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# Emerging contaminants, SARS-COV-2 and wastewater treatment plants, new challenges to confront: A short review

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ABSTRACT

The current pandemic caused by SARS-CoV-2 has put public health at risk, being wastewater-based epidemiology (WBE) a potential tool in the detection, prevention, and treatment of present and possible future outbreaks, since this virus enters wastewater through various sources such as feces, vomit, and sputum. Thus, advanced technologies such as advanced oxidation processes (AOP), membrane technology (MT) are identified through a systematic literature review as an alternative option for the destruction and removal of emerging contaminants (drugs and personal care products) released mainly by infected patients. The objectives of this review are to know the implications that the new COVID-19 outbreak is generating and will generate in water compartments, as well as the new challenges faced by wastewater treatment plants due to the change in a load of contaminants and the solutions proposed based on the aforementioned technologies to be applied to preserve public health and the environment.

## 1. Introduction

Until now, seven types of coronaviruses that infect humans are known and some of them are present in the common cold. The coronavirus named SARS-CoV produces severe acute respiratory syndrome (SARS), in which incubation time is 3 to 7 days. Symptoms of infection include fever, cough, shortness of breath, potential pneumonia, acute respiratory syndrome, kidney damage, and even death. Simple measures have been recommended by the World Health Organization (WHO) to prevent its proliferation: social distancing, self-isolation, respiratory hygiene, and the quite common hand hygiene. The population that is most vulnerable to this virus is usually those over 65 years old and with concomitant diseases, so greater caution and care must be taken with them. Its structure consists of 4 types of variable proteins: envelope protein (E), nucleocapsid protein (N), spike protein (S), and membrane protein (M) (Chaudhry and Sachdeva, 2020; Daverey and Dutta, 2021; Lesimple et al., 2020; Wathore et al., 2020).

Coronaviruses have the characteristic of being enveloped viruses, with one of the longest RNA genomes, which gives great plasticity to accommodate, modify and acquire genes to adapt to various species (Jones et al., 2020). The factor that is relevant for receptor recognition and allows the entry into the host cell is the S-glycoprotein, allowing then cross-species transmission. Its physiopathology is still being studied, but it is known that these viruses are usually very contagious when the patient is symptomatic also including the incubation period (days 1–14) when the person is usually asymptomatic. The most common pathways of transmission are aerosol; when the person talks, exhales, coughs, or sneezes, and fomites (objects that carry the pathogens); when the droplets are heavy and cant remain in the air, following then on floors or surfaces (Achak et al., 2021; El-Baz et al., 2020; Nghiem et al., 2020). These viruses can enter into sewage through various sources such as sputum, vomit, feces, even the already mentioned handwashing (Amoah et al., 2020; Nghiem et al., 2020), and they tend to be more resistant than bacteria to free chlorine according to the WHO (La Rosa et al., 2020). However, the scientific community is using this type of wastewater entry as an opportunity to conduct epidemiological studies, since monitoring and study of this magnitude could show much more representative results of patients that are not being detected due to the absence or scarcity of symptoms, and thus use it as a warning system of future new COVID-19 outbreaks (Chaudhry and Sachdeva, 2020; Mallapaty, 2020). Viruses can survive in wastewater because they attach to solid surfaces such as sludge, which acts as an indicator of biosolids concentration in sewage; these biosolids are classified according to the US-EPA in 2 classes: Class A (used for gardening) and Class B (used in

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agriculture and forestry) (Mohan et al., 2021). Therefore, sludges also represent an epidemiological advantage/opportunity for wastewater-based epidemiology (WBE) since the viral sample is usually even more concentrated in comparison to wastewater (Langone et al., 2021; Sharma et al., 2020).

Finally, in recent months people are much more aware of hygiene, also isolation and quarantine centers have been constructed by the government of the majority of countries, so the use of water has increased significantly reaching very high peaks according to a study made in India where the use of water has been five times more in comparison to the average use, generating then as consequence a 25% of the demand and wastewater generation. Drinking and clean water services are essentials, and the lack of these could have an impact on the economy, public health, safety, and welfare of the population (Kataki et al., 2021; Sowby, 2020).

That is why the objectives of the review are to know the different perspectives to consider when the wastewater treatment plants treat the different discharges, due to an increase in water demand and emerging contaminants by different sources as well as propose some treatment alternatives based on some technologies that are less harmful to the environment to preserve the sustainable development for future generations.

