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Review of Method and a New Tool for Decline and Inactive SARS-CoV-2 in Wastewater Treatment

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ABSTRACT

Following the recent outbreak of the COVID-19 pandemic caused by the SARS-CoV-2 virus, monitoring sewage has become crucial, according to reports that the virus was detected in sewage. Currently, various methods are discussed for understanding the SARS-CoV-2 using wastewater surveillance. This paper first introduces the fundamental knowledge of primary, secondary, and tertiary water treatment on SARS-CoV-2. Next, a thorough overview is presented to summarize the recent developments and breakthroughs in removing SARS-CoV-2 using solar water disinfection (SODIS) and UV (UVA (315–400 nm), UVB (280–315 nm), and UVC (100–280 nm)) process. In addition, Due to the fact that the distilled water can be exposed to sunlight if there is no heating source, it can be disinfected using solar water disinfection (SODIS). SODIS, on the other hand, is a well-known method of reducing pathogens in contaminated water; moreover, UVC can inactivate SARS-CoV-2 when the wavelength is between 100 to 280 nanometers. High temperatures (more than 56°C) and UVC are essential for eliminating SARS-CoV-2; however, the SODIS systems use UVA and work at lower temperatures (less than 45°C). Therefore, using SODIS methods for wastewater treatment (or providing drinking water) is not appropriate during a situation like the ongoing pandemic. Finally, a wastewater-based epidemiology (WBE) tracking tool for SARS-CoV-2 can be used to detect its presence in wastewater.

1. Introduction

Globe is battling the Coronavirus disease 2022 (COVID-19) pandemic. The COVID-19 outbreak has caused over 524 million infections and over 6.2 million deaths as of May 26, 2022 (Covid19WHO). Therefore, it is best, to begin with, a global perspective (Organization 2021). A severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) was identified as the virus by the International Committee on Taxonomy of Viruses (ICTV), and the disease was named COVID-19 (CoV) belongs to the *Coronaviridae* family, a section of the *Nidovirales* (Lvov et al. 2020). Therefore, it is imperative to minimize adverse effects on human health, the environment, and the economy (Lesimple et al. 2020). Coronavirus also causes respiratory tract infections in mammals and birds (Contini et al. 2020). There are four subfamilies within this family, from alpha to delta; the alpha and beta subfamilies can affect humans (Suhail et al. 2020). Humans have been infected with seven coronaviruses in these two subfamilies: 229E, OC43, SARS-CoV, NL63, MERS,

HKU1, and SARS-CoV-2 (Al-Sharif et al. 2021). SARS-CoV, MERS, and SARS-CoV-2 viruses are extraordinarily pathogenic (Rabaan et al. 2020), leading to severe acute respiratory syndrome (Lai et al. 2020). Another coronavirus strain found in China and genetically related to SARS-CoV is causing COVID-19; therefore, this strain has become known as SARS Coronavirus 2 (SARS-CoV-2) (El Zowalaty et al. 2020). It can cause upper and lower respiratory infections (Lieberman et al. 2002). During 2002–2003 there was an outbreak of SARS-CoV, and in 2012 an outbreak of MERS-CoV spread in the Arabian Peninsula (Pavli et al. 2014). Despite the fact that SARS-CoV-2 is frequently reported in regularly updated data, averaging 100 by 10 nm in spectral resolution (Zangmeister et al. 2020). When using a membrane-based treatment process, size is essential as it determines which membrane pore size is appropriate for removing the viral particles (Lesimple et al. 2020).

Initially, two primary methods of SARS-CoV-2 transmission have been reported: direct contact and aerosols produced when an infected person sneeze or (Zahmatkesh et al. 2022a) cough; in addition, SARS-

