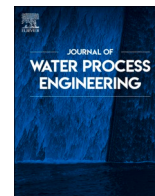




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Direct and indirect effects of SARS-CoV-2 on wastewater treatment

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ABSTRACT

The novel SARS-CoV-2 is expanding internationally. While the current focus is on limiting its transmission from direct contact with infected patients and surfaces during the pandemic, the secondary transmission potential via sewage should not be underestimated, especially in low-income and developing countries with weak wastewater treatment technologies. Recent studies have indicated SARS-CoV-2 positivity also be detected in the feces of patients. Therefore, the risk of transmission and infection can be increased into sewage by the fecal-oral way, mainly in some parts of the globe with a high amount of open defecation. This review collected scattered data and recent studies about the direct and indirect effects of coronavirus in the water cycle. The direct impacts of COVID-19 on wastewater are related to the presence of the coronavirus and suitable viral removal methods in different phases of treatment in wastewater treatment plants. The indirect effects of COVID-19 on wastewater are related to the overuse of cleaning and disinfecting products to protect against viral infection and the overuse of certain drugs to protect against virus or novel mental problems and panic to COVID-19 and consequently their presence in wastewater. This unexpected situation leads to changes in the quality of wastewater and brings adverse and harmful effects for the human, aquatic organisms, and the environment. Therefore, applying effective wastewater treatment technologies with low toxic by-products in wastewater treatment plants will be helpful to prevent the increasing occurrence of these extra contaminants in the environment.

1. Introduction

The crisis of COVID-19, which is caused by the new coronavirus SARS-CoV-2, is presently posing a considerable threat to the economic growth and the health of the world, especially developing countries. SARS-CoV-2 is a single-stranded virus with a positive-sense of RNA and spherical shape, which belongs to the Coronaviridae family [1–6]. SARS-CoV-2 is more transmitted between the people rather than SARS-CoV and MERS-CoV, especially in dense population places such as public transportations, industrial processing factories, prisons, nursing homes, and etc. [7–9]. Despite the worldwide lockdown attempts, the rates of positive COVID-19 cases are still high. The World Health Organization (WHO) has reported the principal ways of coronavirus exposure are inhalation of respiratory droplets produced when a patient sneezes, coughs, and exhales or direct contact with infected surfaces [10]. Recent scientific researches announced the possible waterborne transmission of the SARS-CoV-2. Moreover, the presence of coronavirus RNA was confirmed by several reports in wastewater treatment plants (WWTPs) [11,12]. The risk of transmission by the fecal-oral way into sewage can

also be a crucial concern and should be highlighted in the areas that have not adequate water treatment and sanitation facilities [12,13]. Even when the respiratory tract shows negative, stool may stay positive for SARS-CoV-2, and it raises a set of concerns about the possible presence of the virus in the effluent and choosing the appropriate methods for wastewater treatment to inactivate the virus [14].

Moreover, during the COVID-19 pandemic, the municipal wastewater can usually observe other excessive contaminants like disinfectants, pharmaceuticals, and disposable personal protective equipment, which are generally excreted by humankind activities [15]. The COVID-19 pandemic has also raised the consumption of certain drugs comprising antimicrobials and antidepressants between people due to improper attempts to protect themselves against the COVID-19 with antibiotics (while it is a viral sickness) and the worldwide occurrence of anxiety and depression. As a result, they can be found in the environment, particularly in the urban water cycle, which is harmful to aquatic organisms and the environment [16–19].

The purpose of this review is to collect the present knowledge about the case of disturbances caused by COVID-19 in wastewater, both

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directly and indirectly, that can encourage researchers in various fields to conduct further research about this emerging problem. The direct existence of the COVID-19 in sewage and wastewater by human droplets, stool, or hospital wastes, the capability of transmission in this way, and effective methods to inactivate the virus in the wastewater. Indirect effects of COVID-19 on wastewater include increased use of disinfectants, hand sanitizers, and surfactants (including detergents and soaps) and the over or misuse of certain medications (such as antimicrobials, antidepressants, etc.). Ultimately, collecting the efficient removal methods for these emerging wastewater contaminants is the other aim of this research.

2. Impact of COVID-19 on wastewater

2.1. SARS-CoV-2

Most viruses found out in stools, such as SARS coronavirus, can come from the superior respiratory tracts by deglutition respiratory secretions. The virus can be destructed by stomach acidity, but it may be protected when mixed with meals or potential resistor to acidic pH. Therefore, it can pass through the intestine. Moreover, it can derive from the replication of the virus in intestinal cells [20,21]. In 2002 and 2003, during the two outbreaks of SARS-CoV, up to 73% of infected people during the disease development had gastrointestinal symptoms, and the existence RNA of SARS-CoV was illustrated in the fecal specimens, even after ten weeks from the onset of symptoms [22,23]. Researches during the MERS-CoV pandemic showed that one-fourth of infected people announced symptoms, like abdominal pain or diarrhea, before severe respiratory symptoms, and in 14.6% of stool specimens, MERS-CoV RNA was detected [24,25]. Zhou et al. reported that intestinal mucous cells were extremely sensitive to MERS-CoV and could help viral replication [26].

Recent studies demonstrated SARS-CoV-2 positivity also be detected in the feces of patients in the absence of diarrhea and other gastrointestinal symptoms. For example, live SARS-CoV-2 was observed inside the stool of two infected persons without diarrhea symptoms [14]. Lescure et al. have also confirmed SARS-CoV-2 in urine specimens of patients [27]. Tang, A. et al. found SARS-CoV-2 from stool specimen of an asymptomatic ten-year child, which was evident for considering stool to be an extra routine diagnostic specimen separate from the respiratory tract samples [28]. The coronavirus viral concentration in feces of infected people who tested positive were exhibited in the range of almost 10^4 – 10^8 copies/L. However, in sewage, feces dilution is caused to reduce the viral load between almost 10^2 – $10^{6.5}$ copies/L [29]. Although the possible infection of coronavirus is not proved, the existence of the virus is confirmed in the stool of a human until 33 days when the infected person's test is negative for SARS-CoV-2 [12]. The risk of infection increase in some parts of the globe and with a high amount of open defecation. According to UNICEF, 892 million people around the world still use open defecation [30]. For example, statistical data on November 2019 demonstrated that in India, about 28.7% of rural people still do not have access to any type of toilet [31]. Hence, a considerable amount of viruses would be expected in sewage from the number of diagnosed infected individuals, which has been exhibited in studies from many countries affected by this crisis. Currently, real-time reverse-transcriptase polymerase chain reaction (rRT-PCR), nested RT-PCR and quantitative RT-PCR (RT-qPCR), are the methods which are applied for the tracing of COVID-19 RNA [29] (Table 1).