## 2. Water as a possible source of SARS-CoV-2 transmission

Recent studies have demonstrated that the presence of SARS-CoV-2 decays rapidly depending on: a) solids content and composition as a secondary factor in river water and wastewater, b) both sea and river water environments, especially in seawater due to the negative effect of salinity over enveloped viruses, c) the temperature, is less probable to develop at 20 °C more than at 4 °C, d) presence of detergents in wastewater and e) UV-light and organic matter. Therefore, river water, seawater, or wastewater containing infected individual's feces are unlikely to infect other individuals (Achak et al., 2021; Camilo et al., 2021; Sala-comorera et al., 2021). Despite the aforementioned, surfaces that are repeatedly used by infected people with severe symptoms can lead to a progressive accumulation of viral load if the surface is not constantly cleaned (Jones et al., 2020).

SARS CoV-2 presence in water should be considered as a risk specially in poor and vulnerable populations with scarce resources (Guerrero-Latorre et al., 2020; Street et al., 2020; Tortajada et al., 2020). In addition to deficiencies in wastewater discharge and treatment, these places are often accompanied by significantly poor and fragile health policies, resulting in higher exposure and mortality risk (Quilliam et al., 2020). Some articles have published the SARS-CoV-2 quantification and detection in wastewater and effluents in various countries(Baldovin et al., 2020; Guerrero-Latorre et al., 2020; Hasan et al., 2020; Hata et al., 2020; Wu et al., 2020). However, the fact that some wastewaters are discharged directly into rivers and drainage systems that contains viruses, microorganisms, antibiotic-resistant bacteria, and emerging contaminants in general without a pre-treatment; is an issue that we must not leave aside and could harm humans health and environment (Achak et al., 2021).

In developing countries, the risk of transmission is quite high because, according to UNICEF, 892 million people tend to defecate either in open spaces, share them to be used for large/many families, or like the case in India where 28.7% of them do not have access to any latrine (Jones et al., 2020; Kataki et al., 2021) and also because the wastewater is discharged directly to rivers and local effluents without any treatment. This risk increases due to the lack of sufficient resources to afford chemical neutralizers that help to deactivate the virus in daily use waters, which are already mostly treated by natural systems such as sludge and/or lagoon stabilizations (Arslan et al., 2020). In principle, the virus present in the discharges should be considerably diluted, however, according to a study published by Bibby and Peccia, 2013, 80% of samples from five treatment plants in the United States from a type B sludge drainage system had virus presence. This was explained by the fact that there are two types of wastewater treatment procedures in the United States which include combined drainage systems (stormwater drainage and runoff) and sanitary drainage systems (Corpuz et al., 2020; Franklin and Bevins, 2020).

## 3. Emerging contaminants produced by the treatment and fight against SARS-CoV-2

Hospitals are big producers of wastewater because of their considerable number of discharges in the kitchen, operation room, laundry, and research labs; therefore, it makes sense to think that they're one of the main producers of emerging contaminants as well as being responsible for the high viral loads in wastewater. Not only they do contribute to the emission of emerging contaminants (such as pharmaceuticals and their transformation products), through feces or urine of their patients, but also through direct disposal of expired drugs, detergents, and antiseptics that are part of this category. These contaminants could be detected in trace concentrations of ug/L to ng/L, so, inadequate treatment and transport of these compounds either in wastewater or solids, could generate a risk to public health and the environment due to its potential charge of toxic chemicals, pathogenic microorganisms, and radioactive elements (Achak et al., 2021; Khan et al., 2021; Kumari and Kumar, 2021).

Drugs can reach the groundwater and threaten the quality of drinking water, additionally; they could reach and accumulate in the food chain through the sludge used for agriculture purposes. Antibiotics are a special group of drugs that should be targeted because in combination with high microbial biomass, could cause potential damage and also become a reservoir of antimicrobial-resistant bacteria. As a result, patients who were infected by accidental ingestion of contaminated food and/or contaminated water may host multidrug-resistant bacteria (Khan et al., 2021; Kumari and Kumar, 2021).

