wendtner, M.; Aldabbagh, S.; Dittmer, U.; Gold, H.; Graf, P.; Bonin, F.; Rambaut, A. and Wendtner, C. (2013). Clinical features and virological analysis of a case of Middle East respiratory syndrome coronavirus infection. Lancet Infect Dis 13: 745–751. https://doi.org/10.1016/S1473-3099(13)70154-3

El-Senousy, W.M.; Abu Senna, A.S.M.; Mohsen, N.A.; Hasan, S.F. and Sidkey, N.M. (2020). Clinical and environmental surveillance of rotavirus common genotypes showed high prevalence of common P genotypes in Egypt. Food Environ. Virol., 12(2): 99–117. https://doi.org/10.1007/s12560-020-09426-0

El-Senousy, W.M. and Shouman, M. (2021). Human coronavirus NL63 among other respiratory viruses in clinical specimens of Egyptian children and raw sewage samples. Food Environ. Virol., 13: 322–328. https://doi.org/10.1007/s12560-021-09479-9.

FDA. (2020). Food safety and the coronavirus disease 2019 (COVID-19). https://www.fda.gov/food/food-safety-during-emergencies/food-safety-and-coronavirus-disease-2019-covid-19. Accessed 2 September 2020

Ferronato, N. and Torretta, V. (2019). Waste mismanagement in developing countries: a review of global issues. Int. J. Environ. Res. Public Health, 16: 1060. https://doi.org/10.3390/ijerph16061060

Fong, T.T. and Lipp, E.K. (2005). Enteric viruses of humans and animals in aquatic environments: health risks, detection, and potential water quality assessment tools. Microbiol Mol. Biol. Rev., 69(2): 357–371. https://doi.org/10.1128/MMBR.69.2.357-371.2005

Fong, T.T. Mansfield, L.S.; Wilson, D.L.; Schwab, D.J.; Molloy, S.L. and Rose, J.B. (2007). Massive microbiological groundwater contamination associated with a waterborne outbreak in Lake Erie, South Bass Island, Ohio. Environ. Health Perspect., 115(6): 856–864. https://doi.org/10.1289/ehp.9430

FSS. (2020). Coronavirus (COVID-19) and food, coronavirus questions and answers. https://www.foodstandards.gov.scot/consumers/food-safety/coronavirus/questions-and-answers-covid-19. Accessed 2 September 2020

Gallardo-Escárate, C.; Valenzuela-Muñoz, V.; Núñez-Acuña, G.; Valenzuela-Miranda, D.; Benaventel, B.P.; Sáez-Vera, C.; Urrutia, H.; Novoa; B.; Figueras, A.; Roberts, S.; Assmann, P. and Bravo, M. (2020). The wastewater microbiome: a novel insight for COVID-19 surveillance. Sci. Total. Environ., 764: 142867. https://doi.org/10.1016/j.scitotenv.2020.142867

Gandhi, M.; Yokoe, D.S. and Havlir, D.V. (2020). Asymptomatic transmission, the Achilles' heel of current strategies to control Covid-19. N. Eng. J. Med., 382: 2158–2160. https://doi.org/10.1056/NEJMe2009758

Gautret, P.; Colson, P.; Lagier, J.C.; Parola, P. and Raoult, D. (2020). Does spitting in public play a role in transmitting SARS-CoV-2? Travel. Med. Infect. Dis., 36: 101759. https://doi.org/10.1016/j.tmaid.2020.101759

Gerba, C.P. (2009). Environmentally transmitted pathogens. In: " Environmental Microbiology."Maier, R.M.; Pepper, I.L. & Gerba C. P. (Eds.). Academic Press, Elsevier, New York, pp. 445–484. https://doi.org/10.1016/B978-0-12-370519-8.00022-5

Gonçalves, J.; Koritnik, T.; Mioč, V.; Trkov, M.; Bolješič, M.; Berginc, N.; Prosenc, K.; Kotar, T. and Paragi, M. (2020). Detection of SARS-CoV-2 RNA in hospital wastewater from a low COVID-19 disease prevalence area. Sci. Total. Environ., 755: 143226. https://doi.org/10.1016/j.scitotenv.2020.143226

Gonzalez, R.; Curtis, K.; Bivins, A.; Bibby, K.; Weir, M.H.; Yetka, K.; Thompson, H.; Keeling, D.; Mitchell, J. and Gonzalez, D. (2020) COVID-19 surveillance in Southeastern Virginia using wastewater-based epidemiology. Water Res., 186: 116296. https://doi.org/10.1016/j.watres.2020.116296

Gundy, P.M.; Gerba, C.P. and Pepper, I.L. (2009). Survival of coronaviruses in water and wastewater. Food Environ. Virol., 1(1): 10. https://doi.org/10.1007/s12560-008-9001-6

Han, M.S., Seong, M.W.; Heo, E.Y.; Park, J.H.; Kim, N.; Shin, S.; Cho, S.I.; Park, S.S. and Choi, E.H. (2020). Sequential analysis of viral load in a neonate and her mother infected with severe acute respiratory syndrome coronavirus 2. Clin Infect Dis 71 (16): 2236–2239. https://doi.org/10.1093/cid/ciaa447