Additionally, medical wastewater of toxic and hazardous materials must be treated before sending out to the wastewater system. Sewage services in healthcare facilities must be managed precisely and in a different way after the COVID-19 crisis, especially in the areas with low financial and technical resources like Palestine and India or some regions of Africa [30,32,33]. Moreover, huge demand in consumption of personal protective equipment (PPE) such as masks, gloves, and shields, and improper disposal of this infected solid waste into the environment

Table 1
Detection of SARS-CoV-2 in wastewater in some parts of the world.

Location	Detection method	Type of sample	Positive sample	References
Milan and Rome, Italy	A novel nested PCR	Municipal wastewater	6/12	[34]
Louisiana, USA	RT-qPCR	Municipal wastewater	2/7	[35]
New York, USA	RT-qPCR	Municipal wastewater	18/22	[36]
Istanbul, Turkey	RT-qPCR	Municipal wastewater	2/2	[37]
		wastewater treatment sludges	7/7	
Southeast Queensland, Australia	RT-qPCR	Municipal wastewater	5/7	[38]
		Municipal wastewater	2/9	
Valencia, Spain	RT-qPCR	Untreated wastewater	35/42	[40]
		Secondary treated water	2/18	
Tehran, Iran	RT-qPCR	Treated wastewater samples of different WWTPs	2/10	[41]

can increase not only the physical pollutants in water bodies but also can increase the risk of coronavirus transmission.

2.2. Cleaning and disinfecting products

Coronavirus can remain viable on surfaces such as stainless steel, cardboard, and plastic for hours or even days [42,43]; therefore, one of the best effective and practical ways to prevent and cope with the spread of coronavirus is to disinfect the surface and hands, and washing them successively. In recent research, it turns out that during the pandemic (from January to February 2020) in Wuhan city of China, almost 2000 tons of disinfectant were released into sewage systems [44,45]. These huge contaminated water, without any treatment, can directly be discharged into water bodies or can reduce the water quality and create significant problems for wastewater treatment. This situation not only brings a high danger risk for drinking water resources but also threatens the marine environment [46,47]. It turns out that excessive and successive use of disinfectants can increase drinking water consumption by 20%, which could lead to more than 15–18% wastewater generation [46]. Furthermore, the huge consumption of disinfectants, detergents, and soaps could find ways to access and contaminate water bodies which is one of the major environmental concerns related to the COVID-19 pandemic [46,47]. Antimicrobial resistance has become one of the other crucial concerns around the world due to the overuse of antimicrobials (antivirals, antibiotics, and antiparasitics) and extreme consumption of alcohol, surfactants, and hydrogen peroxides as the cleansing agents which are caused microorganisms resistance [48].

2.2.1. Surfactants

According to WHO, proper handwashing with soap and rubbing both sides of hands take at least 20–30 s [49]. The detriment to coronavirus spike proteins can lead to the inactivation virus [50]. Detergents and soaps are consist of surfactants, which are explained as the damaging factor for spike proteins or peplomers of the virus. For example, the Ebola virus, which indicates spike-protein mediated host attachment, can be inactivated by surfactant nanoemulsion; therefore, researchers have widely approved surfactants [51]. Surfactants are considered emerging pollutants that are not easily degradable and are stable in the environment for a long time. They are toxic for microorganisms and mammals in different environmental matrices [52,53].

In addition, during the pandemic, there are many other tasks, including disinfecting the indoor or outdoor environment, washing

clothes, showers, and cleaning, which consume a large amount of water [46]. A single hand washes for each person might consume two liters of water if the tap is closed. This amount of water used can be increased to 4 L if the tap is remained open. Under these circumstances, each person consumes more quantity of water than before. For example, in Bundelkhand city of India, water demand was increased 60%–70%. In a similar way, massive operations of fumigation and disinfection have been done in all around words in order to disinfect avenues, streets, hospitals, markets. This situation contributed to huge wastewater generation, which mainly contains pollutants such as detergents [46].

The other main problem of common soap in hard water is sedimentation, which has led to the improvement of organic chemicals. In spite of the fact that the structural characteristics of these developed compounds are like soap, their chemical properties are different, and they can foam whenever they are being used in hard or acid water. Detergents formulation consists of several types of surfactants. Surfactants relied on their electrolytic dissociation and are mainly separated into four groups according to the charge on their head group, including non-ionic, amphoteric, anionic, and cationic [54–56]. Properties of surfactants can be defined by the head group of them [57]. Various used types of surfactants are shown in Table 2, and several impacts of detergents on wastewaters are explained in Table 3

2.2.2. Hand sanitizer

Hand sanitizer can be separated into two main groups: alcohol-free or alcohol-based. Alcohol-based hand sanitizers are recommended by WHO during the COVID-19 pandemic due to their several advantages, including rapid action and protection against viruses and bacteria. This situation leads to the huge consumption of alcohol-based hand sanitizers. For example, in Japan, in April 2020, the production of alcohol disinfectants in the Kao company increased by 2000% to fight the shortage [67,45]. It turns out the overuse of hand sanitizer might become harmful to the environment and human health [68]. Overusing hand sanitizer contributes to antimicrobial resistance, putting more burdens on healthcare professionals, who already have been struggling with this problem [44]. The most effective formulation of hand sanitizer contains 62%–95% alcohol because it could inactivate viruses and denature the proteins of microbes. In general, alcohol-based hand sanitizers are mainly made up of isopropyl alcohols and ethanol [67,45]. Ethanol has a huge directly negative impact on aquatic organisms. Many kinds of research have been done to investigate the effects of ethanol on various species. In addition, the large amounts of isopropanol in water might lead to environmental impairment due to its high potency to decrease oxygen in the water, which ultimately brings adverse effects on the aquatic living system [69].