The WHO recommends regular hand washing in conjunction with the use of hand sanitizers that have alcohol by principal component as prophylaxis ("Coronavirus Disease (COVID-19)," 2020). These soaps will inactivate and encapsulate the viral molecules inside the formed micelles that will then be carried away by the action of water by dissolving the lipid bilayer of SARS-CoV-2 (Usman et al., 2020). Keeping in mind the abovementioned, it is logical to think that the increasing use of antibacterial soaps and chemical biocides in these last months could threaten the ecosystem (Usman et al., 2020).

Many soaps and detergents present as part of their composition linear alkylbenzene sulfonates (LAS) used as surfactants, hand sanitizers by its part have ethanol, iso-propyl alcohol, glycerol, and hydrogen peroxide, which once they enter to the sewage might damage the soil and be toxic to aquatic animals. Apart from the mentioned components; chlorhexidine, triclosan, and some quaternary ammonium compounds employed can be persistent in the environment increases the risk of multi-antibiotic resistance caused by genetic mutations (Daverey and Dutta, 2021).

Personal protective equipment (PPE), equipment, and reagents used for the COVID-19 test are also an important topic in emerging contaminants because of the increasing use of masks and its inadequate disposal of, which leads to microplastics that could threaten ecosystems and marine wildlife (Ji et al., 2021; Michael-Kordatou et al., 2020).

Because of the outbreak of SARS-CoV-2, several medicines are being repurposed (repositioned drugs); for example, ribavirin, lopinavir, ritonavir, chloroquine, and rapamycin, and have been used as part of the treatment or as self-medication (especially in places where the healthcare systems are not adequate) constituting one of the most common emerging contaminants in aquatic systems (Kumari and Kumar, 2021; Usman et al., 2020) causing serious damage to aquatic compartments and biota (Table 1). This is the case of antiviral compounds, anticancer drugs, antihypertensive drugs, immunosuppressants, antipsychotics and antihistamines, antifungal agents, antibacterial agents, and therapeutic

**Table 1**
Chemical compounds increased by SARS-CoV-2 outbreak.

| Use | Compound | By-product | Organism to which it causes the toxic effect | Toxic effect | Reference |
|---|---|---|---|---|---|
| Humanized monoclonal antibody | Tocilizumab (TCZ) | N.S[a] | Alga<br>Alga<br>Crustacean<br>Fish | Growth rate inhibition<br>Biomass Inhibition<br>Immobility<br>Embryotoxicity | (Race et al., 2020) |
| Antirheumatic drug | Chloroquine | Oxalic acid | Bacteria | Bioluminescence Inhibition | (Midassi et al., 2020; Race et al., 2020) |
| | | | Alga<br>Crustacean | Growth inhibition<br>Immobility | |
| | | Oxamic acid | Fish<br>Plant<br>Crustacean | Protein content<br>Relative transpiration<br>Immobility | |
| | Hydroxychloroquine | Oxalic acid<br>Oxamic acid | Alga<br>Crustacean | Growth rate<br>Immobility | (Bensalah et al., 2020; Race et al., 2020) |
| Steroid drug | Dexamethasone | N.S[a] | Alga<br>Aquatic invertebrates<br>Amphibians<br>Fish | Ecotoxicity | (Tarazona et al., 2021) |
| Macrolide antibiotic | Azithromycin | N.S[a] | Cyanobacteria | N.S[a] | (Tarazona et al., 2021) |
| Antiretroviral drug | Remdesivir | N.S[a] | N.S[a] | N.S[a] | (Race et al., 2020) |
| | Lopinavir | N.S[a] | N.S[a] | N.S[a] | |
| Anthelmintic drug | Ivermectin | N.S[a]<br>N.S[a]<br>N.S[a] | Alga<br>Fish<br>Soil invertebrates | Carcinogenicity<br>Teratogenicity<br>Hypersensitivity | (Kumar et al., 2020; Tarazona et al., 2021) |
| Disinfectant | Sodium hypochlorite | Trichlorome-thane<br>Tribromome-thane<br>Bromodichlo-romethane<br>Dibromochlo-romethane | Human being | Bladder cancer and infertility | (Zhang et al., 2020) |

[a] N.S: not specified.

antibodies (Batalha et al., 2021). Here it should be noted that, antiviral and antibiotics drugs have to be specially mentioned since their use in the past years has been increased and with that, the antiviral and antibiotic resistance as already mentioned (Cela-Dablanca et al., 2021). An article that reports the ecotoxicological effects of some of the repositioned drugs (drugs that are used to treat similar viruses) used for COVID-19 has been recently published; the important points considered were: a) surface water, which is often used for drinking purposes might be contaminated with some antiviral drugs that are difficult to remove such as oseltamivir, b) ivermectin is expected to produce a high risk due to its indiscriminate use triggered by some “fake news”, c) “one health” and “sustainability” are some terms that require to be considered in Public Health. (Kumari and Kumar, 2021; Tarazona et al., 2021).