Hart, O.E. and Halden, R.U. (2020). Computational analysis of SARS-CoV-2/COVID-19 surveillance by wastewater-based epidemiology locally and globally: feasibility, economy, opportunities and challenges. Sci. Total. Environ., 730: 138875. https://doi.org/10.1016/j.scitotenv.2020.138875

Hasan, S.W.; Ibrahim, Y.; Daou, M.; Kannout, H.; Jan, N. and Lopes, A. (2020) Detection and quantification of SARS-CoV-2 RNA in wastewater and treated effluents: surveillance of COVID-19 epidemic in the United Arab Emirates. Sci. Total. Environ., 764: 142929. https://doi.org/10.1016/j.scitotenv.2020.142929

Heller, L.; Mota, C.R. and Greco, D.B. (2020). COVID-19 faecal-oral transmission: are we asking the right questions? Sci. Total. Environ., 729: 138919. https://doi.org/10.1016/j.scitotenv.2020.138919

Holshue, M.L.; DeBolt, C.; Lindquist, S.; Lofy, K.H.; Wiesman, J.; Bruce, H.; Spitters.; C.; Ericson, K.; Wilkerson, S.; Tural, A.; Diaz, G.; Cohn, A.; Fox, L.; Patel, A.; Gerber, S.I.; Kim, L.; Tong, S.; Lu, X.; Lindstrom, S.; Pallansch, M.A.; Weldon, W.C.; Biggs, H.M.; Uyeki, T.M.; Pillai, S.K. and Washington State 2019-nCoV Case Investigation Team. (2020) First case of 2019 novel coronavirus in the United States. N. Eng. J. Med., 382: 929–936. https://doi.org/10.1056/NEJMoa2001191

Hussain, S.; Pan, J.; Chen, Y.; Yang, Y.; Xu, J, Peng, Y.; Wu, Y.; Li, Z.; Zhu, Y.; Tien, P. and Guo, D. (2005). Identification of novel subgenomic RNAs and noncanonical transcription initiation signals of severe acute respiratory syndrome coronavirus. J Virol 79(9): 5288–5295. https://doi.org/10.1128/JVI.79.9.5288-5295.2005

Johansson, M.A.; Vasconcelos, P.F.C. and Staples, J.E. (2014). The whole iceberg: estimating the incidence of yellow fever virus infection from the number of severe cases. Trans. R. Soc. Trop. Med. Hyg., 108 (8): 482–487. https://doi.org/10.1093/trstmh/tru092

Jones, S. and Yan, H. (2020). Hundreds of people celebrated the July 4 weekend at a Michigan lake. Now some have Covid-19. CNN health.

Kujawski, S.A.; Wong, K.K.; Collins, J.P.; Epstein, L.; Killerby, M.E.; Midgley, C.M.; Abedi, G.R.; Ahmed, N.S.; Almendares, O.; Alvarez, F.N.; Anderson, K.N.; Balter, S.; Barry, V.; Bartlett, K.; Beer, K.; Ben-Aderet, M.A.; Benowitz, I.; Biggs, H.M.; Binder, A.M.; Black, S.R.; Bonin, B.; Bozio, C.H.; Brown, C.M.; Bruce, H.; Bryant-Genevier J.; Budd, A.; Buell, D.; Bystritsky, R.; Cates, J.; Charles, E.M.; Chatham-Stephens, K.; Chea, N.; Chiou, H.; Christiansen, D.; Chu, V.; Cody, S.; Cohen, M.; Conners, E.E.; Curns, A.T.; Dasari, V.; Dawson, P.; DeSalvo, T.; Diaz, G.; Donahue, M.; Donovan, S.; Duca, L.M.; Erickson, K.; Esona, M.D.; Evans, S.; Falk, J.; Feldstein, L.R.; Fenstersheib, M.; Fischer, M.; Fisher, R.; Foo, C.; Fricchione, M.J.; Friedman, O.; Fry, A.; Galang, R.R.; Garcia, M.M.; Gerber, S.I.; Gerrard, G.; Ghinai, I.; Gounder, P.; Grein, J.; Grigg, C.; Gunzenhauser, J.D.; Gutkin, G.I.; Haddix, M.; Hall, A.J.; Han, G.S.; Harcourt, J.; Harriman, K.; Haupt, T.; Haynes, A.K.; Holshue, M.; Hoover, C.; Hunter, J.C.; Jacobs, M.W.; Jarashow, C.; Joshi, K.; Kamali, T.; Kamili, S.; Kim, L.; Kim, M.; King, J.; Kirking, H.L.; Kita-Yarbro, A.; Klos, R.; Kobayashi, M.; Kocharian, A.; Komatsu, K.K.; Koppaka, R.; Layden, J.E.; Li, Y.; Lindquist, S.; Lindstrom, S.; Link-Gelles, R.; Lively, J.; Livingston, M.; Lo, K.; Lo, J.; Lu, X.; Lynch, B.; Madoff, L.; Malapati, L.; Marks, G.; Marlow, M.; Mathisen, G.E.; McClung, N.; McGovern, O.; McPherson, T.D.; Mehta, M.; Meier, A.; Mello, L.; Moon, S.; Morgan, M.; Moro, R.N.; Murray, J.; Murthy, R.; Novosad, S.; Oliver, S.E.; O'Shea, J.; Pacilli, M.; Paden, C.R.; Pallansch, M.A.; Patel, M.; Patel, S.; Pedraza, I.; Pillai, S.K.; Pindyck, T.; Pray, I.; Queen, K.; Quick, N.; Reese, H.; Reporter, R.; Rha, B.; Rhodes, H.; Robinson, S.; Robinson, P.; Rolfes, M.A.; Routh, J.A.; Rubin, R.; Rudman, S.L.; Sakthivel, S.K.; Scott, S.; Shepherd, C.; Shetty, V.; Smith, E.A.; Smith, S.; Stierman, B.; Stoecker, W.; Sunenshine, R.; Sy-Santos, R.; Tamin, A.; Tao, Y.; Terashita, D.; Thornburg, N.J.; Tong, S.; Traub, E.; Tural, A.; Uehara, A.; Uyeki, T.M.; Vahey, G.; Verani, J.R.; Villarino, E.; Wallace, M.; Wang, L.; Watson, J.T.; Westercamp, M.; Whitaker, B.; Wilkerson, S.; Woodruff, R.C.; Wortham, J.M.; Wu, T.; Xie, A.; Yousaf, A.; Zahn, M. and Zhang, J. (2020). Covid-19 investigation team clinical and virologic characteristics of the first 12 patients with coronavirus disease 2019 (COVID-19) in the United States. Nat. Med., 26: 861–868. https://doi.org/10.1038/s41591-020-0877-5

