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EDITED BY
Prosun Bhattacharya,
Royal Institute of Technology, Sweden

REVIEWED BY
Zakaria Al-Qodah,
Al-Balqa Applied University, Jordan
Nnanake-Abasi Offiong,
Topfaith University, Nigeria

*CORRESPONDENCE
Sarah Ibrahim,
sarah.mounir.ibrahim@gmail.com

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The effects of COVID-19 on the water sector

Sarah Ibrahim*

Independent Researcher, Beirut, Lebanon

The COVID-19 pandemic affected public health, economy, social life, and the environment. It infected and killed millions of people around the world. Most of the recent literature has focused on the medications to combat this virus, including antivirals and vaccines, but studies about its effect on the environment are still rare, particularly on the water sector. Most of the studies concentrate on the effect of water availability on COVID-19, the effect of the used medications on the water, and the probability of transmission of SARS-CoV-2 through water. Herein, we have summarized the effects of COVID-19 on the water sector from many perspectives. We show different methods to detect the effect of the pandemic on water and also methods to investigate the presence of the virus or its RNA in the water. We also show the different effects of its presence in the wastewater, the probability of transmission, the detection of different variants, and the prediction of new waves. We also show the disadvantages and advantages of the pandemic in the water sector. We finally suggest some recommendations to face this pandemic and the future pandemics for the governments and water policymakers, water treatment plants, general population, and researchers. The aim of this review is to show the different aspects of the pandemic in order to give a general idea about what must be done in order to minimize its effect and any probable pandemic in the future.

KEYWORDS

COVID-19, pandemic, water, wastewater, transmission

Introduction

Coronaviruses are enveloped, positive-sense RNA viruses that cause respiratory and gastrointestinal infections in both animals and humans (Drexler et al., 2014; Chan et al., 2015). They cause common cold, mild respiratory infections, and some severe infections such as severe acute respiratory syndrome (SARS), Middle East respiratory syndrome (MERS), and, most recently, coronavirus disease 2019 (COVID-19) (Chan and Chan, 2013; Chin et al., 2020). COVID-19 is caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which was first detected in Wuhan (the capital of Hubei in China) during 2019 (Tang, X et al., 2020). Until July 2022, the WHO has declared variants of interest (VOIs) (Table 1) and five main variants as variants of concern (VOCs) of SARS-CoV-2 (Table 2). The variant of interest is the variant that is known to cluster in many countries with significant transmission in the community. In addition to that, it has specific mutations that affect the transmissibility of the virus, the severity of the disease, immune escape, and the escape of diagnostic or therapeutic interventions. On the other hand, the variant of concern is a VOI with an increase in the transmissibility, increase in detrimental change in COVID-19 epidemiology, increase in the virulence of the virus, change in clinical disease presentation, or decrease in the efficiency of public health and social measures or the applied diagnostics, vaccines, and therapeutics (World Health Organization, 2022).

Many infected people are asymptomatic, while others develop symptoms that range from mild to severe. Many COVID-19 patients have gastrointestinal symptoms and sometimes without respiratory symptoms (Tian et al., 2020) because the virus uses angiotensin-converting enzyme 2 (ACE2) as the receptor (Yan et al., 2020), and the latter is found abundantly in the small intestine of humans (D'Amico et al., 2020).

Although this virus is airborne, water, sanitation, and hygiene (WASH) are considered essential for protection against it (United Nations Children's Fund and World Health Organization, 2020). That is mainly because people will search for water when there is a lack of piped good water and thus make more contact with people and increase their risk of being infected. On a global scale, one in five people lack access to clean and sufficient water. This is particularly true for megacities in developing countries, where there is no proper infrastructure (United Nations Children's Fund and World Health Organization, 2019). About 57 million people in Europe and North America have no access to piped water at home, while 21 million people have no access to basic drinking water services (WWAP, 2019), including those who are usually considered among the neglected populations (refugees, the homeless, *etc.*) (Panhuis, 2018). In Europe alone, 31 million people have no basic sanitation, and 48 million people have no access to piped water being delivered to their homes (UN Water, 2020). Thus, populations and subpopulations that face water scarcity might have faced or faced additional problems during the pandemic. The presence of the virus in wastewater, rivers, and seawater has also been studied (Cahill and Morris, 2020; Guerrero-Latorre et al., 2020; Liu et al., 2020) to assess its threat to public health and the water sector. However, studies about its effects on the hydrosphere are still rare (Hader et al., 2020).

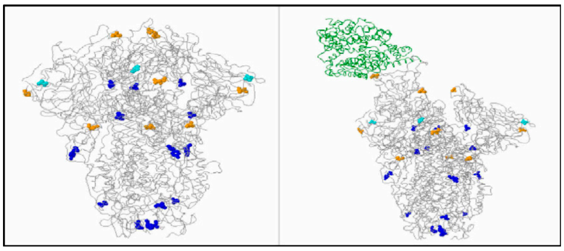
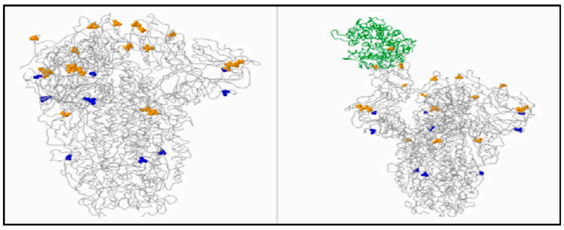
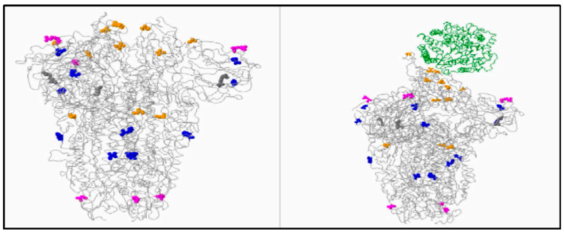
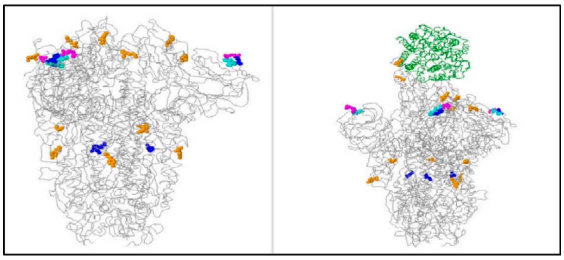
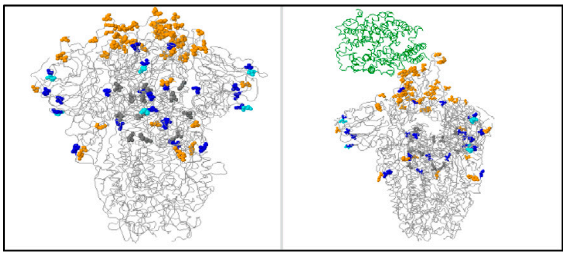
The persistence of SARS-CoV-2 in the water medium is yet unknown (Heller et al., 2020). It is an enveloped virus; thus, it can be inactivated with less contact time with chlorine than non-enveloped viruses (Paleologos et al., 2020). Water, being an unsuitable environment for SARS-CoV-2 survival, can be disinfected by chlorine-based disinfectants that have a residual chlorine level ˃ 0.5 mg/L (Wang, J., et al., 2020a). Traditional water treatment techniques are also thought to inactivate the virus (Kitajima et al., 2020). Thus, the WHO suggested that a residual chlorine of 5 mg/L for tap water and 6 mg/L for hospital wastewater could be helpful (Wang, J., et al., 2020a). It has been shown that coronaviruses can be inactivated by 20 mg/L chlorine with a minimum contact time of 1 min (Wang, X.W., et al., 2005). A minimum of 1.0 mg/L free chlorine residual is required to disinfect swimming pools (HPSC, 2020). China, following its zero-COVID-19 strategy, increased the use of chlorine in order to decrease the risk of transmission through wastewater (Zambrano-Monserrate et al., 2020).

The pandemic changed many aspects of the daily lives of humans, including work that shifted to home and online. It also affected the water sector in many ways, which is the aim of this study. Interviews with people in Finland, for example, revealed that the water utilities did not open their offices to the public and banned their visits unless there was an emergency case. Services were restricted to online and the use of the telephone; any non-urgent work was postponed, and they even met online. They exchanged information and lent staff to any neighboring utility

TABLE 1 Variants of interest of SARS-CoV-2 (adopted from the World Health Organization, 2022 available at https://www.who.int/activities/tracking-SARS-CoV-2-variants (accessed on 21 July 2022)).

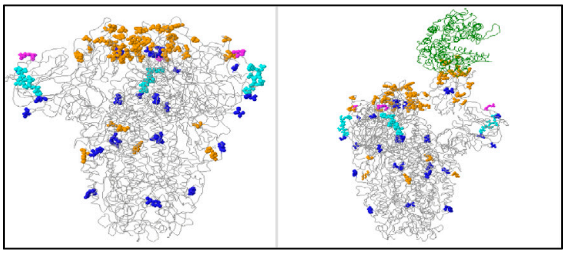
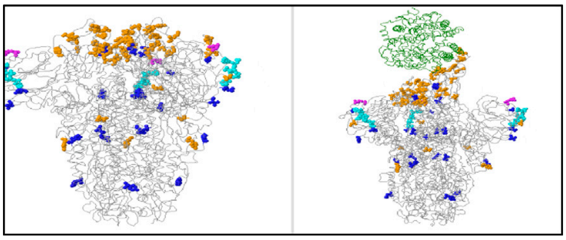
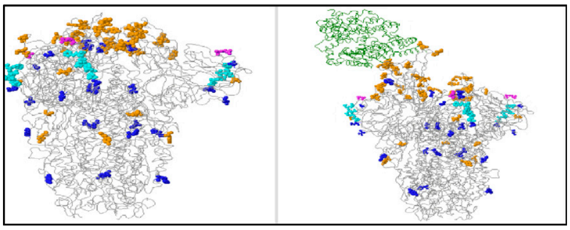
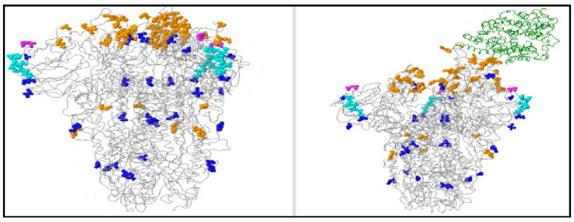
HO label	Pango lineage*	GISAID clade	Nextstrain clade	Earliest documented sample	Date of designation
Epsilon	B.1.427 B.1.429	GH/452R.V1	21C	The United States of America, Mar-2020	VOI: 5-Mar-2021. Previous VOI: 6-Jul-2021
Zeta	P.2	GR/484K.V2	20B/S.484K	Brazil, Apr-2020	VOI: 17-Mar-2021. Previous VOI: 6-Jul-2021
Eta	B.1.525	G/484K.V3	21D	Multiple countries, Dec-2020	VOI: 17-Mar-2021. Previous VOI: 20-Sep-2021
Theta	P.3	GR/1092K.V1	21E	The Philippines, Jan-2021	VOI: 24-Mar-2021. Previous VOI: 6-Jul-2021
Iota	B.1.526	GH/253G.V1	21F	The United States of America, Nov-2020	VOI: 24-Mar-2021. Previous VOI: 20-Sep-2021
Kappa	B.1.617.1	G/452R.V3	21B	India, Oct-2020	VOI: 4-Aprl-2021. Previous VOI: 20-Sep-2021
Lambda	C.37	GR/452Q.V1	21G	Peru, Dec-2020	VOI: 14-Jun-2021. Previous VOI: 9-Mar-2022
Mu	B.1.621	GH	21H	Colombia, Jan-2021	VOI: 30-Aug-2021. Previous VOI: 9-Mar-2022