Hydroxychloroquine and chloroquine have also been widely used despite their unproven effect against COVID-19, increasing as a consequence of their presence in wastewater. On the other hand, chlorine-based disinfectants can be transformed into highly toxic products leading to bladder cancer and reproductive problems due to their residual chlorine and/or monochloramine (Ji et al., 2021).

## 4. Wastewater treatment for virus and emerging contaminants removal

In wastewater treatment plants, it is important to know the viability of the virus in: a) wastewater from effluents that can be re-used, b) sludge from biosolids, c) other by-products and d) formation of aerosols by aeration, or forced pumping (Foladori et al., 2020; Ji et al., 2021). Because of this, the Center for Disease Control and Prevention (CDCP) of the United States acclaims that workers in treatment plants must have protocols to prevent possible occupational transmission due to the aforementioned causes (Amirian, 2020). The WHO indicates the management that should be taken with waste, water, sanitation, and hygiene by a standardized treatment process that should be applied to reduce the potential risks that this virus could cause due to its presence in excreta and wastewater (WHO, 2020). Frequently, the quality and efficacy of a disinfection process in water are judged considering only the level of turbidity or the specific action to one indicator bacteria (Adelodun et al., 2020; Kataki et al., 2021), however, it is also relevant to contemplate the wide microbial and viral load that it brings. A publication made by Corpuz et al. (2020), shows that some wastewater treatments are not sufficiently effective in reducing the genomic concentrations of a virus; UN's World Water Development Report that in 2017 only 20% of wastewater was sufficiently treated. Some of the factors that affect coronavirus survival are listed in Table 2, however, retention time, the quantity of organic matter and light exposure, as well as the aerobics organisms that might be present in the environment should be also considered (Achak et al., 2021; Kataki et al., 2021).

Low-income countries usually have a deficiency in the regulation,

**Table 2**
Factors that affect coronavirus survival (Amoah et al., 2020; Carraturo et al., 2020; Collivignarelli et al., 2020; Kataki et al., 2021).

| Factor | Description |
|---|---|
| Viral structure | The characteristic of coronaviruses of being enveloped viruses, makes them prone to have shorter survival periods due to the action of proteolytic enzymes and detergents in the external lipid layer of the virus. |
| Characteristics/composition of wastewater | The inactivation of the virus is influenced by the presence of chemicals with antiviral activity, proteolytic enzymes present in the bacteria, also the high molecular weight present in the matter dissolved in the wastewater and the inhibition of the matrix of the native flora. |
| Temperature | The temperature increase causes a protein and nucleic acid denaturation, as well as an increase in the activity of the extracellular enzymes. |
| pH | An acidic pH generates an RNA denaturation, by the protonation of guanine-cytosine base pairs and the formation of Hoogsteen base pairs. |

normative, and treatment of emerging contaminants, so are the ones that could suffer the most serious consequences of releasing these contaminants into their aquatic environment, depending on their toxicity, chemical composition, and possible bioaccumulation in the food chain (Bandala et al., 2021; Khan et al., 2021; Michael-Kordatou et al., 2020). As the vaccines cannot be afforded by all of the countries, at least not immediately, many of them are going to continue their use generating and contributing in that way to the over-use, accumulation, and increase of pharmaceutical drugs and their load in water bodies, plants and aquatic organisms (Kumari and Kumar, 2021).

As aforementioned, emerging contaminants in wastewater threaten human health and aquatic environments due to their persistence, mobility, and activity in the environment. Especially in the current context in which we find ourselves where the quantity of medicines is being considerably incremented in the effort to control COVID-19 symptoms such as dyspnea or fever. These drugs are usually metabolized in small portions, being the rest released by the patient organism into sewage by urine and feces (Bandala et al., 2021). Linear alkylbenzene sulfonates (LAS) and anionic surfactants present in soaps and detergents are degradable in their majority just aerobically, but the nonionic surfactants have low degradation in aerobic treatment. Despite this, there is not much information about the increment of drugs, hygiene products and so the presence of emerging contaminants in water, leaving a gap for the wastewater treatment plants that might not have taken conscience yet of the change of load that the current sewage brings (Bandala et al., 2021; Daverey and Dutta, 2021).