Table 2

The classification of most commonly used surfactants and their applications [58,59,60–62].

Type	Compound name	Abbreviation	Formula	Application
Anionic surfactants	Sodium dodecyl sulphate	SDS	$\text{NaC}_{12}\text{H}_{25}\text{SO}_4$	Cleaning and hygiene products
	Sodium dodecyl benzenesulfonate	SDBS	$\text{C}_{18}\text{H}_{30}\text{NaO}_3\text{S}$	As a detergent in cleaning products
	Linear alkylbenzene sulfonate	LAS	–	Household detergents
	Sodium alkyl sulphate	SAS	$\text{C}_n\text{H}_{2n+1}\text{OSO}_2\text{ONa}$	Personal care products
	Alkyl ethoxy sulphate	AES	–	Personal care products
	sodium lauryl sulphate	SLS	$\text{C}_{12}\text{H}_{25}\text{NaO}_4\text{S}$	Household detergents
	Alpha olefin sulfonate	AOS	$\text{C}_n\text{H}_{2n-1}\text{SO}_3\text{Na}$	Excellent foaming and detergency characteristics/shampoos and other bath products
Cationic surfactants	Quaternary ammonium compound	QAC	–	Found in disinfectant wipes, sprays, and other household cleaners
	Benzalkonium chloride	BAC	–	Antiseptic and disinfectant
	Cetylpyridinium bromide	CPB	$\text{C}_{21}\text{H}_{38}\text{BrN}$	Antiseptic
	Cetrimonium bromide	CTAB	$\text{C}_{19}\text{H}_{42}\text{BrN}$	Topical antiseptic/antiseptic agent against bacteria and fungi
Non-ionic surfactants	Alcohol ethoxylates	AE	–	Degreasers, emollients/detergents
	Amphoteric surfactants	Cocamidopropyl betaine	CAPB	$\text{C}_{19}\text{H}_{38}\text{N}_2\text{O}_3$

Table 3

Several impacts of detergents on wastewaters and the environment.

Impact of detergents	Explanation	References
Reduction of dissolved oxygen levels	<ul style="list-style-type: none"> • Due to the incomplete degradation of surfactants, massive foam can be created in rivers and streams near dams. This layer of foam, on the surface of waters, reduces oxygen penetration rate from air into water, contributing to aquatic organisms becoming defective in the adsorption of dissolved oxygen. • Entering phosphate into water leads to eutrophication, causing the noticeable growth of algae, which is resulting in a decrease in dissolved oxygen levels. 	[63,64]
Detrimental effect on fish	<ul style="list-style-type: none"> • In high concentration, disrupt the fish vision • Damage to fish gills • Lead to alteration chemical and physical parameters of waters (pH, turbidity, salinity, and temperature), which reduce water quality and can affect the used dissolved oxygen concentration for fish. • Almost deadly for the fish at the detergent concentration above 200 ppm • Bringing signs of distress, slow swimming, and difficulty breathing in fish 	[63,65]
Detrimental effect on soil ecosystem	<ul style="list-style-type: none"> • Even though detergents are useful for photosynthetic function, their existence brings negative effects on the germination of the plants • Soil structure gradually destroyed • Plant health be affected by their negative effect • Increasing the pH of the soil, resulting in separation of soil elements • The electrical conductivity of soil be increased by irrigation with water containing detergent content 	[53,64,66]

2.3. Pharmaceutical compounds

During the COVID-19 pandemic, the consumption of certain drugs, such as antibiotics, antidepressants and sedatives, drug of abuse, anabolic steroids, vitamin supplements, antidiarrheals, antitussives, antipyretics, and analgesics has increased among people. This increase in demand and use of the drugs has enhanced concern globally, which is affecting developing and even developed countries [16,70–72].

The consumption of antimicrobials in the prevention and therapy of COVID-19 is arising. A lot of people incorrectly try to protect themselves against the COVID-19 by self-medicate with antibiotics, despite it is a viral sickness. These attempts are mainly prevalent in developing

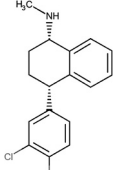
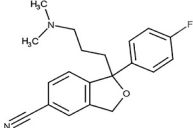
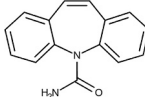
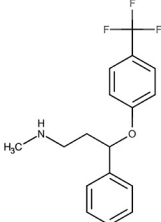
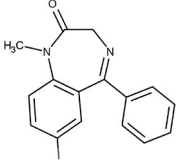
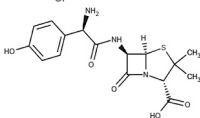
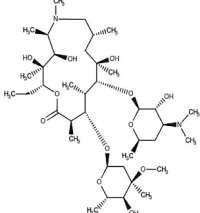
societies [73,74]. The primary wave of COVID-19 widespread may have significantly affected antimicrobial utilization in hospitals. Silva et al. evaluated the antimicrobial consumption of specific hospital during the COVID-19 pandemic in Brazil. They found a 2500% higher rate of azithromycin consumption in the COVID-19 emergency department and a 2000% higher rate of azithromycin consumption in the clinical ward. Moreover, the usage of amoxicillin/clavulanate had a notably higher rate in all COVID-19 clusters [71]. The WHO and other specialists suggested that antimicrobial treatment should not be started for suspected or affirmed mild COVID-19 unless in critically COVID-19 patients with a high clinical suspicion of bacterial infection [75].