TABLE 2 Variants of concern of SARS-CoV-2.

Lineage	Spike protein model[a]	Emergence[b]
Alpha (B.1.1.7)		United Kingdom, September 2020
Beta (B.1.351)		South Africa, August 2020
Gamma (P1)		Brazil, July 2020
Delta (B.1.617.2)		India, December 2020
Omicron (BA.1)		South Africa, December 2021

(Continued on following page)

TABLE 2 (*Continued*) Variants of concern of SARS-CoV-2.

Lineage	Spike protein model[a]	Emergence[b]
Omicron (BA.2)		South Africa, December 2021
Omicron (BA.4)		South Africa, January 2022
Omicron (BA.5)		South Africa, January 2022
Omicron (BA.2.12.1)		North America, December 2021

[a]Photograph taken from https://covariants.org/variants (accessed on 21 July 2022).
[b]Information taken from https://viralzone.expasy.org/9556?fbclid=IwAR235CgJF4Cg4xjPswlQDXKeOkb32erZsII8xWswpP9Csdl0_xpCLPVmplY (accessed on 21 July 2022).

that was facing troubles. Also, plumbers minimized or even avoided any contact with customers and co-workers (Juuti and Rajala, 2020).

The literature is focusing on the effect of water availability on COVID-19 cases and deaths, the improvement of water quality during lockdowns, the effects of microplastics, the probability of fecal–oral transmission, and the pollution with chemicals used during the pandemic. Herein, the aim is to discuss, in addition to that, the various aspects of the pandemic on the water sector, including the disadvantages and advantages. This review shows the methods of detection of the SARS-CoV-2 and its genetic material in the water sector, the detection of water quality improvement during lockdowns, the effects of sewage contamination on marine life, water quality, and public health, the negative and positive consequences of governments' plans for the water sector, and the recommendations to follow in order to face this pandemic and future pandemics.

Methods to detect the effects of COVID-19 lockdown on water quality

Diverse methods are available to detect the presence of SARS-CoV-2 in water and the effect of COVID-19 on the water sector. These methods include remote sensing, which is an effective method to detect pollution using satellite images. It also includes water quality assessments to determine whether or not a

TABLE 3 Different methods to detect the effects of COVID-19 lockdown on water quality.

Technique	Method	Aim	Author
Remote Sensing	Landsat 8 OLI images	Determine the effect of the pandemic on	Patel et al. (2020)
		-the Yamuna River	Yunus et al. (2020)
		-Vembanad Lake	
	Sentinel-2 images and the normalized difference turbidity index (NDTI)	Study the effect of the lockdown on water quality in the Ganga River	Garg et al. (2020)
	Landsat 8 OLI images and Sentinel-2 images were used (using Acolite software for radiometric calibration)	Study the effect on the hydrological residence time in Wuhan lakes and Vembanad Lake	Avtar et al. (2020)
	Sentinel-3 WST images	Determine fecal pollution by estimating the *E. coli* concentration and water quality of the coastal area in Tangier, Morocco	Cherif et al. (2020)
	Real-time monitoring water quality sensors	Study the water quality in Dubai Creek lagoon	Rajshree et al. (2020)
	The Copernicus Open Access Hub website can be used to obtain Sentinel- 3 Ocean and Land Color Instrument (OLCI) Level-1 full resolution scene and processing it after that using the Sentinel Application Platform (SNAP)	Study the effect on phytoplankton biomass along Indian coastal waters	Mishra, D.R. et al. (2020)
Water quality assessments	Dissolved oxygen (DO) estimation before and during the lockdown	Determine the effect of the lockdown on the water quality in	Chakraborty et al. (2020)
		-a Gangetic delta	Dhar et al. (2020)
		-a stretch of River Ganga, respectively	
	Physico-chemical and biological parameter testing and analysis of the most probable number method (MPN)	Determine the microbial water quality in the Mandakini River	Chaurasia et al. (2020)

TABLE 4 Different techniques used to examine wastewater for the presence of SARS-CoV-2 or its RNA.

Technique	Sample	Author
Procedure of direct flocculation (Calgua et al., 2013) with bovine extract solution and RT-qPCR	Untreated wastewater samples from wastewater treatment plants	Mlejnkova et al. (2020)
Two-phase separation (PEG-dextran method) and the ultracentrifugation associated with RT-qPCR	Sewage samples of six cities and the airport	Medema et al. (2020a)
	12 influent sewage samples collected between February and April 2020 from wastewater treatment plants in Milan and Rome	La Rosa et al. (2020a)
Serial dilution and RT-PCR assay to detect the one COVID-19 infected person amongst 10,000 people • Samples that showed presence of the virus were diluted 5–200 times by model wastewater and reanalyzed. Then, the infection rate was calculated from the positive samples using the lowest dilution showing positive results	Sewage inspection chambers in a residential area and one from a university campus in the city of Kazan, Russia	Kuryntseva et al. (2020)
Time-course quantitative analysis by RT-qPCR	Raw wastewater samples and several major wastewater treatment plants in Paris	Wurtzer et al. (2020)
RNA extraction of SARS-CoV-2 by electronegative membranes and ultrafiltration	Wastewater in a catchment in Australia with a period of 6 days from the same wastewater treatment plant	Ahmed et al. (2020)
Electronegative membrane vortex (EMV) and membrane adsorption for direct extraction of RNA for better detection with low case numbers in community	Wastewater and river water in Yamanashi Prefecture, Japan	Haramoto et al. (2020)
Examined viral inactivation and enrichment, nucleic acid extraction, and RT-qPCR	Water treatment plant	Wu, F et al. (2020)

pollutant is present in an environment and whether or not it is affecting quality for specific usage (Bagchi and Bussa, 2011). For example, the biological oxygen demand (BOD) increases in the water with the increase of disposed organic wastes and is inversely proportional to the dissolved oxygen (DO), which is necessary for aquatic organisms (Chakraborty et al., 2020) (Table 3).

Methods to investigate SARS-CoV-2 in wastewater

The presence of enteric pathogens in the wastewater effluents is an epidemiological method that has also been used for monitoring COVID-19 (Lodder and Husman, 2020; Quilliam et al., 2020). Diverse techniques were used in this domain (Table 4).

Methods to investigate the presence of SARS-CoV-2 in water

For the detection in water, a preprint in medRxiv used the skimmed milk flocculation method using 2 L of water (Fernandez-Cassi et al., 2018) and extracted the nucleic acids using RT-qPCR and N1 and N2 primers (CDC, 2020) and the human adenovirus to indicate the presence of fecal contamination (Allard et al., 2001). Porcine epidemic diarrhea virus (PEDV), an enveloped virus of the *Coronaviridae* family used as a surrogate for SARS-CoV-2, was examined and compared to mengovirus, a non-enveloped member of the *Picornaviridae,* in tap, sea, and surface water. Then, 20 L was used as a sample of each water type to have large water volumes for the purpose of their experiment, primarily concentrated by DEUF and spiked with 10^7 genomic copies of PEDV and 10^8 of mengovirus. Also, after that, different modification options were used for concentration according to the different water types and assessed with two RT-qPCR quantification assays, and the latter were assessed for sensitivity to inhibitors (Cuevas-Ferrando et al., 2020b).

Wastewater and COVID-19

Transmission of COVID-19 through wastewater

The presence, persistence, and transmission of SARS-CoV-2 through wastewater have gained most of the attention regarding its effects on the water sector (Ahmed et al., 2020; Amirian, 2020; Randazzo et al., 2020a; Nghiem et al., 2020; Venugopal et al., 2020). This is due to the probable threat of the virus being consumed with water that is contaminated by sewage and human excretions including feces and urine (Amirian, 2020; Cao et al., 2020). For example, open defecation that is frequently found in poor nations because each region has public bathrooms that might be crowded and/or far, while private bathrooms are scarce, if present, can transmit the virus to the surface water that might be used by downstream consumers. Sewage water that has the virus can pass to daily consumed water by being directly disposed of in surface water that can be later consumed or through cracked sewage pipes that pass near the clean water pipes. The absence of wastewater treatment plants, a lack of periodic maintenance for sewage and drinking water networks, and a lack of strict environmental rules are the main causes of this probable type of pollution. Also, wastewater treatment plants that are not subjected to periodic maintenance can be a probable cause of virus transmission. That can be either through creating bioaerosols during the treatment process that may affect the workers if they are not taking precautions (Luo et al., 2020) and disposal of sewage water without proper treatment or a leakage from the incoming pipes toward clean water. The virus can enter the water system also from directly disposed wastes or wastewater from hospitals and isolation centers (Verlicchi et al., 2010; Wang, J., et al., 2020b; Wang, W., et al., 2020) that enter surface water. These might contain, in addition to the execretion of patients, medical wastes with infectious material from the patients disposed of without proper treatment (Mousazadeh et al., 2021). The virus may also reach the water system from the disposal of nearby septic tanks and might affect the workers if they are not taking precautions. The polluted water can be used for drinking, washing fruits and vegetables, and irrigation (Figure 1).