Some of the detection techniques for COVID 19 related pharmaceuticals that have been used are capillary electrophoresis, ELISA-based methods, spectrophotometric, electroanalytical, liquid chromatography, and the most employed high-performance liquid chromatography (HPLC). New electrochemical sensing devices based on reduced graphene oxide with metallic nanoparticles (especially Cu) have been developed for this purpose and have been used in the detection of drugs; these sensors are reported to be easy to prepare from using cheap materials (Bandala et al., 2021).

Wastewater treatment can be performed by several methods including the use of chemical disinfectants (chlorine-based disinfectants, peroxyacetic acid, hydrogen peroxide and povidone-iodine), advanced oxidation processes, ultraviolet irradiation, coagulation-filtration, and membranes (Table 3) which are used in the three disinfection steps, that include a combination of physical, chemical and biological processes, to avoid the spread of different pathogens (Achak et al., 2021; Ji et al., 2021). These steps are a) primary grade: to separate organic and inorganic solids; not effective at all for SARS-CoV-2 because of its size, b) secondary grade: removes solids that are dissolved, dispersed, or suspended, c) tertiary grade: improves the water quality featuring advanced oxidation processes (AOPs), filtrations and chlorination and with the combination of disinfection in an increased dosage could enhance the inactivation of COVID-19 in wastewater (Almeida et al., 2020; Ji et al., 2021; Nghiem et al., 2020; Patel et al., 2020; Venugopal et al., 2020).

The most common chlorine treatments need a contact time and a dose demand to achieve the efficacy of the disinfection since many times its action is neutralized by organic matter. $ClO_2$ seems to be really helpful in the deactivation of this virus by passing through the capsomere and reacting the with RNA inside the virus, nonetheless; hypochlorite ($ClO^-$) has demonstrated to have a better action against SARS-CoV (Kataki et al., 2021; Mohan et al., 2021; Sharma et al., 2020). Even though chlorine-based disinfectants are widely mentioned in wastewater disinfection strategies, they generate about 600 types of by-products that are highly toxic (Table 3), not to mention that when chlorine reacts with ammonia a new product named chloramine ($NH_2Cl$) is less effective against viruses; fulvic and humic acids (present in soil) can react with chlorine forming trihalomethane ($CHCl_3$) and haloacetic acids which are potential human carcinogens (Achak et al., 2021; Kataki et al., 2021). WHO proposes as a solution to reduce these by-products by

**Table 3**
Wastewater treatment technologies (Lesimple et al., 2020; Mohan et al., 2021; Patel et al., 2020).

| Technology | Treatment | Description |
|---|---|---|
| AOP (advanced oxidation processes) | Chlorine treatment | It acts as a selective oxidant, reacting in this way with the capsid protein and damaging the Cys, Trp and Tyr, causing the inhibition of replication and injection of the genome as well as UV treatment. |
| | Algae systems | Sedimentation, temperature increase, degradation by sunlight is part of the treatment mechanism of these systems. |
| | UV inactivation | 200 to 300 nm is the active UV wavelength range that can damage the bacteria or virus, nonetheless; ~254 nm is recognized as the best one for microbial disinfection. Its efficiency depends of the contact time, temperature and the presence of organic matter. Usually inactivates the virus by damaging the RNA, so on the replication through oxidation processes, altering the permeability and damaging the capsid proteins. |
| | Nanomaterials | They include the use of photocatalysts and membranes which incorporate nanomaterials. Metal oxide semiconductors utilized are for example $TiO_2$ and ZnO. |
| | Ozone treatment | A certain amount of contact time is needed to achieve the disinfection. |
| Membrane technologies (MTs) | Reverse Osmosis | Usually used as part of pre-treatment systems, in order to remove particles and post-treatment in order to complete the removal of emerging contaminants that may remain after a water treatment process. |
| | Nanofiltration | The pore sizes present in these membranes are much smaller than the viruses that are present as common contaminants in water. |
| | Ultrafiltration | Usually used as a pre-treatment before reverse osmosis, however; it has also been used by several authors in the removal of bacteria and viruses. |
| | Microfiltration | They are mostly used for the removal of protozoa and bacteria. |
| | Ceramic membranes | They have been used for filtration in combination with ozonation and coagulation as a pre-treatment for virus removal. |