The increased antimicrobials usage can have critical outcomes with the existence of antimicrobial elements in the environment, which can stimulate resistance of the antimicrobials, and even in minimal amounts can present unpleasant impacts in non-target creatures. It has been indicated that above 80% of amoxicillin is discharged by urine from the person's body after 2 h, and consequently, the existence of amoxicillin in

water sources and wastewaters can lead to harmful ecological problems [76]. A new typhoid fever epidemic in Pakistan has been related to the resistance of antibiotics due to inappropriate consumption of drugs, weak sanitation, and polluted water supplies [77].

Moreover, the novel COVID-19 pandemic has influenced people's mental health due to bereavement, fear lockdown, and loss of income in society, leading to an increase in depressive episodes in the countries such as UK, China, Spain, and the USA [16,78,79]. Antidepressants, which are considered in the classification of psychiatric drugs, are in the first step of therapy to treat depression, anxiety, and episodes which are resulting from the imposed quarantine. Psychiatric drugs are in the category of organic compounds which are comprising sertraline, carbamazepine, fluoxetine, citalopram, etc. [80]. Results indicated that European countries are the most antidepressants consumers in the world based on the Organization for Economic Co-operation and Development (OECD) data [81]. These drugs are relatively metabolized and excreted; hence, they enter into wastewater, and traditional treatments are not

Table 4
Specifications and environmental impacts of some antidepressants, sedatives, and antimicrobials.

Category type	Drug name	Drug bank ID	Structure	Impacts on water and the environment	Ref.
Antidepressants and sedatives	Sertraline	DB01104		<ul style="list-style-type: none"> • Endocrine-disrupting compound • Changes in crucial physiological functions such as behavior, growth, reproduction of aquatic species 	[72,85]
	Citalopram	DB00215		<ul style="list-style-type: none"> • Inducing significant foot detachment from the substrate in two kinds of freshwater snails 	[86]
	Carbamazepine	DB00564		<ul style="list-style-type: none"> • Relatively limited acute toxicity on the studied organisms such as fish, algae, bacteria, and micro-crustaceans. 	[87]
	Fluoxetine	DB00472		<ul style="list-style-type: none"> • Disrupt the endocrine systems of some aquatic creatures 	[88]
	Diazepam	DB00829		<ul style="list-style-type: none"> • Detected in the tissues of some aquatic organisms • Disrupting behavioral traits of animals • Sublethal toxic effects in fish such as gene expression alterations 	[89]
Antibiotics	Amoxicillin	DB01060		<ul style="list-style-type: none"> • Cause antibiotic resistance, decreasing the effectiveness of available antibiotics • Change microbial ecosystems potentially 	[76,90]
	Azithromycin	DB00207			

able to remove them. Varied literature confirms the existence of antidepressants in water sources worldwide and wastewater treatment plants, which can potentially be toxically bioaccumulated in the tissues of water organisms such as some aquatic plants, mollusks, and fishes [82]. The fate of these emerging pollutants, whenever released into the environment, depends on the physical and chemical nature of the pharmaceutical components. This issue is significant because several of these ingredients have been found in drinking water sources and wastewater effluents [70,83,84].

Nason et al. detected different chemicals and evaluated their trends from daily collected samples from March 19 to April 15, 2020, and weekly composite samples from March 19 to June 30, 2020, in primary wastewater sludge from WWTPs in New Haven, CT, USA. However, they did not know what chemicals were existed before analyzing samples. About antidepressant drugs, sertraline and citalopram had a clear increase in daily and weekly samples, respectively. Moreover, they found an increase in the concentration of some opioids and drugs of abuse such as methadone, hydromorphone, and cocaine in the weekly samples and increasing acetaminophen as a drug to relieve the symptoms of COVID-19 comprising headache and fever in their weekly sample analysis. The increased concentrations of hydroxychloroquine as a drug that received considerable attention due to its potential to treat COVID-19 were also obvious in daily sludge samples in the third week of investigation [72]. The specifications and environmental impacts of some drugs are

collected in Table 4.

Therefore, the COVID-19 pandemic has huge negative direct and indirect impacts on water and wastewater quality. All of the already mentioned new contaminants can find a way to reach surface water and negatively affect the environment (Fig. 1).

3. Wastewater treatment during COVID-19

The treated wastewater from treatment plants is usually discharged into receiving bodies of water or reused for purposes such as recreation and irrigation. This section deals with the introduction and evaluation of the effectiveness of different physical, biological, and chemical methods and unit operations that are currently used to remove organic contaminants and deactivate viruses. Hence, they can generally be used at the varied stages of the wastewater treatment during the COVID-19 pandemic.

3.1. Coronavirus removal

Preventing the spread of the virus in the environment all around the world is crucial before utilizing reclaimed water. There are three main phases to treat the infected water from coronavirus to safe water for recycling or reusing. The first treatment phase includes physical actions such as screening, grit chamber, and initial sedimentation in order to



Fig. 1. The possible pathways of different contamination in water during the COVID-19 pandemic.

eliminate infected solids that are suspended in the wastewater. The second and third treatment phases consist of biological treatment actions to eliminate the biodegradable organic matter, and physico-chemical treatment actions to further decrease turbidity, remaining organics, heavy metals, and pathogens such as coronavirus, respectively [91,92]. Although specific additional research about these methods on SARS-CoV-2, regular monitoring of their efficiency in real water treatment with considering all factors affecting virus survival and environmental considerations is needed to choose the best disinfection technology.

3.1.1. First treatment phase

The first treatment phase consists of physical processes that include the elimination of volatile and fixed solids suspended in sewage via physical barriers. Virus adsorption onto the large suspended solids in sewage, which is accompanied by gravitational sedimentation, is considered as the main and first mechanism in the treatment phase for the virus removal [93]. However, according to the available scientific reports, the gravitational sedimentation in the primary treatment phase is insufficient for the viral removal entirely from the sewage. The removal of coronavirus RNA through wastewater treatment operations has been seen for additional treatments comprising secondary and tertiary treatment, and tertiary treated wastewater is reused for irrigation and public domain directly [94].