The dose–response model of SARS-CoV when applied to SARS-CoV-2 shows the probability of infection with SARS-CoV-2 from different activities (Table 5). The number might be underestimated and need to be updated according to the dose–response of SARS-CoV-2 considering the different variants (Kumar et al., 2021).

The virus can also be transmitted through wastewater or the sanitary plumbing system in the same building and to other buildings due to aerosol transmission as shown in Figure 2.

Presence of SARS-CoV-2 genetic material in wastewater

The virus half-life in hospital wastewater is estimated to be 4.8–7.2 h at 20°C (Hart and Halden, 2020; Robson, 2020). It can survive even after it leaves the human body if it is found in a suitable environment that supports its survival (Mao et al., 2020). Thus, its discharge can cause a potential risk of transmission by being discharged untreated into the environment and surface water that is used by people in low-income countries as the main water source or the groundwater during recharging (Adelodun et al., 2020).

FIGURE 1
Probable routes of transmission of SARS-CoV-2 through wastewater.

TABLE 5 Expected dose and probability of infection to SARS-CoV-2 for various water activities under various viral concentration scenarios, adopted from Kumar et al. (2021).

Activity	Virus concentration in the water body (PFU/L) (assumption)	Volume of water ingestion[a] (mL/event)	Expected viral dose, λ (log PFU/event)	Chance of infection per event, P(r|λ) (log)	No. of events per year (assumption)	Annual chance of infection (log)
Swimming	0.01	—	−4.2	−6.84	—	−5.84
	0.1	6.0	−3.2	−5.84	10	−4.84
	1	—	−2.2	−4.84	—	−3.84
	10	—	−1.2	−3.84	—	−2.84
Fishing	0.01	—	−4.7	−7.31	—	−5.61
	0.1	2.0	−3.7	−6.31	50	−4.61
	1	—	−2.7	−5.31	—	−3.61
	10	—	−1.7	−4.31	—	−2.61
Canoeing/rowing	0.01	—	−4.6	−7.25	—	−5.95
	0.1	2.3	−3.6	−6.25	20	−4.95
	1	—	−2.6	−5.25	—	−3.95
	10	—	−1.6	−4.25	—	−2.95

[a]Medians of water ingestion estimated by Dorevitch et al. (2011).

So far, no data are available about the needed viral quantity that transmits the infection through the fecal–oral pathway (CDC, 2020), but the infectious virion was extracted from patients' feces (Holshue et al., 2020; Ling et al., 2020), and the RNA was still found in patients' feces even after negative presence was apparent in the respiratory system. These observations confirmed that shedding from the digestive tract can occur for a longer time period than that from the respiratory tract (Wu, Y et al., 2020). The virus was found in diverse conditions (Table 6).

The virus was detected in the wastewater (Igomu, 2020) after it was thought that it is not stable in the environment and can be removed by following simple disinfection methods. While some studies found infectious viruses in patients' feces (Wang, W.,

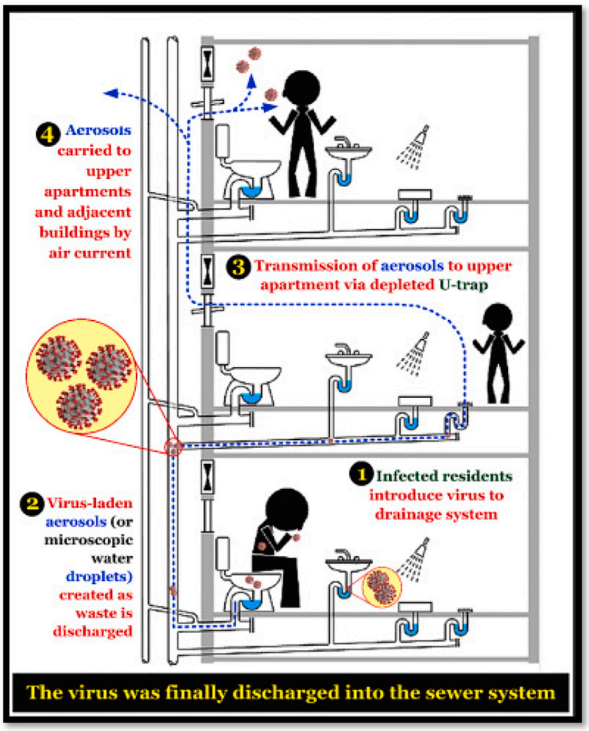


FIGURE 2
Possible transmission route of the SARS-CoV-2 virus, adopted from Tran et al. (2021).

et al., 2020; Xiao et al., 2020a; Zhang, Y et al., 2020), others showed that the virus loses its infectivity in a rapid way in the wastewater (Annalaura et al., 2020; Venugopal et al., 2020). Other studies did not detect the virus either in the effluents after sewage treatment (Randazzo et al., 2020a) or in the rivers affected by sewage (Haramoto et al., 2020). It is important to note that the presence of genomic material is not equal to the viability of the virus (Guerrero-Latorre et al., 2020), but in rural areas in low-income countries where the people use unsafe surface water (Armah et al., 2018) and in the cities where people share water systems, the fear of potential spread of the virus is high (Amirian, 2020). Not enough data have been collected from countries with low sanitation (Guerrero-Latorre et al., 2020). In many developing countries, it is common for the pit latrine sanitation system to be near the groundwater source and for open defecation to be near the surface water (World Health Organization, 2013; Back et al., 2018; Bhallamudi et al., 2019), and untreated wastewater is directly released into the environment (Adelodun et al., 2019). Even if at a low risk, transmission and contamination with excreta must not be ignored (CDC, 2020; Nghiem et al., 2020; Quilliam et al., 2020; University of Stirling, 2020; Yeo et al., 2020). A biofilm of bacterial colonies can help the virus persist in the wastewater piping systems and be transmitted to households by being aerosolized in the shower (Naddeo and Liu 2020).

Persistence of SARS-CoV-2 in wastewater

Transmission of SARS-CoV-2 through wastewater depends on its half-life, which is affected by many factors including chlorine disinfection (Zhang, D et al., 2020), temperature (Hart and Halden, 2020), and UV ozone (Wang, J., et al., 2020a). The time estimated to reach 90% reduction of SARS-CoV-2 at room temperature is 2 days for tap water, 1.6 and 2.1 days in wastewater, representing high and low titers, respectively. While at 50 and 70°C, it is estimated to be

TABLE 6 Different conditions showing positive results for samples related to sewage and human excretion.

Types of samples	Number of samples	Result	Author
Throat swabs, sputum, urine, and stool	82 patients	9 out of 17 cases of stool samples showed positive result on RT-PCR analysis	Pan et al. (2020)
Hospital surfaces, sewage samples, and respiratory and stool specimens of patients	33 hospitalized patients	No RNA on test surfaces	Wang, J., et al. (2020b)
		Positive results of inlet and outlet of preprocessing disinfection pool	
Stool samples	10-year-old asymptomatic boy	Positive results 17 days after the last contact with infected person	Tang, A et al. (2020)
Stool samples and endoscopy of esophageal, gastric, duodenal, and rectal tissues	73 hospitalized patients	Positive stool results in patients after negative respiratory results	Xiao et al. (2020a)
Plasma, stool, and urine	29 post-COVID-19 cases	51.7% of the cases had positive RT-PCR test results in at least one sample of plasma, stool, or urine	Tejerina et al. (2022)
Nasopharyngeal and blood, urine, and stool samples	5 patients	RNA detection in stools	Lescure et al. (2020)
Oropharyngeal swab, stool, urine, and serum samples	66 patients	16.7% positive test results with a median of 11 days after symptom onset	Ling et al. (2020)
Wastewater samples	24 h 10 L samples once a week	RNA positive tests by quantitative RT-PCR, showing community transmission	Lodder and de Roda Husman (2020)

15 and 2.2 min in wastewater. The mean first-order decay rate constants differ between wastewater at high titer, where it is estimated to be 1.4 $days^{-1}$, and wastewater at low titer, where it is 1.1 $days^{-1}$, while that for tap water is 1.2 $days^{-1}$ at high titer. The estimated decay rate constants for both the RNA and the virus indicate a higher persistence of the RNA than that of the virus. The T_{90} for wastewater at high titer is 3.3 *versus* 1.6 days; at low titer, 26.2 *versus* 2.1 days; and for tap water, 33.2 *versus* 2 days. The RNA of SARS-CoV-2 can be detected even when the virus itself is below the limits of detection, indicating that the presence of the RNA alone is not a sufficient indicator for an infectious virus. In the case of unsterilized wastewater and at a certain temperature, SARS-CoV-2 has higher persistence than other coronaviruses (Bivins et al., 2020a). Compared to other coronaviruses, a systematic review and meta-analysis of human coronaviruses show that 99% reduction times increase with the decrease in temperature from 22°C–25°C to 4°C–6°C from about 2 days to 50 days (Silverman and Boehm, 2020). While SARS at a temperature of 20°C was infectious for 4–5 days (Duan et al., 2003) and at room temperature with an alkaline PH, it remained infectious for 4 days (Lai et al., 2005), the presence of suitable temperature and biofilms can enhance its presence in domestic sewage up to 14 days (Wang et al., 2005), while the presence of efficient disinfection can reduce it and rapidly inactivate it by 2 days (Gundy et al., 2009) because in the absence of sufficient disinfection, the outbreak of SARS showed persistence of the virus (Naddeo and Liu. 2020). Thus, research about the persistence of SARS-CoV-2 in different water systems is still rare. Also, research about its threat either for humans or for other species is still rare.