Kumar, M.; Patel, A.K.; Shah, A.V.; Raval, J.; Rajpara, N.; Joshi, M. and Joshi, C.G. (2020a). 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. https://doi.org/10.1016/j.scitotenv.2020.141326

Kumar, V.; Kumar, P.; Singh, J. and Kumar, P. (2020b). Current status of water pollution by integrated industrial hubs (IIHs) in India. In: "Environmental degradation: causes and remediation strategies." Kumar, V. & Singh, J. (Eds.). Agriculture and Environmental Science Academy, Haridwar, India, pp. 104–119. https://doi.org/10.26832/aesa-2020-edcrs-0

La Rosa, G.; Bonadonna, L.; Lucentini, L.; Kenmoe, S. and Suffredini, E. (2020). Coronavirus in water environments: occurrence, persistence and concentration methods - a scoping review. Water Res., 179: 115899. https://doi.org/10.1016/j.watres.2020.115899

La Rosa, G.; Della Libera, S, Iaconelli, M.; Ciccaglione, A.R.; Bruni, R., Taffon, S.; Equestre, M.; Alfonsi, V.; Rizzo, C.; Tosti, M.E.; Chironna, M.; Romanò, L.; Alessandro Remo Zanetti, A.R. and Muscillo, M. (2014). Surveillance of hepatitis A virus in urban sewages and comparison with cases notified in the course of an outbreak, Italy 2013. BMC. Infect. Dis., 14(419): 1–11. https://doi.org/10.1186/1471-2334-14-419

La Rosa, G. and Muscillo, M. (2013). Molecular detection of viruses in water and sewage. In: " Viruses in food and water: risks, surveillance and control." Cook, N. (Ed.). Woodhead Publishing Limited, Cambridge, UK, pp. 97–125. https://doi.org/10.1533/9780857098870.2.97

La Rosa, G.; Mancini, P.; Bonanno Ferraro, G.; Veneri, C.; Iaconelli, M.; Bonadonna, L.; Lucentini, L. and Suffredini, E. (2021). SARS-CoV-2 has been circulating in northern Italy since December 2019: evidence from environmental monitoring. Sci. Total. Environ., 750: 141711. https://doi.org/10.1016/j.scitotenv.2020.141711

Lai, C.C.; Liu, Y.H.; Wang, C.Y.; Wang, Y.H.; Hsueh, S.C.; Yen, M.Y.; Ko, W. and Hsueh, P. (2020) Asymptomatic carrier state, acute respiratory disease, and pneumonia due to severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2): facts and myths. J. Microbiol. Immunol. Infect., 53(3): 404–412. https://doi.org/10.1016/j.jmii. 2020. 02.012

Lai, M.Y.Y.; Cheng, P.K.C. and Lim, W.W.L. (2005). Survival of severe acute respiratory syndrome coronavirus. Clin. Infect. Dis., 41(7): e67–e71. https://doi.org/10.1086/433186

Lescure, F.X.; Bouadma, L.; Nguyen, D.; Parisey, M.; Wicky, P.H.; Behillil, S.; Gaymard, A.; Bouscambert-Duchamp, M.; Donati, F.; Hingrat, Q.L.; Enouf, V.; Houhou-Fidouh, N.; Valette, M.; Mailles, A.; Lucet, J.; Mentre, F.; Duval, X.; Descamps, D.; Malvy, D.; Timsit, J.; Lina, B.; van-der-Werf, S. and Yazdanpana, Y. (2020). Clinical and virological data of the first cases of COVID-19 in Europe: a case series. Lancet Infect. Dis., 20(6): 697–706. https://doi.org/10.1016/S1473-3099(20)30200-0