3.1.2. Secondary treatment phase

Biological techniques such as membrane bioreactor, activated sludge, extended aeration biological processes, etc., are mainly used as part of the secondary treatment phase in the wastewater treatment plants [94]. Past studies have exhibited a higher elimination of the intestinal viruses by secondary treatment processes rather than the first treatment processes. Other studies have also reported the coronavirus resistance and survival in primary treatment was slightly higher than in secondary treatment due to the existence of higher organics in the primary treatment stage, which were protecting viruses from damaging [95,96].

In the activated sludge technique, uptake of viral particles on the organic biomass and elimination by sedimentation through the secondary clarifier assigned as the important and main mechanism for the virus elimination in the wastewater treatment [97].

The membrane bioreactor is used in the secondary treatment phase of wastewater to remove viral particles considerably, and it consists of membrane filtration and a suspended growth bioreactor. Membrane technology is cost-effective and environmentally friendly, with small or no chemical usage, a considerable decrease in the equipment size, and easy accessibility [98,99]. Based on recent studies, the high energy requirement is the major limitation of this technology, which is among 0.45 and 0.65 kWh·m⁻³ for the highest optimum performance [100,101]. Membrane bioreactor operations are designed with more retention times of solids towards activated sludge processes, which leads to varied treatment performances and other related conditions. The disadvantages of membrane compared to activated sludge are related to more operational difficulties and complexity [102]. Simmons et al. applied the membrane bioreactor process in the secondary treatment phase and could attain the log removal values of 6.8, 6.3, 4.8 for enterovirus, adenovirus, and norovirus, respectively [103].

SARS-CoV-2 is greatly similar to other coronaviruses, and they are seriously affected by decontaminants or various environmental parameters such as pH, temperature, presence of sunlight, and solids. According to current studies, coronaviruses are more fragile in the environment than intestinal viruses like norovirus, adenoviruses, rotavirus, and hepatitis virus, which exist in wastewater treatment plants [104,105]. The longer period time for retention in the wastewater treatment plants could assist the inactivation of coronavirus in swedge dramatically, and this effect is definitely expected to be further obvious at upper temperatures [106].

3.1.3. Tertiary treatment phase

The third phase of treatment includes operations such as coagulation, filtration, ultraviolet (UV), chlorination, ozonation, performic acid, nanomaterials, etc. [92]. Nanomaterials such as titanium dioxide, zero-valent iron, and carbon nanotubes (CNTs) have been applied for the inactivation and elimination of viruses in sewage [107,108]. The structure of the virus consists of a genome and, a protein capsid without or with an envelope. The initial purpose of the viral disinfection (such as UV, chlorination, ozonation, etc.) is to change one of these parts by applying environmental stress [105]. The viral envelope is more vulnerable to disruption. Hence, non-enveloping virus illustrates the upper resistance to inactivation and less susceptibility to unfavorable situations [109].

3.1.3.1. Chlorination. Free available chlorine was released through disinfection procedures, and its main sources are chlorine elements, chloramines, sodium hypochlorite, chlorine dioxide, calcium hypochlorite, and chloroisocyanurates. The presence of chlorine as hypochlorite ion (ClO⁻) and hypochlorous acid (HOCl) stay the most successful methods to combat viral particles. Hypochlorite is one of the powerful oxidizing agents which is oxidizing organic contaminants effectively, while undissociated hypochlorous acid is the microbiocidal agent primarily [110,111].

Wang et al. reported that the SARS-CoV was inactivated completely in sewage for 30 min at the free residual concentration of ClO₂ equal to almost 2.19 mg/L or chlorine concentration greater than 0.4 mg/L. [95]. Chin et al. confirmed these results by some tests conducted in vitro on SARS-CoV-2, utilizing 1:99 diluted household bleach in order to inactivate the virus after 5 min [42].

One of the major concerns and challenges in successful chlorination can be the existence of ammonia, which required chlorine for additional co-pollutants and pH. The Cl binds with the ammonia make a chlorine combination (chloramines), which is not effective and efficient enough against viral particles like free chlorine. Therefore, it is definitely pivotal to assure that Cl is not adsorbed by different demanding substrates such as organic matter, ferrous ion, ammonia, hydrogen sulfide, and nitrites. Organic matters normally neutralize chlorine-based materials, which cause short-term risks on the environment for plants and soil [112,113].

Randazzo et al. reported preliminary research on the existence of coronavirus RNA in wastewater after the second and third treatments. After normal activated sludge, about 11% of samples remained positive to coronavirus RNA; however, after the third treatment, 100% of samples changed to negative by using disinfection with NaClO, and in several cases, which can be combined with ultraviolet (UV) [40]. Zhang et al. used a high dose of sodium hypochlorite to disinfect hospital sewage from SARS-CoV-2; however, this method had a high level of residual by-products, which possessed notable environmental risks [114].

3.1.3.2. Performic acid. Performic acid is a less-stable common disinfectant and oxidizing agent with the formula CH₂O₃, which is a combination of hydrogen peroxide (35%) and formic acid (10 to 20%) [115]. It has many benefits over chlorine and can be more efficient to inactivate viruses, bacteria, and fungus during wastewater treatment [116]. Performic acid also can apply at conditions with low-temperature (under 25 °C); hence, it can be used in cold areas or during winter [117]. Performic acid decomposes quickly, which leads to enhance the amount of reactive oxygen and consequently making more powerful disinfection and produce non-toxic H₂O₂ and formic acid as by-products [118].

3.1.3.3. Ultraviolet (UV). UV radiation effectively controls the growth of microbial in any medium, like air, water, and any kind of surface. Currently, different environmental public settings around the world, such as health care facilities, hospitals, airports, and shopping centers, are considering the UV disinfection devices implementation for

disinfection of the surfaces that are frequently touched and streams of circulating air. However, the applied UV-C energy dosage must be balanced in order to obtain acceptable biocidal efficiency levels and prevent excessive energy that can damage the surfaces and reduce the predicted lifetime [119].