Importance of wastewater-based epidemiology during the pandemic

The pandemic showed the importance of wastewater-based epidemiology because it helps to evaluate the number of cases in the tested region, predict any future waves, and determine the circulating variants in the population (Wurtzer et al., 2022). This technique was previously used to analyze the success of the vaccination campaign against the poliomyelitis virus (Vammen and Guillen, 2020) and determine the usage of legal and illegal drug use and the presence of infectious diseases. In Australia, the number of cases from clinical observations was fair compared to the estimated number of cases from sewage water testing (Ahmed et al., 2020). In Spain, samples from six wastewater treatment plants were examined at the influent, secondary, and tertiary treatment levels. The results show a decrease in genomic copies from influent to secondary levels and a complete absence at the tertiary level. Wastewater samples collected in March 2019 were found positive for SARS-CoV-2, which indicates the infection's presence before the detection of cases. The number of genomic copies increased as the number of confirmed cases increased (Chavarria-Miro et al., 2020). In France, it was detected in raw (Wurtzer et al., 2022). In Italy, it was found in some untreated wastewater (La Rosa et al., 2020b(a, b)). In the U.S., the cases of clinical observations were less than those estimated from wastewater testing (Wu F et al., 2020). RNA was detected days before the confirmed cases in Spain (Randazzo et al., 2020a) and before the peak in Paris (Würtzer et al., 2020). The viral RNA was detected in the wastewater from the inflow in the Czech Republic (Mlejnkova et al., 2020). Australia, New Zealand, the Netherlands (Medema et al., 2020a (a); World Health Organization, 2022 (c)), and parts of Brazil (Agência Nacional de Águas et al., 2020; Secretaria Estadual de Saúde do Rio Grande do Su, 2020) assessed COVID-19 using environmental surveillance. WBE was used to evaluate COVID-19 in Massachusetts (Wu, F et al., 2020; Wu et al., 2022), New York (Green et al., 2020), Connecticut (Peccia et al., 2020), Montana (Nemudry et al., 2020), Virginia (Gonzalez et al., 2020), and Louisiana (Sherchan et al., 2020) in the United States. Studies were also carried out in Chile (Ampuero et al., 2020), Canada (D'Aoust et al., 2020), the Netherlands (Medema et al., 2020a (a); Medema et al., 2020b (b)), Australia (Ahmed et al., 2020), India (Arora et al., 2020), China (Zhang, D et al., 2020; Zhang et al., 2021), Japan (Hata et al., 2021), Turkey (Alpaslan Kocamemi et al., 2020), and Germany (Westhaus et al., 2020). In Italy, studies were conducted in Milan and Rome (La Rosa et al., 2020a (a)) in addition to Milan, Turin, and Bologna (La Rosa et al., 2021). In Spain, studies were conducted in Murcia (Randazzo et al., 2020a (a)), Valencia (Randazzo et al., 2020b (b)), Barcelona (Chavarria-Miró et al., 2020), and Santiago de Compostela (Balboa et al., 2020). In France, studies in Paris (Wurtzer et al., 2022) and Montpellier (Trottier et al., 2020) were conducted for detection. The wastewater showed the presence of SARS-CoV-2 variants 16 days earlier and detected multiple instances of virus transmission that were not detected by clinical genomic surveillance (Karthikeyan et al., 2022). The RNA of SARS-CoV-2 was detected also in the surface water in Ecuador (Guerrero-Latorre et al., 2020) and rivers from Rio Grande do Sul, Brazil (Secretaria Estadual de Saúde do Rio Grande do Sul, 2020). The level of viral particles was higher in July than the level in March in the city of Kazan, similar to registered results in the city, but the average sickness rate was higher than the registered one (Kuryntseva et al., 2020). Therefore, wastewater plays a key role in the pandemic that must not be underestimated. It might be a potential threat to the public's health if it is not monitored well, and it can be used as a resource to trace the pandemic's development and thus prevent any future surge.

Negative consequences of the pandemic on the water sector

Negative effects on marine life and water quality

COVID-19 can affect many aspects of the water sector negatively. For instance, the inappropriate disposal of the

FIGURE 3
Marine life affected by disposal of wastewater containing SARS-CoV-2 and personal protective equipment.

personal protective equipment used in the pandemic may cause a shift in the main sources of marine litter pollution to a worrisome scale when compared with the efforts to decrease this kind of pollution. The problem might increase with the interruption of the marine litter monitoring programs due to the gap between the monitoring and the intensifying pollution (Canning-Clode et al., 2020). It can affect aquatic organisms because face masks are manufactured from plastic polymers, particularly polypropylene (Aragaw, 2020), and can be transformed into microplastics, which can bioaccumulate in the food chain after being ingested by the organisms (Silva et al., 2020) and sometimes cause their death. They can be trapped in it or consume it. Wastewater that contains the virus might transmit it to many marine mammals such as species of whales, dolphins, seals, and otters (Mathavarajah et al., 2021) (Figure 3).

It can also create a niche for microbial and biofilm formation and thus affect the aquatic microorganisms' communities (Aragaw, 2020). Laboratories that are diagnosing the virus can pollute both the soil and water with their plastic and chemical wastes (Corman et al., 2020). It generates high concentration of diverse drugs (Escher et al., 2011), for example, hydroxychloroquine and chloroquine that were suggested to treat COVID-19 and are considered emerging pollutants (Zurita et al., 2005; Daughton, 2014) that can bioaccumulate and persist in the water system (Ramesh et al., 2018) and can enter the freshwater ecosystem because of the lack of efficient treatment of wastewater (Ashfaq et al., 2017). Disposable medical products were reported on the beaches (Saadat et al., 2020) and sea floor (CNN, 2020), but still, there are no enough studies showing the differences in concentration and nature of the used therapeutics before and after the outbreaks. (Gwenzi et al., 2022).

The pandemic can pollute the water bodies, particularly in developing countries, such as the African countries, due to the ineffective water treatment found in these countries, by 1) the presence of pharmaceutical products in wastewater, as in the case of HIV treatment, which is the main pharmaceutical product in South Africa, and water treatment techniques are not able to remove them (Horn et al. 2020), 2) the presence of disinfections that can reach water resources, such as triclosan (Anger et al., 2013) and ethanol, and 3) the presence of the pathogen itself in cross-contaminated water resources which may increase its probability of becoming a waterborne disease (Mupatsi, 2020).

Negative effects on public health

SARS-CoV-2 genes (N1 and N2) were found in the rivers of Quito, Ecuador, in high amounts, indicating that the real number of infected people is underdiagnosed (Guerrero-Latorre et al., 2020). The presence of SARS-CoV-2 in the river might be a potential risk to downstream users, and this risk was studied in WWTP workers by subjecting them to different concentrations of SARS-CoV-2 in the sewage (Zaneti et al., 2021). The absence of efficient wastewater treatment coverage can be the cause of the high case numbers near the rivers of Quito (Guerrero-Latorre et al., 2020). In addition, its disposal in the environment has undiscovered consequences on wildlife and livestock, and this is important particularly because the *Coronaviridae* family is linked to frequently occurring zoonotic spillover (Franklin and Bevins, 2020).

Concerns about the fecal–oral and fecal–nasal transmission pathways for SARS-CoV-2 have been raised recently (Kang et al. 2020). That is due to detecting the virus in the feces by electron microscopy (Zhang, Y et al., 2020) and isolating it by cell culture (Xiao et al., 2020b). A systematic review and meta-analysis by Silverman and Boehm (2020) determined the temperature, and the persistence of SARS-CoV-2 in unsterilized wastewater is higher than that of other coronaviruses, but its first-order decay rate constant has a similar sensitivity to temperature. On the other hand, Kang et al. (2020) showed evidence in a high-rise building for fecal aerosol transmission with the presence of RNA detected in environmental samples. Cross-contamination of soil and water results from the leaking sewage network due to underinvestment. Feces usage in agriculture produces virus-containing runoff during rainy days and contaminates surface and groundwater. SARS-CoV-2 presented in water must gain more attention in low-income countries where the sewage network lacks maintenance (Paleologos et al., 2020). Although the probability is small, a potential risk for drinking water is present. Hence, some countries closed swimming pools and recreational water areas to minimize the risk (Paleologos et al., 2020). Low temperature facilitates the long survival of the virus; thus, it can spread to residual treatment plants (Venugopal et al., 2020). It was detected up to 25 days in untreated wastewater; hence, a potential route of fecal–oral transmission is possible (Shutler et al., 2021). Similar to several enteric viruses that spread by toilet flushing (Verani et al., 2014; Naddeo and Liu, 2020), SARS-CoV-2 can be spread *via* the wastewater plumbing system within and between buildings (Gormley et al., 2020). The virus can be transmitted by aerosolization of showers after it invades bacteria that live in the piping system as biofilms (Khadse et al., 2020; Naddeo and Liu, 2020; Vammen and Guillen, 2020). Thus, it affects the quality of water being consumed by people and increases the probability of waterborne diseases. Also, during the pandemic, some of the hospitals' activities were stopped, and their staff members were transferred to the COVID-19 emergency. This increased the chance of waterborne diseases such as the growth of *Legionella* in the water systems that are rarely used (Istituto Superiore di Sanit`ISS), 2019). The change in water pressure can cause detachment of the biofilms that are formed in the inner surface of the water network, releasing the microorganisms in the water. If it is not properly managed, it causes a threat to both the patients and the health workers (De Giglio et al., 2020). For this, the European Society of Clinical Microbiology and Infectious Diseases (ESCMID) Study Group for *Legionella* Infections suggested recommended actions to water system management in hospitals in the presence of *Legionella* (European Society of Clinical Microbiology and Infectious Diseases, 2020).