Ling, Y.; Xu, S.; Lin, Y.; Tian, D.; Zhu, Z.; Dai, F.; Fan, W.; Zhi-Gang, S.; Wei, H.; Jun, C.; Bi-Jie, H.; Sheng, W.; En-Qiang, M.; Lei, Z.; Wen-Hong, Z. and Hong-Zhou, L. (2020). Persistence and clearance of viral RNA in 2019 novel coronavirus disease rehabilitation patients. Chin. Med. J., 133(9):1039–1043. https://doi.org/10.1097/CM9.0000000000000774

Lodder, W. and de Roda Husman, A.M. (2020). SARS-CoV-2 in wastewater: potential health risk, but also data source. Lancet Gastroenterol. Hepatol., 5(6): 533–534. https://doi.org/10.1016/j.scitotenv.2020.139076

Lodder, W.J.; Rutjes, S.A.; Takumi, K. and de Roda Husman, A.M. (2013). Aichi virus in sewage and surface water, the Netherlands. Emerg. Infect. Dis., 19(8): 1222–1230. https://doi.org/10.3201/eid1908.130312

Luo, C.; Yao, L.; Zhang, L.; Yao, M.; Chen, X.; Wang, Q. and Shen, H. (2020). Possible transmission of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) in a public bath center in Huai'an, Jiangsu Province, China. JAMA Netw. Open., 3(3): e204583. https://doi.org/10.1001/jamanetworkopen.2020.4583

Martin, J.; Klapsa, D.; Wilton, T.; Zambon, M.; Bentley, E.; Bujaki, E.; Fritzsche, M.; Mate, R. and Majumdar, M. (2020). Tracking SARS-CoV-2 in sewage: evidence of changes in virus variant predominance during COVID-19 pandemic. Viruses, 12: 1144. https://doi.org/10.3390/v12101144

Masters, P.S. (2006). The molecular biology of coronaviruses. Adv. Virus Res., 66: 193–292. https://doi.org/10.1016/S0065-3527(06)66005-3

Mautner, A. (2020). Nanocellulose water treatment membranes and filters: a review. Polym. Int. 69(9): 741–751. https://doi.org/10.1002/pi.5993

Medema, G.; Heijnen, L; Elsinga, G.; Italiaander, R. and Brouwer, A. (2020). Presence of SARS-Coronavirus-2 RNA in sewage and correlation with reported COVID-19 prevalence in the early stage of the epidemic in the Netherlands. Environ. Sci. Technol. Lett., 7(7): 511–516. https://doi.org/10.1021/acs.estlett.0c00357

Mejjad, N.; Cherif, E.K.; Rodero, A.; Krawczyk, D.A.; El Kharraz, J.; Moumen, A.; Laqbaqbi, M. and Ahmed Fekri, A. (2021). Disposal behavior of used masks during the COVID-19 pandemic in the Moroccan community: potential environmental impact. Int. J. Environ. Res. Public Health, 18: 4382. https://doi.org/10.3390/ijerph18084382

Michael-Kordatou, I.; Karaolia, P. and Fatta-Kassinos, D. (2020). Sewage analysis as a tool for the COVID-19 pandemic response and management: the urgent need for optimised protocols for SARS-CoV-2 detection and quantification. J. Environ. Chem. Eng., 8(5): 104306. https://doi.org/10.1016/j.jece.2020.104306

Mizumoto, K.; Kagaya, K.; Zarebski, A. and Chowell, G. (2020). Estimating the asymptomatic proportion of coronavirus disease 2019 (COVID-19) cases on board the Diamond Princess cruise ship, Yokohama, Japan, 2020. Euro. Surveill., 25(10): 1–5. https://doi.org/10.2807/1560-7917.ES.2020.25.10.2000180

Mlejnkova, H.; Sovova, K.; Vasickova, P.; Ocenaskova, V.; Jasikova, L. and Juranova, E. (2020). Preliminary study of SARS-CoV-2 occurrence in wastewater in the Czech Republic. Int. J. Environ. Res. Public Health, 17(15): 5508. https://doi.org/10.3390/ijerph17155508

Nabi, G.; Siddique, R. and Khan, S. (2020). Detecting viral outbreaks in future using enhanced environmental surveillance. Environ. Res., 188: 109731. https://doi.org/10.1016/j.envres.2020.109731

Nemudryi, A.; Nemudraia, A.; Wiegand, T.; Surya, K.; Buyukyoruk, M.; Cicha, C.; Vanderwood, K. K.; Royce Wilkinson, R. and Wiedenheft, B. (2020). Temporal detection and phylogenetic assessment of SARS-CoV-2 in municipal wastewater. Cell Rep. Med., 1(6): 1–6. https://doi.org/10.1016/j.xcrm.2020.100098

Nhamoa, G.; Nhemachena, C. and Nhamo, S. (2019). Is 2030 too soon for Africa to achieve the water and sanitation sustainable development goal? Sci. Total. Environ., 669: 129–139. https://doi.org/10.1016/j.scitotenv.2019.03.109