the previous removal of the organic charge in wastewater through pre-filtration. For this reason, other disinfectants are proposed such as a) Sodium dichloro isocyanurate (NaDCC) which is a slow-release source of chlorine has and adherence to the recommendations to water treatment and not causes any serious health damage, b) hydrogen peroxide: added in pre-treatment, highly safe to the environment, more efficient germicide and degrader of organic matter in combination with UV radiation, c) benzalkonium chloride: destabilizes the surface of the pathogen trough and electrostatic interaction, it is environmentally friendly, e) peracetic acid and performic acid: have a presence of disinfection by-products and are powerful oxidant (Kataki et al., 2021).

Ultraviolet irradiation disinfection is an effective, clean, and cost-effective method for the deactivation of the majority of waterborne pathogens; recently, it was demonstrated that UV-C irradiation (200–280 nm) is highly effective in inactivating SARS-CoV-2. Passive solar heating (a technique used to kill soil pathogens) was shown recently that can inhibit the virus SAS-CoV-2; the air heated inside vehicles in parling lots under the sun can reach temperatures of 52–57 °C in 90 min this method could be used as a cheap method for water disinfection; more studies are required (Biasin et al., 2021; Wang et al.,

**Table 4**
Technologies with advanced oxidation processes.

| Compound studied | Technology used | Description | Reference |
|---|---|---|---|
| Hydroxychloroquine | Advanced electrochemical oxidation | Two boron-doped diamond diodes (BDD) are used as part of the oxidation that will degrade the drugs into $CO_2$ and intermediates that are usually no longer stable compounds due to a big production of OH* radicals form the electrochemical oxidation of water at the surface of these two BDD. | (Bensalah et al., 2020) |
| Chloroquine | Electro-Fenton oxidation | BDD anodes are used with the addition of $FeSO_4$ in the solution in order to generate a greater number of free radicals in the AOP and thus improving the cost-effectiveness, even though, the pH has to be controlled. | (Midassi et al., 2020) |
| Virus | Photocatalyst | The photocatalyst $Ag_3PO_4$/g-$C_3N_4$ synergizes the effects of $Ag_3PO_4$ with those of g-$C_3N_4$ achieving and improving the efficiency of the absorption of visible light; consequently, a greater destruction of the viruses by means of the ROS. | (Cheng et al., 2018) |
| | Ozone | The is a powerful oxidant which, by generating ROS, could attack the virus in different places of its structure, especially the S-glycoprotein, inhibiting the infection process. | (Tizaoui, 2020) |
| | Flat-sheet polyvinylidene fluoride (PVDF) and filters based on PVDF coated with multiwalled carbon nanotubes layer (MWCNTs) | A flat-sheet of PVDF is employed, showing a bacteriophage photocatalysis inactivation where the membrane acted as a fence. MWCNTs functionalized with different silver-based filters demonstrated to remove effectively viral bacteriophages but with a virus retention limitation after the filtration. | (Mohan et al., 2021) |
| | Cold plasma (CP) | The plasma acts facilitating the production of UV radiation with reactive oxygen and/or nitrogen species (RONS) that are also the limiting factor and acts damaging the nucleic acids, oxidizing nucleic acids, proteins and lipids. | (Mohan et al., 2021) |

2021).

Being the SARS-CoV-2 size 100 μM, membrane technology (MT) can be used in all the steps of Wastewater Treatment Plants (WWTPs), principally in the pre-treatment, allowing the separation of viruses and/or bacteria. The type of filtration and the type of pathogen that removes depends basically on the pore size: a) Microfiltration (0.1–10 μm): bacteria/protozoan cysts, b) ultrafiltration (0.01–0.1 μm), and c) nanofiltration (0.001–0.01 μm) (Mohan et al., 2021).

AOP's are chemical treatment procedures to remove organic materials by oxidation with reactive oxygen species (ROS), such as OH* and $O_2$* from water. AOP includes a) Fenton, which uses the reaction of ferrous salts with $H_2O_2$ to form radicals OH*, b) photo-Fenton, similar to Fenton but also uses UV radiation to enhance the process efficiency and c) photocatalysis, the most common materials used are semiconductors nanoparticles such as $TiO_2$ and engineered carbon NPs due to its efficiency to generate electron-holes and in consequence ROS, that make contact with the virus surface and permit the rapid inactivation trough shape distortion, protein oxidation and gene damage, by the action of UV radiation, without the use of oxidants (Mohan et al., 2021; Paiva et al., 2018) (Table 4).