Negative effects of chemicals used during the pandemic

In response to the pandemic, the governments took different precautions to reduce the infection, and in many cases, their efforts were directed toward fomite and droplet transmission, which was thought to be the main route of transmission at the beginning of the pandemic. For example, in Surabaya, Indonesia, a drone for dispersing clouds of disinfectants was used for disinfection purposes over the city (Wardoyo and Geddie, 2020). Unfortunately, disinfectants, such as bleach and glutaraldehyde, increase the risk of progressive lung diseases (Svanes et al., 2018; Dumas et al., 2019). Some compounds used in the disinfectants affect human health in a negative way. These include increased risk for asthma (Kogevinas et al., 2007; Obadia et al., 2009), decreased lung functions (Svanes et al., 2018), and increased risk for chronic obstructive pulmonary disease (Dumas et al., 2019). Many contaminants can reach the drinking water and also affect human health negatively. For example, polyfluoroalkyl substances (PFAS) that are found in many household items have been linked with cancer, high cholesterol levels, delay in development, obesity, thyroid diseases, immune suppression in children (Ganesan and Vasudevan, 2015; Pennings et al., 2016; Sunderland et al., 2019), and cardiovascular diseases in the case of perfluorooctanoic acid (PFOA) (De Toni et al., 2020). It is also linked to a reduced immune response to vaccines in a certain community found in the Faroe Islands (Grandjean et al., 2017). Chlorine, used for disinfection, can also influence the sustainability of the aquatic ecosystem, affect many organs including the respiratory systems, and cause many health issues (Rismanbaf and Zarei, 2020; Xu et al., 2020) in addition to accumulating in the aquatic biota and harming the living organisms (Zhang, H et al., 2020). Traces of sodium hypochlorite increased during the pandemic with the increase in disinfectants usage and became part of landfill leachate. It reacts with water to form hypochlorous acid and with bromine to form hypobromous acid (Rook 1974). These two acids combined with natural organic matter form genotoxic and carcinogenic disinfection by-products (Medeiros et al. 2019).

Negative effects of COVID-19 combined with natural water disasters

Floods may affect the pandemic because of the difficulties in keeping people away from others who are not living with them in the same house while rescuing and providing suitable accommodations for them (Mukherjee et al., 2020b). Thus, it can increase the contact between people and increase their probability of being infected. An example of this was the floods in Germany, where people used emergency shelters and were at risk during the spread of the Delta variant (Deutsche Welle, 2020).

Both drought, which is a natural disaster that reduces crop yield, and the COVID-19 pandemic, which affects the food supply chain and food demand, co-occurred on all the continents at different degrees, with developing countries that lack social safety nets on their own being most affected (Laborde et al., 2020; Mishra, A., et al., 2020). Restrictions introduced by the pandemic increased the difficulty of transporting the agricultural products, especially in the regions affected by drought and where junior water right owners might not have enough water for irrigation (Espitia et al., 2020; Kerr, 2020). COVID-19 has increased the challenges in countries with scarce freshwater resources. It increased the impact of drought and water shortage in many countries suffering from a decline in the rainfall pattern, including Ireland, the United Kingdom, Turkey, Ethiopia, Kenya, Syria, Poland, Romania, Kosovo, and India (Anim and Ofori-Asenso, 2020; Bhowmick, 2020; Cotterill et al., 2020; Irish Water, 2020; Smart Water Magazine, 2020; Union for the Mediterranean, 2020).

Negative effects of COVID-19 on the availability of water for poor populations

The financial crisis caused by the pandemic affected socioeconomic developments and can affect sustainable development goals if it continues (Mukherjee et al., 2020b). Socioeconomic indicators of water and sanitation are strongly correlated with the spread, recovery, and death cases in many countries, but not all. Thus, interacting factors, including WASH, influence the spread of COVID-19 (Roy et al., 2020). The pandemic formed a challenge to provide populations with clean water in many countries (Brauer et al., 2020). Low-income countries and the socioeconomic vulnerable populations are the most affected by this crisis (Lafortune et al., 2020); for instance, it affects access to clean water (Mukherjee et al., 2020b) and safe sanitation (Solberg and Akufo-Addo, 2020). For example, in many Indian cities it increased the gap between the supply and the demand due to the travel restrictions that affected the movement of tankers. Moreover, the need to obtain water obliged people to stand in long lines for long hours; these gatherings and lack of proper masking might increase their vulnerability to the infection. COVID-19 may increase the gap in access to water and sanitation between the poor populations in certain situations and the rest of that society (Hara et al., 2020). Analyzing the relationship between the pandemic and access to water in Sub-Saharan Africa showed that poor access to water used for sanitation in many populations is associated with high fatality rate (Amankwaa and Fischer, 2020). Poor access to water was found to be linked to COVID-19 transmission in Nigeria (Odith et al., 2020) and Sub-Saharan Africa (Amankwaa & Fischer, 2020; Jiwani & Antiporta, 2020). Water sharing and water insecurity increase social contact between people and thus increase their probability of being infected. People fetch water in areas with water insecurity and do not risk their position in the waiting line. Moreover, waiting for the opportunity to get water during a pandemic where water is essential; thus, they may have more social contact with others who might be infected (Stoler et al., 2020). It is to be noted here that in Mexico City, the residents left their houses to live with their relatives where the water supply is more reliable (King and Kahn, 2020). In the Navajo Nation, the communities with water shortages faced a spike in COVID-19 cases (Chappell, 2020). Moreover, handwashing with soap is not frequently used in many homes in the slums of Indonesia and India. The pressure on water and soap availability also increased the possibility of generating disease due to water scarcity while purchasing water from the vendors who did not wear masks and using public toilets, communal bathing, and common washing facilities (Parikh et al., 2020). Most Pacific Islands face a water shortage. For example, the rural areas in the Republic of the Marshall Islands (RMI), the Solomon Islands, and Vanuatu have had a high percentage of households without water and soap facilities (Lal et al., 2020).

Negative effect of COVID-19 on water consumption

In Turkey, generally, the consumption of water increased in the country with the spread of the virus in March due to recommendations regarding disinfection and hygiene, and then it decreased in major cities when the lockdown was applied to these cities because the people moved to their hometowns and increased again, and after the cases started to decrease, the people started to return to the major cities (Yilmaz and Osborn, 2020). According to a study (Sayeed et al., 2020), 88.4% of the people washed their hands more during the pandemic, and 1,179% more water was wasted because people kept the faucet on while washing their hands. In a case study in Joinville, Southern Brazil, residential water consumption increased by 11% (Kalbusch et al., 2020).

Negative effects of governments' water plans during the pandemic

Many governments tried to support the water sector during the pandemic, but their efforts did not reach their goals. Shifting the usage of water from the agriculture sector to cities decreased the production, and shifting the usage in the opposite direction did not help in combating the pandemic (Cooper, 2020). For example, in Ghana, even with efforts to reduce the negative impact on the most vulnerable households, the free water directive still was not sufficient. That is due to many factors such as 1) the lack of a clear plan for payment to the private water providers, 2) not including the sachet water in the initiative even though it provides drinking water to the poorest people, and 3) not receiving regular water supply, which forced people to store water in order to face the low pressure of the received water and the water-providing valve (Amankwaa and Ampratwum, 2020).

Even though there were plans to provide water during the pandemic to the most vulnerable communities in Ghana, the people living in poor urban communities may have less access to water. This is because the majority of these people have no piped water in their homes, and they buy water from the water vendors, which is not free, and because of that, they have difficulty minimizing their social contact with others to stay safe. In addition to these communities, people who had their supply previously disconnected or had challenges with the company that provided water also suffer from a lack of water (Shang-Quartey, 2020).

COVID-19 exposed inequalities present in Jakarta's community with a particular threat to the poor people. The economic crisis reduced poor communities' income and thus reduced revenue on water and its availability in these communities. As a consequence, they also faced a risk of piped water cut-off. It inspired the national government to promote water privatization with help from international agencies. The provincial government on the other hand promoted public–private cooperation in flood mitigation projects (Marwa, 2020). The council in Cape Town increased its water tariff by 4%, thus affecting low- and middle-income people who consume more than 6 kiloliters per month (Ruiters, 2020). Although rural areas in Burkina Faso claimed to pay more than urban areas, they were deprived of the free water provided by the response plan, which increased inequalities between the two areas. Users tended to use the water provided by standpipes, free of charge, after the social block, so a portion of the water bill that was covered by the state finishes and thus causes a loss for ONEA. The state delayed compensating ONEA, which worsened the operator's situation due to its high debt ratio. Inhabitants of Bissighin in Burkina Faso drilled wells to face frequent water cuts and low flow. Some vulnerable households drilled wells that lacked guarantee for good water quality (Baron and Guigma, 2020). In Burkina Faso, water consumption increased. People crowded to collect free water at standpipes and thus created a problem to minimizing social contact. People who were unable to pay water bills or those who live away for free provide water at standpipes had to pay for informal water vendors; thus, even if the water was free, they had to pay for its transport (Baron and Guigma, 2020).

Positive consequences of COVID-19 on the water sector

Positive effects on water quality and marine life

During the lockdown, the major pollution sources affecting the aquatic ecosystems were either partially or completely closed (Häder et al., 2020). The lockdown enhanced the water quality index in the Yamuna River in India (Arif et al., 2020), although it did not reach the standard limits determined by the CPCB (Patel et al., 2020). It also decreased the turbidity, suspended particulate matter (SPM), biological oxygen demand (BOD), and chemical oxygen demand (COD), although the FC increased due to the presence of domestic and livestock excretions (Patel et al., 2020). The water quality improved in the Dwarka River to the range of permissible limits, and the dissolved oxygen increased due to the lockdown and absence of dust admixture with drainage debouches (Mandal and Pal, 2020). The decrease in the usage of motorboats in Venice improved its water quality (Braga et al., 2020; Clifford, 2020; Link, 2020; Saadat et al., 2020). The water quality in the River Ganga (Ganges) was also improved (Mani, 2020), the DO levels increased, and the BOD levels dropped (Sandrp, 2020). The dissolved oxygen (DO) in the Ganga River increased considerably in Kolkata City during the lockdown (Dhar et al., 2020). Likewise, the turbidity in the Ganga River decreased due to a decrease in discharged effluent (Garg et al. 2020). The DO levels increased in the Gangetic delta region of West Bengal during the lockdown after industrial activities had stopped (Chakraborty et al., 2020). Similarly, the water quality showed improvement in the Mandakini River (Chaurasia et al., 2020). Because of improved water quality, some places became suitable for wildlife and fisheries (Ramachandran, 2020). Decrease in pollution was apparent in Haridwar Ghats since holy bathing and dumping of flowers and wastes decreased in Buddha Nullah because industries were closed (Hindustan Times, 2020) and in the Yamuna River (Lokhandwala and Gautam, 2020). Suspended particulate matter was reduced in Vembanad Lake (Yunus et al., 2020) and the Sabarmati River (Aman et al., 2020) during the lockdown. Wastewater discharge in the Boukhalef River decreased (Cherif et al., 2020).