Nishiura, H.; Kobayashi, T.; Suzuki, A.; Jung, S.M.; Hayashi, K.; Kinoshita, R.; Kinoshita, R.; Yang, Y.; Yuan, B.; Akhmetzhanov, A. R. and Linton, N. M. (2020). Estimation of the asymptomatic ratio of novel coronavirus infections (COVID-19). Int. J. Infect. Dis., 94: 154–155. https://doi.org/10.1016/j.ijid.2020.03.020

Nomoto, H.; Ishikane, M.; Katagiri, D.; Kinoshita, N.; Nagashima, M.; Sadamasu, K.; Yoshimura, K. and Ohmagari, N. (2020). Cautious handling of urine from moderate to severe COVID-19 patients. Am. J. Infect. Control, 48(8): 969–971. https://doi.org/10.1016/j.ajic.2020.05.034

Nzediegwu, C. and Chang, S.X. (2020). Improper solid waste management increases potential for COVID-19 spread in developing countries. Resour. Conserv. Recycl., 161: 104947. https://doi.org/10.1016/j.resconrec.2020.104947

Omole, D.O.; Jim-George, T. and Akpan, V.E. (2019). Economic analysis of wastewater reuse in Covenant University. J. Phys. Conf. Ser., 1299(1): 12125. https://doi.org/10.1088/1742-6596/1299/1/012125

Peccia, J.; Zulli, A.; Brackney, D.E.; Grubaugh, N.D.; Kaplan, E.H.; Casanovas-Massana, A.; Ko, A.I.; Malik, A.A.; Wang, D.; Wang, M.; Warren, J.L.; Weinberger, D.M.; Arnold, W. and Omer, S.B. (2020). Measurement of SARS-CoV-2 RNA in wastewater tracks community infection dynamics. Nat. Biotechnol., 38: 1164–1167. https://doi.org/10.1038/s41587-020-0684-z

Pecson, B.; Gerrity, D.; Bibby, K.; Drewes, J.E.; Gerba, C.; Gersberg, R.; Gonzalez, R.; Haas, C.N.; Hamilton, K.A.; Nelson, K.L.; Olivieri, A.; Rock, C.; Rose, J. and Sobsey, M. (2020) Editorial perspectives: will SARS-CoV-2 reset public health requirements in the water industry? Integrating lessons of the past and emerging research. Environ Sci Water Res. Technol., 6: 1761–1764. https://doi.org/10.1039/D0EW90031A

Peeri, N.C.; Shrestha, N.; Rahman, M.S.; Zaki, R.; Tan, Z.; Bibi, S.; Baghbanzadeh, M.; Aghamohammadi, N.; Zhang, W. and Haque, U. (2020). The SARS, MERS and novel coronavirus (COVID-19) epidemics, the newest and biggest global health threats: What lessons have we learned? Int. J. Epidemiol., 49(3): 717–726. https://doi.org/10.1093/ije/dyaa033

Peng, J.; Wu, X.; Wang, R.; Li, C.; Zhang, Q. and Wei, D. (2020). Medical waste management practice during the 2019-2020 novel coronavirus pandemic: Experience in a general hospital. Am. J. Infect. Control, 48(8): 918–921. https://doi.org/10.1016/j.ajic.2020.05.035

Prado, T.; Fumian, T.M.; Mannarino, C.F.; Maranhão, A.G.; Siqueira, M.M. and Miagostovich, M.P. (2020). Preliminary results of SARS-CoV-2 detection in sewerage system in Niterói municipality, Rio de Janeiro, Brazil. Mem. Inst. Oswaldo. Cruz., 115: e200196. https://doi.org/10.1590/0074-02760200196

Prüss-Ustün, A.; Wolf, J.; Bartram, J.; Clasen, T.; Cumming, O.; Freeman, M.C.; Gordon, B.; Hunter, P.R.; Medlicott, K.; Johnston, R. (2019). Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: An updated analysis with a focus on low- and middle-income countries. Int. J. Hyg. Environ. Health, 222(5): 765–777. https://doi:10.1016/j.ijheh.2019.05.004

Qi, R.; Huang Y.; Liu J.W.; Sun, Y.; Sun X.; Han, H.J.; Qin, X.; Zhao, M.; Wang, L.; Li, W.; Li, J.; Chen, C. and Yu, X. (2018). Global prevalence of asymptomatic norovirus infection: a meta-analysis. EClinicalMedicine 2: 50–58. https://doi.org/10.1016/j.eclinm.2018.09.001

Quevedo-león, R.; Bastías-Montes, J.; Espinoza-Tellez, T.; Ronceros, B.; Balic, I. and Muñoz, O. (2020). Inactivation of coronaviruses in food industry: the use of inorganic and organic disinfectants, ozone, and UV radiation. Sci. Agropecu., 11(2): 257–266. http://dx.doi.org/10.17268/sci.agropecu.2020.02.14

Randazzo, W.; Cuevas-Ferrando, E.; Sanjuán, R.; Domingo-Calap, P. and Sánchez, G. (2020a). Metropolitan wastewater analysis for COVID-19 epidemiological surveillance. Int. J. Hyg. Environ. Health, 230: 113621. https://doi.org/10.1016/j.ijheh.2020.113621