In recent years the ultraviolet disinfection technique is more interested in water treatment because it is a clean disinfectant and effective against most waterborne pathogens comprising several microbial pollutants that are relatively resistant [120]. Moreover, this method can easily operate and install, and it is non-corrosive. The viral particles under the UV light lose their potential to infect and replicate by damaging the genome and protein comprising the break down of the phosphodiester bonds and the links with extra molecules [121]. Darnell et al. showed the partial inactivation of SARS-CoV by UV-C light irradiation (254 nm, dose 4016 $\mu\text{W cm}^{-2}$), which could reach to 400-fold reduction in infectious viral load at 1 min with enhancing efficiency up to 6 min. The viral particles became totally inactivated after almost 15 min below the limit of the detection, while no impacts of UV-A (365 nm, with dose 2133 $\mu\text{W cm}^{-2}$) exposure were observed on the virus over a 15 min period of the exposure [122]. Disinfection efficiency of UV may be reduced dramatically by algae with biofouling of the lamp, colored and turbid substances protecting microorganisms [123]. Hence, the secondary treatment followed by UV helps residual protection and assures microbial shielding redundancy.

3.1.3.4. Ozonization. Ozone is a clean and potent oxidizing factor, which is an effective microbicide against protozoan, bacteria, and viruses by attacking viruses and destroying the viral protein. The ozone technique has exhibited excellent performance against non-enveloped and enveloped viruses in water, aerosols, and surfaces, comprising analogous viruses in morphology to SARS-CoV-2 [124,125]. Ronaldo et al. assessed the virucidal performance of ozonated water, which is a strong oxidizing factor, against SARS-CoV-2. The source of ozonated water at a low concentration (0.2–0.8 ppm) was the particular faucet, which demonstrated the reduction of two \log_{10} in virus infectiveness after exposure to ozonated water for about 1 min, in comparison to control groups [126].

The combination of treatment techniques comprising UV treatment, ozonation, and chlorination could inactivate about almost 99.99% of fecal coliform in water, and no coronavirus was found after disinfection. The studies revealed that applying the ozonation technique enhanced transmittance of UV by almost 20–30% inside the water, and as a result, UV dose can be decreased [127].

3.2. Removal of other emerging contaminants

In general, conventional treatment systems that are existing today might not be able to completely remove these huge amounts of organic micropollutants during the COVID-19 pandemic in urban wastewaters. Although additional research is needed, various pharmaceuticals components were detected in the inlet and outlet waters in different wastewater treatment plants in the past, which means several kinds of these substances could not be removed effectively by existing systems. Hence, more specific and effective treatments are needed in order to reduce the environmental impacts of sewage. Proper water treatments include chemical precipitation to remove phosphorus, ionic exchange for removing ions, biological systems to eliminate nitrogen, AOPs for removing toxic organic compounds, distillation for volatile organic compounds removal, and adsorption for removal of inorganic and organic pollutants. Some of these water treatment methods have not to be applied on a large scale and are under research because there is a lack of information about their reactor design issues, proper data about their mechanisms, and the impacts of operational variables [46,128,129]. In the following, different water treatment methods with proper efficiency for cleaning and pharmaceutical compounds are discussed, and the

advantage and disadvantages of each method are mentioned in Table 5. Moreover, some of the related studies with these methods are summarized in Table 6.

3.2.1. Adsorption

In order to separate the interface of two phases, adsorption can be used with two classifications: chemisorption and physisorption, depending on the adsorbate and adsorbent interactions. One of the significant advantages of the adsorption method is the regeneration or recycling of adsorbents, which makes it economical for use in water treatment. The reusing of the adsorbent mainly relied on the regeneration efficiency of the adsorbent. The pharmaceuticals and surfactants adsorption depends on the properties of the solution, adsorbent, and adsorbate. For example, surface charge, pore volume, pore size, and surface area of the adsorbent, and continuously the polarity, size, molecular weight, hydrophobicity, functionality, geometry, and solubility for adsorbate in an aqueous solution [130–133]. Many different adsorbents have been synthesized for the removal of pharmaceutical compounds and surfactants from water.

The nanomaterials can perform very well for surfactant adsorption. Ncibi et al. used carbon nanotubes (CNTs) with adsorption capacities of 156 and 312 mg/g for removal of CTAB and SDBS surfactants. The performance for the removal efficiency of surfactants can be increased by ultrasonication. [134]. Also, carbon nanotubes are effective adsorbents for removing pharmaceutical compounds [135]. However, carbon nanotubes in the largescale application are limited because of several problems such as difficult separation contribute to leakage into water bodies and eventually has adverse effects on human health and ecosystems [134].

Activated carbon can be considered as one of the most effective materials for the adsorption of surfactants and pharmaceutical compounds from wastewater [136–138]. Schouten et al. reported that activated carbon which has a proper microporous structure in the average pore diameter of almost 1.5 nm, can remove anionic surfactants such as LAS and AOS. The pore sizes and ionic strength are important factors for this process. The macro (>50 nm) and *meso* (2–5 nm) pores are suitable for the adsorption of AOS and LAS. It turns out that activated carbon and double-layered hydroxide (LDH) can be considered as the proper candidate for the adsorption of the anionic surfactant due to several properties such as being cost-effective and having high adsorption capacity. The ionic interactions caused higher adsorption in comparison with non-ionic interactions [139]. The effect of pore and particle size on the anionic surfactant adsorption by four activated carbons which have various pore sizes, indicated that the activated carbon with a smaller pore size between 0.56 and 0.77 nm could adsorb more anionic surfactant in comparison with other activated carbons. The particle size

Table 5
Advantages and disadvantages of the organic contaminants removal methods.