The absence of tourists on many beaches such as those in Spain, Ecuador, Mexico, Tuticorin, Salinas, Manta, and the Galápagos Islands were found to become cleaner (Ormaza-González and Castro-Rodas, 2020; Selvam et al., 2020; Zambrano-Monserrate et al., 2020). Also, the lockdown reduced the fecal coliform and the groundwater-borne cationic solutes in Tuticorin City (Selvam et al., 2020). It helped decrease the presence of chlorophyll-a, thus showing improvement in the quality of Indian coastal water. It also facilitated the classification of these waters into urban nutrient-sensitive and nutrient-insensitive regions, which was not possible before this period (Mishra, D.R., et al., 2020).

Even though Wuhan lakes and Vembanad Lake showed a decrease in suspended matter (Yunus et al., 2020), the Chl-*a* increased during the first period of the lockdown but decreased thereafter probably because the prolonged hydrological residence time settled down the surface phytoplankton (May et al., 2003), and the concentration did not change in the second lake probably because it is not a closed lake (Avtar et al., 2020). The prolonged hydrological residence time, the time spent by water at any unit of the network (Leray et al., 2016), increases the primary productivity in the aquatic systems (Hein et al., 1999) and

TABLE 7 Actions taken by different governments and water policymakers to face the pandemic.

Continent	Country	No direct intervention	Fiscal measures	Water measures
Europe	Austria, Greece, Luxembourg, Romania, Luxembourg, and Slovenia	✓	—	—
	Belgium, Croatia, Cyprus, Denmark, Estonia, Finland, Germany, Hungary, Malta, Poland, Slovakia, and Sweden	—	✓	—
	France and Italy	—	—	Financial support
	Bulgaria, Italy, and Portugal	—	—	Temporary suspension of bills
	The Netherlands and Latvia	—	—	Bill extension
	Spain	—	—	- Ban the restriction of water -Financial support to vulnerable households and self-employed workers
	Lithuania	—	—	Encouragement of municipality-based decision to install or reschedule the bill payment
North America	The United States	—	—	Many utilities stopped water cuts during the pandemic - Baltimore • Prevent cutoff for the service from any work utility • Abandon late fees • Allow repayment for those falling behind • Ensure accessibility for water even beyond the emergency • Extend water billing assistance for unemployed • Delay of scheduled rate increase of water bills
Africa and South America	Burkina Faso, the Democratic Republic of the Congo (DRC), El Salvador, Gabon, Ghana, Guinea, Kenya, and Togo	—	—	Provide free water for a period of time
	Uganda	—	—	Prevent disconnecting water from those who did not pay
	Bolivia and Mauritania	—	—	Cover some of the bills
	Ghana, South Africa, and Eswatini (Swaziland)	—	—	Cooperate with informal water providers
	Ethiopia, Kenya, and Eswatini (Swaziland)	—	—	Rehabilitate and develop infrastructure
	South Africa	—	—	Establish hotline for people who need water
	Ivory Coast	—	—	Paid water bills for low-income households
	Ghana	—	—	Absorbed bills for citizens for 3 months
	Cape Town	—	—	Send a water truck and provide water for informal settlements
	Burkina Faso	—	—	- Ask donor organizations to fund a response plan to face the pandemic - For 3 months, fund "social block" that included 8 m^3, cancel delayed payments, and prohibit standpipes charges
	Suva, Fiji	—	—	Improve sanitation systems

shows higher chlorophyll-a concentrations (Stumpner et al., 2020). The water quality of Dubai Creek lagoon improved due to low industrial activities, showing good results in DO, turbidity, PH, salinity, and Chl-*a* (Rajshree et al., 2020). In a case study in Joinville, Southern Brazil, the industrial, commercial, and public water consumption decreased by 53%, 42%, and 30%, respectively (Kalbusch et al., 2020). The arrival of marine species and other positive changes at the beaches of Salinas and Manta, due to the absence of tourism, were noticed by the population, according to a survey (Ormaza-González and Castro-Rodas, 2020). Fish species also increased as industrial pollution decreased (Mantur, 2020).

Positive effect on water consumption

During the pandemic, while implementing lockdown measures in Europe, electricity demand decreased due to slower economic activities, and thus water consumption to generate electricity was also reduced. Water footprint was also decreased as a result of reduced generation of electricity and the usage of different technologies with a less water-intensive mix such as decreasing water-intensive thermal cooling technologies and increasing non-water-consuming technologies. Although lockdown-like measures affect virtual water transfer between neighboring countries, Germany and France increased their virtual water import. On the other hand, Italy reduced its foreign consumption (Roidt et al., 2020).

Positive effects of governments' plans for water availability

Governments and water management officials applied some measures to support the water sector during the beginning of the pandemic (Table 7).

These measures differed according to a country's economic situation mainly, even though some measures were common between rich and poor countries. The pandemic encouraged the competition between the different political parties within some countries to ask for better water service. In rich countries, including many European countries, either they did not make direct intervention in the water sector, such as Austria, Greece, Luxembourg, Romania, Luxembourg, and Slovenia or they implemented fiscal measures to help the consumers pay their bills by providing financial support or creating a relief to compensate their loss of income, such as Belgium, Croatia, Cyprus, Denmark, Estonia, Finland, Germany, Hungary, Malta, Poland, Slovakia, and Sweden. Only 11 European countries implemented water-related measurements, which include financial support such as in France and Italy, temporary suspension of bills such as in Bulgaria, Italy, and Portugal, and bill extension such as in the Netherlands (which also supported the agricultural sector) and Latvia (Antwi et al., 2020). Spain banned the restriction of water and provided financial support to vulnerable households and self-employed workers. The government also postponed the unpaid bills (Spanish Government, 2020). Terrassa created a new public water operator and a citizen observatory. Because the public fountains were closed, the public water company recommended installing provisional meters for the houses with no access to water. The public water operator suggested the allocation of €500,000 to reduce water bills during the second quarter of 2020. It established three discounts: 100% for the first block of domestic consumption and the first block of commercial users beside €5 reduction for the second block of domestic consumption. These discounts were added to the discounts by 50% on the fixed bill (100% for the vulnerable households) offered by the regional water supplier. The council suggested also delaying the payment of the second quarter. Manresa also installed provisional meters for vulnerable houses (Satorras et al., 2020). The water companies also facilitated water access. For example, Canal de Isabel II charged only the consumption part of the water bill and did not charge the fixed fee during the pandemic. It charged 50% of the fixed bill during the first 6 months of emergency lifting and 25% the next 6 months. It also offered a 100% discount for consumption and a 50% discount on the fixed bill charges for those affected by temporary job loss (Canal de Isabel II, 2020). Aigües de Barcelona extended the water bills for 6 months after the emergency state ended, with no interest for the self-employed and the owners of small and medium enterprises (AMB, 2020). EMASESA also delayed the payment for 6 months after the emergency ended (EMASESA, 2020). Lithuania encouraged a municipality-based decision to install or reschedule the bills' payment (Antwi et al., 2020). In addition, the pandemic extended the public consultation process formed for the third cycle of River Basin Management Plan in Ireland (Catchments News, 2020). Due to the importance of water during this pandemic and the economic obstacles facing the people, many utilities in the U.S. stopped water cuts during this time period (Saiiyid, 2020). Baltimore provided other forms of support for the water sector than rushing to reconnect households to the provided water service because it is one of the few cities that has a pre-existing policy against water shutoff (Food & Water Watch, 2020) and did not disconnect any household since 2017 for non-payment (Clemmens, 2017; 2018). The Department of Public Works (2020a) announced that it will not cut off the water service from any work utility (unless it is a case of emergency), and it abandoned all the late fees and proposed plans for repayment for those falling behind in paying their bills. The Baltimore Right to Water Coalition (2020) asked the mayor and the city council to ensure the accessibility of safe and affordable water not just during the emergency but also beyond that. A city councilwoman also asked for 180 days of water billing moratorium. As a response to the pandemic, the city also extended the water billing assistance for the people who showed unemployment eligibility (Department of Public Works, 2020b). It also launched an online application for the assistance program to facilitate the application process and delayed the scheduled rate increase on water bills (Department of Public Works, 2020c).