Randazzo, W.; Truchado, P.; Cuevas-Ferrando, E.; Simón, P.; Allende, A. and Sánchez, G. (2020b). SARS-CoV-2 RNA in wastewater anticipated COVID-19 occurrence in a low prevalence area. Water Res., 181: 1–8. https://doi.org/10.1016/j.watres.2020.115942

Rizou, M.; Galanakis, I.M.; Aldawoud, T.M. and Galanakis, C.M. (2020). Safety of foods, food supply chain and environment within the COVID-19 pandemic. Trends. Food Sci. Technol., 102: 293–299. https://doi.org/10.1016/j.tifs.2020.06.008

Saguti, F.; Magnil, E.; Enache, L.; Churqui, M.P.; Johansson, A.; Lumley, D.; Davidsson, F.; Dotevall, L.; Mattsson, A.; Trybala, E.; Lagging, M.; Lindh, M.; Gisslén, M.; Brezicka, T.; Nyström, K. and Norder, H. (2021). Surveillance of wastewater revealed peaks of SARS-CoV-2 preceding those of hospitalized patients with COVID-19. Water Res., 189: 116620. https://doi.org/10.1016/j.watres.2020.116620

Sangkham, S. (2020). Face mask and medical waste disposal during the novel COVID-19 pandemic in Asia. CSCEE, 2: 100052. https://doi.org/10.1016/j.cscee.2020.100052

Sbaoui, Y.; Bennis, F. and Chegdani, F. (2021). SARS-CoV-2 as enteric virus in wastewater: which risk on the environment and human behavior? Microbiol. Insights., 14: 1–9. https://doi.org/10.1177/1178636121999673

Schmidt, C. (2020) Watcher in the wastewater. Nat Biotechnol 38: 917–920. https://doi.org/10.1038/s41587-020-0620-2

Shen, K.; Yang, Y.; Wang, T.; Zhao, D.; Jiang, Y.; Jin, R.; Zheng, Y.; Xu, B.; Xie, Z.; Lin, L.; Shang, Y.; Lu, X.; Shu, S.; Bai, Y.; Deng, J.; Lu, M.; Leping, Ye.; Wang, X.; Wang, Y.; Gao, L.; China National Clinical Research Center for Respiratory Diseases, National Center for Children's Health, Beijing, China, Group of Respirology; Chinese Pediatric Society; Chinese Medical Association, Chinese Medical Doctor Association Committee on Respirology Pediatrics; China Medicine Education Association Committee on Pediatrics; Chinese Research Hospital Association Committee on Pediatrics; Chinese Non-government Medical Institutions Association Committee on Pediatrics; China Association of Traditional Chinese Medicine; Committee on Children's Health and Medicine Research; China News of Drug Information Association; Committee on Children's Safety Medication and Global Pediatric Pulmonology Alliance. (2020). Diagnosis, treatment, and prevention of 2019 novel coronavirus infection in children: experts' consensus statement. World J. Pediatr., 16: 223–231. https://doi.org/10.1007/s12519-020-00343-7

Sherchan, S.P.; Shahin, S.; Ward, L.M.; Tandukar, S.; Aw, T.G.; Schmitz, B.; Ahmed, W. and 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. https://doi.org/10.1016/j.scitotenv.2020.140621

Shi, C.; Wei, J.; Jin, Y.; Kniel, K.E. and Chiu, P.C. (2012) Removal of viruses and bacteriophages from drinking water using zero-valent iron. Sep. Pur. Technol., 84: 72–78. https://doi.org/10.1016/j.seppur.2011.06.036

SMHC. (2020). Detection of SARS-CoV-2 on an imported chicken wing sample. https://wjw.sz.gov.cn/yqxx/content/post_7998108.html. Accessed 2 September 2020

Street, R.; Malema, S.; Mahlangeni, N. and Matheea, A. (2020). Wastewater surveillance for Covid-19: An African perspective. Sci. Total. Environ., 743: 140719. https://doi.org/10.1016/j.scitotenv.2020.140719

Sun, J.; Zhu, A.; Li, H., Zheng, K.; Zhuang, Z. and Chen, Z. (2020). Isolation of infectious SARS-CoV-2 from urine of a COVID-19 patient. Emerg. Microbes. Infect., 9: 991–993. https://doi.org/10.1080/22221751.2020.1760144

Sunkari, E.D.; Korboe, H.M.; Abu, M. and Kizildeniz, T. (2021). Sources and routes of SARS-CoV-2 transmission in water systems in Africa: are there any sustainable remedies? Sci Total Environ 753: 142298. https://doi.org/10.1016/j.scitotenv.2020.142298

Tang, A.; Tong, Z.D.; Wang, H.L.; Dai, Y.X.; Li, K..F.; Liu, J..N.; Wu, W.; Yuan, C.; Yu, M.; Li, P. and Yan, J. (2020) Detection of novel coronavirus by RT-PCR in stool specimen from asymptomatic child, China. Emerg. Infect. Dis., 26(6): 1–5. https://doi.org/10.3201/eid2606.200301

Termansen, M.B.; Christiansen, A.V. and Frische, S. (2021). SARS-CoV-2 prevalence and transmission in swimming activities: results from a retrospective cohort study. Scand. J. Med. Sci. Sports, 32(1): 242-254. https://doi.org/10.1111/sms.14071