Treatment	Advantage	Disadvantage	References
Adsorption	<ul style="list-style-type: none"> • Easy to operate • Highly efficient • Cost-effective • Environmentally friendly 	<ul style="list-style-type: none"> • Surfactants can be only separated from the wastewater but cannot be destroyed • Need skilled labor 	[174,175]
Advanced Oxidation Processes (AOPs)	<ul style="list-style-type: none"> • Rapid reaction rates • Small footprint • Mineralization of organics 	<ul style="list-style-type: none"> • Removal of residual peroxide may need to be considered 	[176,177]
Biological treatments	<ul style="list-style-type: none"> • Low cost • Easy application • Can be improved by combining with membranes (membrane bioreactors) 	<ul style="list-style-type: none"> • Sludge generation during the treatment • High retention time 	[178,179]
Coagulation and flocculation	<ul style="list-style-type: none"> • Easy application • High pollutant removal efficiency 	<ul style="list-style-type: none"> • Transferring toxic compounds to the solid phase 	[180]

Table 6
Some of the related studies for mentioned wastewater treatment methods.

Types of treatment	Pollutant name	Description	Adsorption capacity/removal capacity	References
Adsorption	CTAB	Adsorbent: polymer resin Lewatit VPOC	250 mg/g	[181]
	CTAB	Adsorbent: natural zeolite (clinoptilolite)	284 mg/g	[182]
	CTAB	Adsorbent: activated carbon (Merck)	207 mg/g	[183]
	SLS	Adsorbent: amino cross-linked chitosan	888 mg/g	[184]
	SDS	microspheres (ACCMs)	825 mg/g	
	SDS	Adsorbent: chitosan hydrogel	76.9 mg/g	[185]
	Carbamazepine	Adsorbent: BGO-CS	11.2 mg/g	[186]
	Carbamazepine	Adsorbent: MOF	99%	[187]
	Acetaminophen	Adsorbent: BGO-CS	13.7 mg/g	[186]
	Amoxicillin	Adsorbent: ACAF	90%	[188]
Advanced Oxidation Processes (AOPs)	SDS	Method: UV-H ₂ O ₂	100%	[156]
	Amoxicillin	Method: UV/H ₂ O ₂ /TiO ₂	70.9%	[189]
	Carbamazepine	Method: PS/Fe(II)/UV-vis	100%	[190]
Biological treatments	LAS	Activated sludge process	99%	[161]
	AE	Anaerobic sludge	99%	[191]
	LAS		71.10% ± 11.3	
Coagulation and flocculation	Effluent sample including various surfactants	-	99%	[180]

has a remarkable effect on the small particle due to the complex compound formation between cations of surfactant molecules and activated carbon. Although using activated carbon has several drawbacks such as inefficient regeneration, poor adsorption selectivity, and expensive synthesis. However, taking advantage of economical raw materials which have efficient regeneration ability for the synthesis of activated carbons can improve this adsorbent for the removal of surfactants [140,139]. Moreover, according to the literature, activated carbons have a high performance in the adsorption of pharmaceuticals. One of the advantages of activated carbon for removing pharmaceuticals is that pharmacologically or toxic active products do not generate [129].

Chitosan is a biocompatible, biodegradable, and non-toxic mucoadhesive biopolymer. It is an economical, renewable, and generally available biomaterial and, after cellulose, is the most abundant natural polysaccharide [141]. Parhizgar et al. investigated that this adsorbent could successfully remove 97% of the SDBS (anionic) surfactant, and its adsorption capacity was almost 6.38 mg/g [142]. Generally, from literature results, the unmodified chitosan has low adsorption capacity in comparison to modified chitosan for anionic surfactants. Chitosan can be modified with various methods such as doping with metals or cross-linking contribution to the higher surface area to having more active sites [143].

3.2.2. Advanced oxidation processes (AOPs)

AOPs can degrade almost all kinds of organic pollutants into harmless products. This method is considered an environmentally friendly process because pollutants could not transfer from one phase to another one, and massive, hazardous sludge does not be produced in this method [144,145]. AOPs can reduce organic pollutant concentration from hundreds ppm to less than near 5 ppb [146]. This method relies on the generation of OH[•] (reactive hydroxyl radicals). After series of oxidation reactions, ultimate mineralization products, which are CO₂ and H₂O, are produced. AOP can mix with ozone (O₃), Fenton's reagent (H₂O₂/Fe²⁺), photocatalysis, and hydrogen peroxide (H₂O₂) and combine with ultraviolet (UV) irradiation, like TiO₂/UV, ozone/H₂O₂/UV, ozone/UV, and H₂O₂/UV. Methods that include UV radiation can be considered as photochemical processes. UV source improves the reduction of Fe²⁺ and Fe³⁺, which can be reacted with H₂O₂ in order to produce more hydroxyl radicals [147,148–150].

Some studies have been done with using AOPs as an effective treatment for pharmaceutical pollutants [130,151] and surfactants [152,153]. Mechanisms of degradation might vary from one method to another one. The Fenton-based AOPs popularity has been much dependent on the selection of iron-based catalysts for water treatment. Although, due to the limitation in the solubility of iron species, the

efforts of research have focused on the development of iron-free Fenton systems for the H₂O₂ activation. However, one disadvantage of using Fenton's technique is sludge formation, which contains iron hydroxide as a secondary product. Thus, sludge disposal should be considered in the initial cost and design process. Moreover, the Fenton process requires continuous pH adjustment because this process needs a lower pH [154–156]. The AOPs are recommended to be applied in new or existing wastewater treatment plants. For highly concentrated wastewater, AOPs are suitable to be considered as pre-treatment to decompose recalcitrant organic contaminants into biodegradable intermediates or products that can later be eliminated in biological post-treatments [154].

3.2.2.1. Ultrasonic. Ultrasonic irradiation (sonochemistry) is a promising technique for the degradation of various types of hazardous organic compounds and pollutants from wastewater with undesirable impacts in the water environment. Ultrasonic irradiation can commence pyrolytic and oxidative degradation procedures. This method does not need any chemical additives and can successfully apply to sludge, colored or turbid solutions. Ultrasonic irradiation exposure induces acoustic cavitation in water. Sonochemistry is in the category of AOPs, a phenomenon that is related to the production, growth, and intense collapse of gaseous bubbles into water (known as cavitation) in the pressure (~1000 atm) and high temperature (~5000 K) conditions. Irradiation of water with ultrasound decomposes water molecules into highly reactive radicals, including •H and •OH. These reactive radicals can react with each other or diffuse to consider as an oxidant [157–159].