In poor countries, the measures taken to support the water sector were at two levels: official and community. At the official level, several African and Latin American countries implemented initiatives to provide water for the most vulnerable populations that cannot afford the water bills. Some countries provided free water for a period of time (such as Burkina Faso, the Democratic Republic of the Congo (DRC), El Salvador, Gabon, Ghana, Guinea, Kenya, and Togo), decided not to disconnect water from those that did not pay (such as Uganda), decided to cover some of the bills (such as Bolivia and Mauritania), cooperated with informal water providers such as tankers (such as Ghana, South Africa, and Eswatini (Swaziland)), and rehabilitated and developed their infrastructure (such as Ethiopia, Kenya, and Eswatini (Swaziland)) (Amankwaa and Ampratwum, 2020). The Colombian president decided to reconnect the water services to the most vulnerable families, whose water service had been disconnected before the pandemic, and froze the tariff during this period. On the other hand, the households continued to add to their service debt because their existing debts and bills for the water they were consuming during the pandemic were not stopped. Also, a rejection from the Mayor of Bogota, Claudia López, and others was responded by permission given by the president to the local leaders to allocate a portion of their budget to the utility services. Thus, the water bills had a discount of 10% in case they were paid in advance, and the discussion about the *minimo vital* re-emerged. The *minimo vital* are programs that guarantee the basic water amount being offered for free to low-income neighborhoods (Arias Castaño and Furlong, 2020). Therefore, the political competition was for the benefit of the poor populations and subpopulations. South Africa established a hotline for the people in need of water to help them, Ivory Coast paid water bills for low-income households, and Ghana absorbed the bills for its citizens for three consecutive months (Amuakwa-Mensah et al., 2020). Some organizations in Colombia and in response to the pandemic took some extra precautions, including improving the infrastructure, monitoring the environmental conditions of the hydrographic micro-basins, and following protocols that ensure water treatment and purification (Roca-Servat et al., 2020). KMMSAJ, in Jakarta, demanded the re-municipalization of water services. It was spreading its demand online and used online discussions and conferences to increase public pressure, while other organizations demanded handwashing facilities and water payment relief. As a result, PAM Jaya only installed handwashing facilities in one third of informal settlements (Marwa, 2020). Cape Town's officials sent a water truck to informal settlements. The council invested money to install tankers, provide water, and deep clean informal settlements. The city's Water and Wastewater Portfolio Committee suggested additional water supply and tankers to improve water access (Ruiters, 2020). Burkina Faso formed a response plan to face the pandemic and asked donor organizations to fund it. For example, the Agence Française de Développement (AFD) supported the public operator, ONEA, and funded free water at standpipes. The state funded "social block" that included 8 m^3 for three months to help urban households and regular and irregular neighborhoods that have private connections with their water bills. It also cancelled delayed payments and prohibited standpipe charges for the same months (Baron and Guigma, 2020). In Suva, Fiji, the sanitation systems were improved to face this pandemic (United Nations Children's Fund, 2020). In Ghana, the water was not disconnected, the government absorbed the bills for a few months, tankers were used to provide water (Emmanuel, 2020), and the Ghana Water Company asked the public to store and preserve water in addition to forming a strategic plan to cooperate with other institutions that have tankers and can provide water for the vulnerable communities (Dapaah, 2020). Protective personal equipment was provided to the workers that had to meet the customers. This shows the importance of public water management (Shang-Quartey, 2020). While at the community level, the frequency of handwashing in Sub-Saharan Africa increased, especially in the rural areas when compared to the urban areas. They wanted to protect themselves more due to many factors including the absence or deficiency of health infrastructure in the rural areas, the difficulty of buying protective equipment due to their poor economic situation, and the higher percentage of elderly people (Amuakwa-Mensah et al. 2020). Also, the community aqueducts took extra precautions, including prolonging the boiling time and its exposure to solar radiation, introducing or expanding the usage of pre-chlorination intake for water, treatment plants, storage tanks, and household filters. While in rural areas and due to the diverse uses of water, domestic treatment was adapted instead of conventional, centralized treatment (Roca-Servat et al., 2020). People with private connections, in Burkina Faso, helped their neighbors and gave them free water from their homes. People stopped sharing food or water with other people using the same dish or plate. They stopped using the water more than once for dishwashing and started washing the dishes twice. They also stopped sharing buckets for washing themselves and started washing their clothes more frequently. Some people established handwashing facilities (Baron and Guigma, 2020). Therefore, countries tried to make water available for the poor populations and subpopulations, but many of these measures are not permanent. This threatens the water availability for these people after these measures are removed. Also, water quality improvement was related to a lack of human activities, but with the absence of lockdown and strict law measures, the water quality will be threatened again.

Recommendations

In this section, we suggest some recommendations for the different participants in the water governance system, including governments and water policymakers, wastewater treatment plants, the general population, and researchers related to the water sector. These recommendations help to monitor and protect the water sector in order to ensure the availability of water with good quality to all populations in the community.

Governments and water policymakers

Recommendations for governments and water policymakers are divided into two parts: the first is to ensure water availability, and the second is to monitor pollution in the water.

For water availability

Water availability decreases the need to search for water resources and thus decreases the probability of virus transmission due to contact with other people. In order to guarantee that water is available for all the population in a certain country, governments and policymakers have to determine the real priorities concerning public health and clean water availability, and for that, they must support the following steps:

- Cooperate at an international level to improve hygiene and enhance access to safe and sufficient water in order to face health threats (Everard et al., 2020).
- Encourage investment in climate change mitigation strategies to decrease the effect of the drought (Mishra, A., et al.,2020).
- Support emergency aid programs to decrease the negative effect on the economic sector (Mishra, A., et al.,2020).
- Move from crisis management to risk management requires reforms. This is achieved by
  i) supporting the usage of digitization in the water sector.
  ii) reducing the leakages in the water system.
  iii) involving the citizens and different stakeholders in an interlinked approach in water management and governance.
  iv) monitoring the pollutants found in the water system (Miglietta et al., 2018; Lamb, 2020; Water Europe, 2020).

-Plan at river basin scale and form co-management policies between countries.

- Develop, at a river basin scale, the region's storage by enhancing the creation of a more resilient system, such as managing wastewater treatment for reuse (UN-Water, 2019; Rodriguez et al., 2020), and managing transboundary water resources.
- Apply restoration and conservation at the watershed level to enhance water security in urban areas and provide some advantages to rural areas (Cooper, 2020).
- Manage the links between the resources and the users located upstream and downstream for the medium term (Cooper, 2020). This increases the water availability for users and thus decreases their need to gather in order to collect water.
- Apply good water governance by
  1) involving the citizens and the communities in the decision-making process.
  2) building knowledge for the involved institutions.
  3) using new data tools such as water accounting that helps to understand and solve water problems (Cooper, 2020).
- Apply integrated water management policies (Upadhyay, 2020) and groundwater management plans (Mukherjee et al.,2020a).
- Create green infrastructure in the cities in order to decrease the flood risks, decrease water treatment costs, and improve the water quality (Cooper, 2020).
- Construct wetlands to treat wastewater produced in remote areas (Wu et al., 2011). Use geosynthetic liners (Patil et al., 2017), pure zeolites, and fly ash zeolites (Jha and Singh, 2012; Koshy and Singh, 2016) to avoid secondary contamination of soil and water. Explore the effectiveness of these techniques on COVID-19 in research.
- Protect wetlands and improve soil moisture to enhance water storage and availability (Cooper, 2020).
- Develop modernized technology in agriculture and include science in risk governance (Mishra, A., et al. 2020).
- Ensure payment for water providers to guarantee substantiality of water supply (Amankwaa and Ampratwum 2020).
- Support municipality-owned water utilities as it showed to be successful because they cooperate with other municipal organizations (Juuti and Rajala,2020).
- For sanitation:
  - Ensure good training for poorer populations that tend to be at high risk due to their malnutrition (França de Freitas,2020; Sabastiani and Costa,2020), especially those at rural areas that have no access to what is happening in the world (Adelodun et al., 2020).
  - Distribute water in an equitable way.
  - Make water services affordable or free in order to reach the most vulnerable populations (Staddon et al., 2020).
  - Ensure access to good-quality piped water.
  - Enhance the availability of regulated water points and kiosks. Install new infrastructure including waterless toilets (Cooper, 2020).
  - Expand the coverage of WASH to include more households, schools, and healthcare facilities to face future pandemics (Lal et al., 2020; United Nations Children's Fund, 2020).
  - Assess water consumption during a crisis to ensure that water is available while the supply is maintained and guaranteed (Kalbusch et al., 2020).
- Support access to good quality drinking water and fully operational wastewater services in an urgent way (García-Ávila et al., 2020).
- Extend the sewer network to reach houses in places that are not connected to the network (Cooper, 2020).
- Follow an affordability water program that is based on percentage-of-income payment and debt forgiveness

as a long-term protection for the water resources (Grant, 2020).
- Ban the water resource privatization and stop the shutoff measures for unpaid bills.
- Apply strict guidelines for disinfectant usage (Quinete and Hauser-Davis, 2020).
- Address water-based needs for refugees to inhibit waterborne disease outbreaks in the refugees' settlements (Rafa et al., 2020).
- Encourage saving water by
  - raising public awareness using social media and education.
  - distributing water resources for washing and drinking where public gatherings are found (Haddout et al., 2020).
- Take into consideration the sustainable usage of water, facilitate water purification, and optimize water utilization for long-term planning (Haddout et al., 2020).
- Support the transition to a low-carbon economy and decrease the effects of climate change by restoring the peatlands. This can be accompanied by
  - monitoring the released greenhouse gases.
  - enhancing their biodiversity and carbon sequestration.
  - developing green paludiculture innovations and blue services including water retention (Rowan and Galanakis, 2020).
- Use the PEG precipitation method for monitoring seawater, as it proves to be the best method for concentrating PEDV in tap water. In addition, low and high centrifugation speeds did not have a significant difference in the recovery process of seawater. Thus, it facilitates the process of involving a large number of laboratories as described in Cuevas-Ferrando et al.(2020a).

Pollution monitoring

Pollution monitoring facilitates the availability of good water quality and thus decreases waterborne diseases and the contact with other people in order to search for water with good quality. Therefore, it is essential to control virus transmission during this pandemic and the spread of other diseases. For that, governments and policymakers must follow the following steps:

- Apply adequate waste management plans and monitoring programs to identify the sources of pollution
- Assess the post-pandemic effect on the marine ecosystem and prepare teams to face this pollution (Canning-Clode et al.,2020)
- Apply quantitative microbiological risk assessment on COVID-19 because rivers can be vectors for viruses that facilitate its spread (Robins et al., 2019)
  - It is a scientific approach to merge the information about a certain pathogen in the water cycle, including its presence, nature, fate, transport, and effect on humans after exposure to this pathogen (Haas et al., 2014)
  - It was previously applied to adenovirus, rotavirus, and enterovirus (Toze et al., 2010; Kundu et al., 2013; McBride et al., 2013)
- Use a low-cost point-of-use device to inactivate or remove the virus, such as ironoxide bio-sand filters (Bradley et al., 2011), zero-valent iron filters (Shi et al., 2012), nanocellulose-based filters (Mautner, 2020), and gravity-based ultrafilters that are used for gastrointestinal pathogens found in wastewater (Chaidez et al., 2016) and those used for enteric viruses (Gerba et al., 2018)
- Take precautions so that the virus will not become waterborne, as what occurred previously with other viruses (Adelodun et al., 2020; Arslan and Xu., 2020; Street et al., 2020), even though no recorded infection till now has been caused by consuming and using water contaminated by the virus (La Rosa et al., 2020b)

Wastewater treatment plants

It is important to monitor wastewater during this pandemic and the future pandemics because this facilitates monitoring the diseases circulating in a population and controlling them. To do that, a wastewater treatment plant must

- Monitor the wastewater to determine the virus presence and investigate any early warning for future viruses that can lead to future pandemics (Bivins et al., 2020b; Daughton, 2020; Espejo et al., 2020; Lodder and de Roda Husman, 2020; Quilliam et al., 2020)
- Share with the public information about the importance of wastewater surveillance in detecting the circulating virus and its variants, as described on the website of the
- CDC: https://www.cdc.gov/healthywater/surveillance/wastewater-surveillance/wastewater-surveillance.html (accessed on 6 May, 2022)
- Metropolitan Council: http://metrotransitmn.shinyapps.io/metc-wastewater-covid-monitor/ (accessed on 6 June, 2022)
- South African National Institute of Communicable Diseases: https://wastewater.nicd.za/ (accessed on 6 June, 2022)
- Support field and laboratory facilities for wastewater testing using low-cost methods (Adelodun et al., 2020) such as paper-based and biosensor devices (Mao et al., 2020; Mavrikou et al., 2020)