Tomas, M.E.; Kundrapu, S.; Thota, P.; Sunkesula, V.C.K.; Cadnum, J.L.; Mana, T.S.C.; Jencson, A.; O'Donnell, M.; Zabarsky, T.F.; Hecker, M.T. and Ray, A.J. (2015). Contamination of health care personnel during removal of personal protective equipment. JAMA Intern. Med., 175: 1904–1910. https://doi.org/10.1001/jamainternmed.2015.4535

Torres, F.G. and De-la-Torre, G.E. (2021). Face mask waste generation and management during the COVID-19 pandemic: An overview and the Peruvian case. Sci. Total. Environ., 786: 147628. https://doi.org/10.1016/j.scitotenv.2021.147628

Tran, H.N.; Le, G.T.; Nguyen, D.T.; Juang, R.S.; Rinklebe, J.; Bhatnagar, A.; Lima, E.C.; Iqbal, H.M.N.; Sarmah, A.K. and Huan-PingChao. (2021). SARS-CoV-2 coronavirus in water and wastewater: A critical review about presence and concern. Environ. Res., 193: 110265. https://doi.org/10.1016/j.envres.2020.110265

USEPA (United States Environmental Protection Agency). (2020). Coronavirus and Drinking Water and Wastewater. https://www.epa.gov/coronavirus/coronavirus-and-drinking-water-and-wastewater.

Van Doremalen, N.; Bushmaker, T.; Morris, D.H.; Holbrook, M.G.; Gamble, A.; Williamson, B.N.; Azaibi Tamin, A.; Harcourt, J.L.; Thornburg, N.J.; Gerber, S.I.; Lloyd-Smith, J.O.; de Wit, E. and Munster, V.J. (2020). Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. N. Eng. J. Med., 382: 1564–1567. https://doi.org/10.1056/NEJMc2004973

Wang, J.; Feng, H.; Zhang, S.; Ni, Z.; Ni, L.; Chen, Y.; Zhuo, L.; Zhong, Z. and Qu, T. (2020b). SARSCoV-2 RNA detection of hospital isolation wards hygiene monitoring during the Coronavirus Disease 2019 outbreak in a Chinese hospital. Int J Infect Dis 94: 103–106. https://doi.org/10.1016/j.ijid.2020.04.024

Wang, J.; Shen, J.; Ye, D.; Yan, X.; Zhang, Y.; Yang, W.; Li, X.; Wang, J.; Liubo Zhang, L. and Pan, L. (2020c). Disinfection technology of hospital wastes and wastewater: suggestions for disinfection strategy during coronavirus Disease 2019 (COVID-19) pandemic in China. Environ. Pollut., 262: 114665. https://doi.org/10.1016/j.envpol.2020.114665

Wang, W.; Xu, Y.; Gao, R.; Lu, R.; Han, K.; Wu, G. and Tan, W. (2020a). Detection of SARS-CoV-2 in different types of clinical specimens. JAMA, 323(18): 1843–1844. https://doi.org/10.1001/jama.2020.3786

Wang, X.W.; Li, J.; Guo, T.; Zhen, B.; Kong, Q.; Yi, B.; Zhong, Li.; Song, N.; Jin, M.; Xiao,W.; Chang-QingGu, X.; Yin, J.; Wei, W.; Yao, W.; Liu; C.; Li; J.; Ou, G. and Li, J. (2005). Concentration and detection of SARS coronavirus in sewage from Xiao Tang Shan hospital and the 309th Hospital of the Chinese People's Liberation Army. Water Sci. Technol., 52: 213–221. https://doi.org/10.1016/j.jviromet.2005.03.022

Wei,W.L.; Chiew, C.J.; Yong, S.E.; Toh, M.P. and Lee, V.J. (2020). Presymptomatic transmission of SARS-CoV-2 — Singapore, January 23–March 16, 2020. MMWR, 69(14): 411–415. https://doi.org/10.15585/mmwr.mm6914e1

Westhaus, S.; Weber, F.A.; Schiwy, S.; Linnemann, V.; Brinkmann, M.; Widera, M.; Greve, C.; Janke, A.; Hollert, H.; Wintgens, T. and Ciesek, S. (2021). Detection of SARS-CoV-2 in raw and treated wastewater in Germany — suitability for COVID-19 surveillance and potential transmission risks. Sci. Total Environ., 751: 141750. https://doi.org/10.1016/j.scitotenv.2020.141750

WHO. (2014) Un-water global analysis and assessment of sanitation and drinking-water (GLAAS) 2014 report: investing in water and sanitation: increasing access, reducing inequalities. https://apps.who.int/iris/bitstream/handle/10665/139735/9789241508087_eng.pdf

WHO. (2019). Climate, sanitation and health. https://www.who.int/water_sanitation_health/sanitation-waste/sanitation/sanitation-and-climate-change20190813.pdf.

WHO. (2020a). COVID-19 and food safety: guidance for competent authorities responsible for national food safety control systems: interim guidance, 22 April 2020. https://apps.who.int/iris/handle/10665/331842. Accessed 2 September 2020

WHO. (2020b). Water, sanitation, hygiene, and waste management for COVID-19: technical brief. 227–406. https://apps.who.int/iris/handle/10665/331305. Accessed 3 March 2020.