Kıdık and Doğan removed and degraded antibiotic amoxicillin by ultrasonic irradiation alone and with ozonation. The ultrasonic irradiation treatment was applied at three different frequencies (575, 861, and 1141 kHz). Due to the synergistic impact, the combination of ultrasound and ozone gave rise to a rate constant of almost 2.5 min⁻¹, which was 625 times more than alone ultrasound. This hybrid degradation pathway, which is considered an advanced oxidative process, confirms the lower toxicity due to the low producing toxic intermediates [160].

Serna-Galvis et al. demonstrated the total elimination and mineralization of the antidepressant drug fluoxetine by sonochemical process combined with biological treatment. The alone biological treatment cannot remove the contaminant, even after five days and under desirable conditions. But, the sonochemical process (600 kHz) was able to eliminate the pharmaceutical. After 240 and 360 min of sonicating in the biological procedure, microorganisms could remove 20 and 70% of the primary total organic carbon, respectively [88].

3.2.3. Biological treatments

Biological treatment is a common method, especially for detergents

and pharmaceutical pollutants that exist in wastewater. The effluent of this method can be returned to the river, and the sludge can be used as a fertilizer for the soil. The mentioned contamination can be considered as a nutrient source or energy for microorganisms in the biodegradation process. The mechanism of biodegradation can be changed by several factors such as anaerobic and aerobic conditions or the chemical structure of the contamination [161–163]. Aerobic degradation can be accomplished in various ways, such as using activated sludge tanks, oxidation ponds, and trickling filters. Each method has a considerable impact on removal efficiency. Although activated sludge tanks have almost 99% removal efficiency for LAS, however, the trickling filters have a wider range of 89.1–99.1% removal efficiencies [161,164]. Moreover, LAS has removal efficiency in the range of 40–85% under anaerobic conditions depending on which method was used [165,166]. In addition, the high chemical oxygen demand (COD) concentration of pharmaceutical wastewater caused it suitable for anaerobic processes. Based on some studies, COD reduction on antibiotic residues was by 70 to 75%, and some research reports that combining a filter and the anaerobic sludge blanket leads to high removal efficiency [167,168].

However, there are many limitations that cause it unsuitable to consider as a sole treatment method for the removal of surfactants from wastewater. One disadvantage is that this method is suitable for a low concentration of surfactant. This is because, in a concentration above almost 1,000,000 µg/L, the surfactant can depolarize the bacterial cell and can destroy function and structure [164,169]. By taking advantage of chemical pre-treatment for wastewater before enters to the treatment plant, mentioned problems could be mitigated. The huge advantage of pre-treatment of wastewater is to convert these compounds to products that could be more biodegraded. There are numerous methods for pre-treatment, and AOPs can be considered as one of the commonly used methods [164,169].

3.2.4. Coagulation and flocculation

Coagulation-flocculation is considered a chemical water treatment method that can usually be applied prior to filtration and sedimentation. This simple and low-cost method is used to improve the ability of a treatment action in order to remove pollutants such as surfactants. Coagulation can form a mass which is large enough to be trapped or settle in the filter. Flocculation is considered as gentle agitation or stirring to reinforce the particles formed to be clustered into large masses to settle from solution. Inorganic coagulants (Polymer-type) such as $\text{Fe}_2(\text{SO}_4)_3$, $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$, and $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ are generally used in this process [170,171]. Residual contents of inorganic coagulants like $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ might cause Alzheimer's disease [172]. Thus, it is better to use fewer inorganic coagulants, and these materials should be replaced with ecofriendly materials [173]. It has been turned out that this method is effective and useful for the removal of the surfactant from wastewaters. In many kinds of research, removing the surfactant was roughly 95% in wastewater, and COD reduction was approximately 88% [147].

4. Conclusion and future perspective

Presently, there is a considerable research gap in the survival of SARS-CoV 2 in the water and the potential of coronavirus transmission by untreated and treated wastewater. The excretion of the virus via feces is quite obvious from recent researches. Hence, this research investigates the occurrence, detection, and recommended removal treatment ways of coronavirus in wastewater with different techniques commonly used at the different stages of the treatment, including primary, secondary, and tertiary phases in the wastewater treatment plants. The research of Nasser et al. is a practical example of using the proposed methods to inactivate the SARS-CoV-2 in WWTP. They evaluated the presence of SARS-CoV 2 in the outlet samples from ultraviolet (UV) disinfection (module outlet 5 to 6) and samples from chlorine disinfection (module outlet 1 to 4) of WWTPs in southern Tehran, Iran, and the results showed

that only chlorine disinfection samples remain positive. Hence, the UV disinfection was more successful than chlorine disinfection, and operators of WWTPs should enhance the free residual chlorine concentration to $\geq 0.5 \text{ mg} \cdot \text{L}^{-1}$ for effective disinfection [192]. The development of environmentally friendly and low-cost processes for viral removal are other opportunities for scholars to manage and reduce the growing health and environmental risks from any similar future crisis.

Another crucial environmental concern related to the COVID-19 epidemic is the extra use of disinfectants, detergents, and soaps and the overuse of specific drugs to protect against virus or novel mental problems related to quarantine. Their excretion into wastewater not only can pollute drinking water resources but also includes a potential threat to the aquatic environment. Hence, future studies should be directed to update and re-design WWTP to remove these extra amounts of organic compounds efficiently and create environmentally-friendly cleaning products such as hand sanitizers and soaps with low toxic by-product formation for humans and environmental safety.

Further communication among regulatory agencies with chemical, biological and medical researchers is needed to explore additional acceptance and validation of these water treatment approaches, which are applied to make claims of successful water treatment, especially during the COVID-19 crisis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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