The wastewater treatment industry faces the constant challenges of foaming, inhibition of the biodegradation of organic compounds, interruption in oxygen diffusion, and denitrification process due to the presence of chemical detergents, soaps. That is why the aforementioned technologies need to be optimized and new technologies are being developed in the effort to find an effective alternative to treat wastewater such as supercritical water oxidation and constructed wetlands (Achak et al., 2021; Daverey and Dutta, 2021).

To show the relevance of a correct wastewater treatment process and some issues, is the case of Wuchang stadium, in Wuhan which was designated as a temporary hospital for COVID-19 patients, where certain actions were applied as a method of disinfection for the sewage systems to reduce the viral load of SARS-CoV-2 (Venugopal et al., 2020). An absence of SARS-CoV-2 RNA was found when 800 mg/L of sodium hypochlorite, with free chlorine >6.5 mg/L was used satisfying the protocols developed in China by the CDCP. Despite this, after 12 h there was a presence of SARS-CoV-2 RNA in effluent when free chlorine was undetectable, which can be explained by the presence of feces that are very rich in organic matter which changes the composition of wastewater as well as interfering with the chemical components that should deactivate the virus, such as $ClO_2$ (Daughton, 2020; Venugopal et al., 2020).

## 5. SARS-CoV-2 as a warning sign

SARS-CoV-2 was identified in wastewater at the beginning of the outbreak, suggesting that it can be used for surveillance and population monitoring (Wastewater-Based Epidemiology (WBE)), as this is an entry to human habits and health through feces, sputum, or nasal secretion that are discharged into sewage, detecting the virus in individuals who have not yet been identified as positive either because they are likely to be asymptomatic, pre-symptomatic, or have mild symptoms providing an advantage over individual testing (Kataki et al., 2021; Michael-Kordatou et al., 2020; Mohan et al., 2021). This WBE can be applied at a municipal level, especially in those communities where access to molecular and serological testing is quite scarce and restricted, but can also be very useful in the detection of some variations that may occur in viral strains, allowing the corresponding entities to be aware of the new variants of the SARS-CoV-2 (El-Baz et al., 2020; Mao et al., 2020; Michael-Kordatou et al., 2020).

To make a proper detection on environmental matrices, the following three steps are important:

I. Concentration: Samples often require a pre-treatment to concentrate the virus and, in this way, increase the possibilities of detection and make an accurate quantification in wastewater samples, especially in surface water bodies where there is a bigger possibility that wastewater will be diluted. Some examples of concentration methods used are ultrafiltration/ultracentrifugation, PEG precipitation, electropositive filter particles, and electronegative membrane adsorption. It is important to mention that in a recent study, electronegative filtration (HA filtration) with bead seems to be the greatest option because of its elevated recovery of all gene targets, moderate initiation cost, and low price per sample (Achak et al., 2021; Bandala et al., 2021; Langone et al., 2021; Laturner et al., 2021; Mohan et al., 2021).

II. Extraction: its purpose is to obtain the RNA from the matrix without causing damage to the nucleic acids, three of the most used techniques are silica-membrane-based spin column, phenol-guanidine isothiocyanate, and paramagnetic particles. The most common steps are: 1) cell lysis, 2) denaturation of DNA and proteins, 3) denaturation and inactivation of RNAses, 4) separation or removal of cellular components, 5) RNA recovery, and 6) RNA elution (Michael-Kordatou et al., 2020).

III. Detection: The current standard method for detection is the reverse transcription-polymerase chain reactor (RT-PCR); the analysis detects the presence of viral nucleic acids, uses repeated cycles of heating and cooling to make many copies of DNA, however, it requires complex equipment, requires at least 4–6 h to complete and it is expensive. Therefore, Point-of-care testing (POCT) is advantageous(Song et al., 2021). Loop-mediated isothermal amplification (LAMP) is similar to RT-PCR but the difference is that the process is carried out at one temperature (60 to 65 °C) making the detection quicker, easy to use, and do not require expensive reagents or instruments (Thompson and Lei, 2020).