Wölfel, R.; Corman, V.M.; Guggemos, W.; Seilmaier, M.; Zange, S.; Müller, M.A.; Niemeyer, D.; Jones, T.C.; Vollmar, P.; Rothe, C.; Hoelscher, M.; Bleicker, T.; Brünink, S.; Schneider, J.; Ehmann, R.; Zwirglmaier, K.; Drosten, C. and Wendtner, C. (2020). Virological assessment of hospitalized patients with COVID-2019. Nature, 581: 465–469. https://doi.org/10.1038/s41586-020-2984-3

Wu, F.; Xiao, A.; Zhang, J.; Gu, X.; Lee, W.L.; Kauffman, K.; Hanage, W.; Matus, M.; Ghaeli, N.; Endo, N.; Duvallet, C.; Poyet, M.; Moniz, K.; Washburne, A.D.; Erickson, T.B.; Chai, P.R.; Thompson, J. and Alm, E.J. (2020). SARS-CoV-2 titers in wastewater are higher than expected from clinically confirmed cases. mSystems, 5(4): e00614–e00620. https://doi.org/10.1128/mSystems.00614-20

Wu, X.; Chen, Y.; Wang, L.; Guo, X.; Cui, L.; Shen, Y.; Li, F.; Sun, H.; Zhang, L.; Shen, J. and Xu, Y. (2022). Effectiveness of disinfectants suitable for inactivating SARS-CoV-2 at cold-chain temperature. Food Environ. Virol., 14: 101–104. https://doi.org/10.1007/s12560-022-09509-0

Wurtzer, S.; Marechal, V.; Mouchel, J.M.; Maday, Y.; Teyssou, R.; Richard, E.; Almayrac, J.L. and Moulin, L. (2020). Evaluation of lockdown effect on SARS-CoV-2 dynamics through viral genome quantification in waste water, Greater Paris, France, 5 March to 23 April 2020. Euro. Surveill., 25 (50): 2000776. https://doi.org/10.2807/1560-7917.ES.2020.25.50.2000776

Xagoraraki, I. and O'Brien, E. (2020). Wastewater-based epidemiology for early detection of viral outbreaks. In: " Women in water quality. Women in engineering and science." O'Bannon, D. (Ed.). Springer, Cham, pp. 75–97. https://doi.org/10.1007/978-3-030-17819-2_5

Xiao, F.; Sun, J.; Xu, Y.; Li, F.; Huang, X.; Li, H.; Zhao, J.; Huang, J. and Zhao, J. (2020). Infectious SARS-CoV-2 in feces of patient with severe COVID-19. Emerg. Infect. Dis., 26: 1920–1922. https://doi.org/10.3201/eid2608.200681

Xinhua News. (2020). COVID-19 outbreak linked to xinfadi market under control. https://www.xinhuanet.com/politics/2020-06/24/c_1126158302.htm. Accessed 2 September 2020.

Xu, D.; Zhang, Z.; Jin, L.; Chu, F.; Mao, Y.; Wang, H.; Liu, M.; Wang, M.; Zhang, L.; Gao, G. F. and Wang, F. S. (2005). Persistent shedding of viable SARS-CoV in urine and stool of SARS patients during the convalescent phase. Eur. J. Clin. Microbiol. Infect. Dis., 24: 165–171. https://doi.org/10.1007/s10096-005-1299-5

Yaacoub, S.; Khabsa, J.; El-Khoury, R.; El-Harakeh, A.; Lotfi, T.; Saad, Z.; Itani, Z.; Khamis, A.M.; El Mikati, I.; Cuello-Garcia, C.A.; Verdugo-Paiva, F.; Rada, G.; Schünemann, H.J.; Rizk, N. and Akl, E.A. (2021). COVID-19 transmission during swimming-related activities: a rapid systematic review. BMC Infect. Dis., 21: 1112. https://doi.org/10.1186/s12879-021-06802-4

Zaneti, R.N.; Girardi, V.; Spilki, F.R.; Mena, K.; Westphalen, A.P.C.; da Costa Colares, E.R.; Pozzebon, A.G. and Etchepare, R.G. (2021). QMRA of SARS-CoV-2 for workers in wastewater treatment plants. Sci. Total. Environ., 754: 142163. https://doi.org/10.1016/j.scitotenv.2020.142163

Zhang, D.; Ling, H.; Huang, X.; Li, J.; Li, W.; Yi, C.; Zhang, T.; Jiang, Y.; He, Y.; Deng, S.; Zhang, X.; Wang, X.; Liu, Y.; Li, G. and Qu, J. (2020). Potential spreading risks and disinfection challenges of medical wastewater by the presence of severe acute respiratory syndrome coronavirus 2 (SARS-COV-2) viral RNA in septic tanks of fangcang hospital. Sci. Total. Environ., 741: 140445. https://doi.org/10.1016/j.scitotenv.2020.140445

Ziebuhr, J.; Snijder, E.J. and Gorbalenya, A.E. (2000). Virus-encoded proteinases and proteolytic processing in the Nidovirales. J. Gen. Virol., 81(4): 853–879. https://doi.org/10.1099/0022-1317-81-4-853