- Follow simple methods for testing wastewater in low-income countries (Street et al. 2020)
- Distribute manuals that include recommendations about the necessary safety measures for sewage treatment plant workers (Babiano, 2020; Nolasco, 2020)
- Apply high treatment standards in wastewater treatment plants that are located near high-risk cities with small flow river basins, intensify the disinfection to contribute in the spread control (Yang et al. 2020), and protect groundwater from sewage leakage from nearby pipelines (Yang et al. 2020)
- Treat medical wastes as hazardous wastes; thus, they must be collected by specialized operators (UN, 2020)
- Apply efficient treatment for high drug concentrations
- Use bioreactors and disinfection methods for decreasing the viral loads in the wastewater (Naddeo and Liu, 2020)
- Use optimized conventional filtration, such as ozonation, UV radiation, and chlorination using sodium hypochlorite
  - This can have good results for disinfection by reaching 2 logs (99%) of virus removal (Khadse et al., 2020)

General population

Good water governance includes the general population in water-related decisions. To maintain the availability of water with good quality during this pandemic and future pandemics, the general population has to

- Use chlorine tablets and boiling as disinfection methods for the drinking water if they are consuming it from a source that has a risk of contamination (Mupatsi, 2020)
- Minimize the risk of transmission through the wastewater plumbing system by
  - Solving the problems of any unexplained foul smells and ignoring them
  - Having a functioning U-bend in the water appliances in both the bathroom and the kitchen
  - Opening the tap water for at least 5 s on all water appliances and paying attention to any floor drains will help preventing the loss of the water trap seal within the U-bend used in the water appliances
  - Sealing any disconnected wastewater pipework from water appliances, using a rubber glove, a plastic bag, and tape
  - Sealing any crack or leak that appears in the pipework with tape and glue
- Monitor large buildings as a whole system (Gormley et al., 2020)
- Save water at the household level by
  - fixing the leaks
  - not allowing the water from the taps and the shower to run unless it is used
  - not using clothes washers and dishwashers unless they are fully loaded
  - using push tap and sensor tap to save water during handwashing
  - following behavioral changes in low-income countries where water is scarce (Sayeed et al. 2020)
- Hospitals must follow a water safety plan. This includes the maintenance of the systems, the training of their staff, and following strict surveillance for environmental microbiological factors (De Giglio et al., 2020)
- Avoid contaminating rivers and coastal areas with untreated wastewater (Shutler et al., 2021)

Research

To monitor the water systems during this pandemic and future pandemics, some topics must gain more attention, and researchers should follow the following steps:

- Apply the Driver-Pressure-State-Impact-Response elements (DPSIR) to determine the human-environmental linkages in boosting zoonoses, including COVID-19, thus making recommendations for future similar cases (Everard et al.,2020)
- Encourage low- and middle-income countries to invest in empowering laboratory networks (Adelodun et al.,2020)
  - Determine the efficiency of the measures taken to face the presence of the virus in the aquatic systems (Iyiola et al., 2020); for example, determine if it is necessary to follow the Chinese protocol of increasing chlorination to prevent transmission through wastewater (Zambrano-Monserrate et al., 2020)
- Study the long-term effects of exposure to the contaminants present in drinking water resulting from their usage and mixing and pay particular attention to the respiratory problems that they cause (Quinete and Hauser-Davis,2020)
- Determine the survival rate, infectivity, and persistence of SARS-CoV-2 in water systems (Cahill and Morris, 2020; Maal-Bared et al.,2020) under different conditions
- Determine the survival of the virus in water resources in tropical, subtropical, and temperate climatic zones due to differences in temperature (Hart and Halden, 2020)
- Investigate the possibility of fecal–oral transmission, especially in low- and middle-income countries (de Lourdes Aguiar-Oliveira et al., 2020)
- Study the potential threat of SARS-CoV-2 on downstream water used for irrigation purposes, recreation purposes, and drinking water (Guerrero-Latorre et al.,2020; Shutler et al.,2021)
- Study the presence of the virus using a large volume of water either naturally contaminated or using a SARS-CoV-

2 spike and determine the method limitation such as the method used by Cuevas-Ferrando et al.(2020a)
- Encourage more research on COVID-19 economy–society interaction to improve the decision-making process (Roy et al.,2020)
- Develop techniques that detect and inactivate the virus in water and wastewater systems (García-Ávila et al. 2020)
- Assess the risk caused by the virus and disinfectants on different water bodies
- Explore more of the secondary disinfectants products present in landfill leachate because leachate composition due to its high amount of organic matter can form dangerous disinfection by-products (Paleologos et al. 2020)
- Apply metagenomic sequencing for water and wastewater transmission to avoid geo-environmental degradation (Paleologos et al. 2020)

Discussion

COVID-19 affects different domains in a human's life, including the environmental sector and particularly the water sector. Literature shows different methods to detect its effect on the water sector, and most of them focus on water quality. Water quality has biological, chemical, and physical indicators. These indicators include chlorophyll, an indication of phytoplankton biomass and algal production, harmful algae that indicates rapid growth for algae or cyanobacteria, turbidity, and suspended substances. To investigate the effect on water quality, remote sensing and water quality assessment can be efficient methods. Remote sensing includes using Landsat 8 OLI images, Sentinel-2, Sentinel-3 WST, Sentinel-3, and the Ocean and Land Color Instrument (OLCI). Landsat 8 is a satellite that can obtain about 500 images per day at a global scale with higher resolution wavelength coverage than ETM+ because it has a coastal/aerosol band that detects suspended substances and chlorophyll and a cirrus band to detect the clouds in the region (Lim and Choi, 2015). Sentinel-2 can support sustainable water management due to its high spatial resolution that allows monitoring inland and coastal water (European Space Agency, 2022). Sentinel-3 WST images have a higher horizontal resolution than Landsat 8 and require minimum post-processing while also being good for near real-time monitoring (Cherif et al., 2020). The Ocean and Land Color Instrument (OLCI) provides information about water quality and ocean ecosystems because it has 21 spectral bands in the visible and near infrared spectrum and a resolution of 300 m, with the swathe width of 1,270 Km (EUMETSAT, 2022). Remote sensing is a useful technique in determining the water quality, for example, the suspended particles in water are indicators of eutrophication as their concentration increases the turbidity and the reflectance in the visible region, particularly the red region (Garg et al.,2020). In addition to that, it saves time and effort needed for field work. It is of particular importance during a pandemic because it shows results in a short time, while obeying the rules of lockdown. On the other hand, water quality assessments determine whether or not a pollutant is present in an environment and whether or not it is affecting quality for specific usage (Bagchi and Bussa,2011). It can show, for example, the biological oxygen demand (BOD), which increases in the water with the increase of deposed organic wastes and is inversely proportional to the dissolved oxygen (DO), which is necessary for aquatic organisms (Chakraborty et al.,2020).

The presence of SARS-CoV-2, the virus causing COVID-19, in wastewater has gained attention in the literature, in which studies show different methods to follow, but the persistence of the virus in wastewater in poor countries is still needed. This topic is important because the virus can be found in feces, urine, and thus in wastewater. Globally, about 80% of wastewater is released untreated into the environment, and this percentage can reach more than 95% in developing countries **(**United Nations Children's Fund and World Health Organization, 2020**).** In poor countries where people usually drink from surface water that can be contaminated by wastewater or use fewer disinfection products, the virus can be a threat to public health because it might be spread through contaminated water. Also, because COVID-19 is transmitted by aerosols, its aerosolization from wastewater cannot be ignored, especially that SARS virus can be transmitted through fecal-aerosolized particles, as the outbreak in the apartment in Hong Kong during 2003 (Hung, 2003). Also, SARS-CoV-2, similarly, can be aerosolized from wastewater and is linked to a cluster where transmission occurs *via* floor drains (Han et al., 2022). Thus, it is important to focus on this topic because people in poor countries might use public toilets due to the absence of a common sewage network in private toilets, for which they must be warned to wear proper masks and take precaution in this case. Also, people in populated cities might use public toilets or live in buildings with improper U-bends in the water appliances, which need to be fixed. During the pandemic, wastewater-based epidemiology has gained attention. It is a useful domain in epidemiology that helps determine the effect of vaccines and to what extent they help prevent the virus from spreading in the population. It also helps to determine the spreading variants in a certain community. In particular, with the presence of the new variants and the waning of the immunity created by the vaccines, it helps determine when a variant is spreading and thus creates an alarm for the health authorities to prevent an upcoming wave of the virus.

The pandemic's negative effects on the water sector are diverse. Some of its effects are temporary, while others might have long-term effects. It is the cause of increased protective personal equipment usage; this can cause an increase of microplastics in water systems resulting from the degradation of masks. The microplastics can affect not only aquatic organisms but also human health. Thus, it causes a threat to public health in case the resulting wastes are not treated properly in a way that saves human health and the environment. It is also the cause of increased medication usage, and some of these medicines can also pose a threat to the water sector and human health if wastewater, particularly medical wastewater, is not treated properly. This threat has higher probabilities in poor countries. Because the virus might be transmitted to the people through the consumption of contaminated water, it adds another threat to the waterborne diseases. This case also has a higher probability in poor countries. Therefore, the pandemic affected the poor populations and subpopulations in a particular way.

It also has some advantages in the water sector. For example, it improves water quality in some regions during lockdowns. Also, because many health authorities consider fomites the main route of transmission instead of aerosols, they try to provide water for their populations, especially the poorest. Their responses varied between poor and rich countries according to their capacities and needs, but in many cases, the poorest populations did not benefit from these efforts. Without requests for proper masking, considering that the virus is mainly transmitted through aerosols, some of the governments' efforts to support the water sector will not only be inefficient but also increase the probability of virus transmission. Hence, most of these benefits are temporary, and some of them are insufficient.

To face this pandemic and the future pandemics, in addition to social justice, governments and water policymakers, wastewater treatment plants, the general population, and researchers have responsibilities to accomplish.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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