Biosensors can also be especially useful in the detection of the virus in aquatic compartments since they are analytical devices with biological elements that generate physicochemical signals, and according to recent studies, they have great advantages such as the use of small sample quantities, cost-effectiveness, and prompt response, The detection of COVID-19 on time, could decrease the transmission of the disease providing accurate information that would help considerably the eradication (Mao et al., 2020; Song et al., 2021). More information can be found in the article "Point-of-care testing detection methods for COVID-19" (Song et al., 2021)

However, there are some limitations in the detection: a) the complexity of the wastewater load (location of specific sites and the very nature of the diluted biomarker), making difficult to establish accurate quantitative predictions of infected patient cases (Mohan et al., 2021; Zhu et al., 2021), which could be solved by sampling campaigns that would first identify infected areas and then identify infected individuals in hotspots (Langone et al., 2021) and b) load of organic contaminants that are present in wastewater and could interfere with the detection (Achak et al., 2021). An exhaustive review for the detection of SARS-CoV-2 in wastewater by PCR methods has been published by Kitajima et al., 2020. It is important to mention that according to a novel report available in RETEMA (Technical Journal of the Environment), the WBE is currently being employed in Burlington VT (USA), Spain and in more than 20 cities by GoAigua, so it is a new technology that is already beginning to be used in developed countries as part of their public health strategy ("Burlington implementa la epidemiología basada en las aguas residuales para frenar el COVID-19 - Actualidad RETEMA," n.d.). Not to mention that already some studies show us the potential of WBE as an early warning in: 1) Murcia, Spain, 2) Amersfoort, The Netherlands Milan, Italy, 3) Ishikawa, Japan, 4) Bozeman MT, USA and 5) New Haven, CT, USA (Zhu et al., 2021).

## 6. Future perspectives

Low-income populations are one of the most affected by this new outbreak because some of them have little or no access to safe and properly treated water. No studies are being conducted on the level of contamination of rivers and lakes as possible risks to public health, thereby attempting to those populations that need more attention. It is also important to quote a phrase mentioned in an article published by Neal (2020): "Countries will be emerging from the impacts of COVID-19 at different times and via different pathways, creating an opportunity for countries that are able to assist and support other countries in human and humane ways. Because water provides an entry point into every aspect of human life and every sector of our globalized and interconnected world, we should take this opportunity to fully embrace a human rights approach in our immediate, medium-term and long-term water-related responses to COVID-19."

There is a need for alternatives for the use of wastewater treatment technologies that are cost-effective and that do not have the risk of generating long-term repercussions, such as chlorine-based disinfectants which are highly toxic, and the scientific community is very concerned about the environmental damage that this will cause in the long term.

The limited knowledge of SARS-CoV-2 behavior in wastewater difficult for the proper treatment in wastewater, leaving a gap that should be taken and studied to improve the technologies proposed to eliminate the presence of the virus in aquatic compartments.

COVID-19 has forced the population to be more aware of their hygiene, as well as disinfection in fomites and all kind of superficies where the virus could be attached, so repercussions will be reflected in Wastewater Treatment Chemicals and Global Water according to a report made in the UK (Kataki et al., 2021). Natural compounds such as microbial and plant-derived surface-active agents, natural humectant-viscosity enhancers, essential oils, and phenolic compounds are innovative and eco-friendly solutions to decrease the charge of the emerging contaminants caused by hygiene products. Nonetheless, economic aspects need to be evaluated and solved through new technologies that increase productivity and reduce the cost by bioprocess optimization, separation processes, or any other innovative technique (Daverey and Dutta, 2021).

Regions with a lack of regulations and poor infrastructure to treat wastewater need help to solve their problem, some treatment alternatives are advanced oxidation processes and membrane technology, which are characterized by their environmental compatibility, versatility, high efficiency, and safety.

## 7. Conclusion

Wastewater-based epidemiology (WBE) can be applied at a municipal level for virus detection, especially in communities where access to molecular and serological testing is quite scarce and restricted. The pathogens and organic pollutants can be inactivated and removed in wastewater through promising technologies as AOPs and membranes, respectively. The WHO recommend short-term solutions as UV radiation and solar irradiation tend to cause less damage to the environment. Finally, new cheap (POCT) techniques of detection and quantification in water should be developed and implemented to have information on the human health risk assessment of SARS-CoV-2.

## Declaration of competing interest

The authors declare that they have no competing interests.

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