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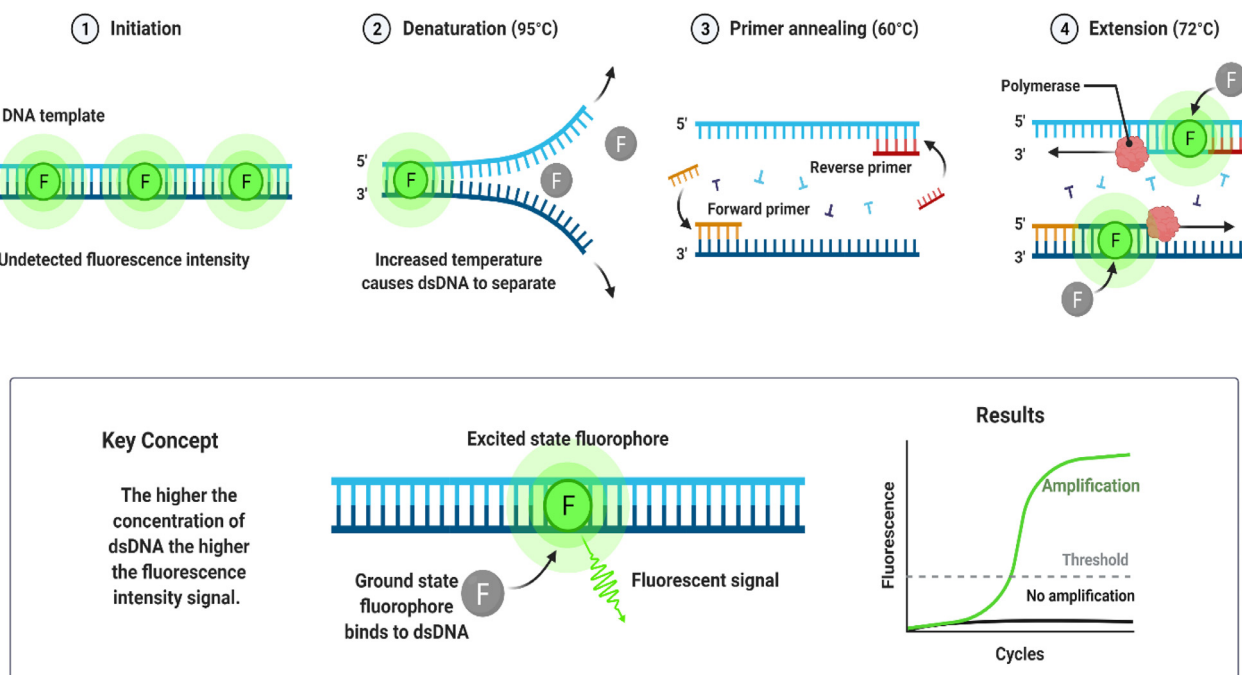


Fig. 1. Fluorescent Dye-Based Real Time PCR (qPCR).

CoV-2 is capable of surviving on various surfaces but has not yet been shown to be a route for transmission (Prather et al. 2020). However, recent studies have found that human feces contain this virus (Foladori et al. 2020). Furthermore, it has been detected in municipal wastewater, which allows the broader environmental impacts to be more widely spread when wastewater is not adequately treated; therefore, a wastewater surveillance system can be established in this way (Pandey et al. 2021). Suppose this virus causes different diseases and is not eradicated. In that case, further screening should be conducted to focus mainly on wastewater treatment and sludge from sewage systems (Mohapatra et al. 2021), sediments, and soils (Anand et al. 2021), Agricultural products (Mancuso et al. 2021), animals (Stout et al. 2020), Water surface, and groundwater (Langone et al. 2021). Therefore, wastewater-based epidemiology (WBE) is crucial to determining whether specialized treatments, such as biosorbents and other materials, effectively retain and remove pathogens and analyze the spread of pathogens from wastewater treatment plants before and after they are discharged (Zahedi et al. 2021).

SARS-CoV-2 was isolated and detected in municipal wastewater in the Netherlands; sewage samples were tested using four qRT-PCR (Fig. 1) assays in six cities and at the airport (Izquierdo-Lara et al. 2021). As a result, it demonstrates, for the first time, that the number of hospitalizations related to COVID-19 is increasing at a regional level in tandem with the number of viral genomes detected in wastewater (Medema et al. 2020). Researchers conducted RT-PCR analyses in Australia on wastewater samples, which show SARS-CoV-2 gene fragments. The virus was detected twice within six days, the same method hospitals use to detect the virus in human samples (Ahmed et al. 2020). In addition, SARS-CoV-2 has been found in sewage from a significant urban treatment facility in Massachusetts (USA) and is estimated to have approximately 100 viral particles per mL of sewage (Wu et al. 2020).

Many factors can influence how viruses behave in wastewater, including inactivation, decay, dispersion, and retardation (Hamouda et al. 2021). Likewise, the temperature is a critical factor for virus survival (Foladori et al. 2020); in various studies, the temperature has been shown to affect virus survival in various types of water (De Oliveira et al. 2021). Moreover, the inactivation rate increases with increasing temperature in sewage, resulting in shorter virus lifetimes

(Arslan et al. 2020). Increasing temperature has been associated with a reduction in viral survival primarily due to the denaturation of proteins and increased activity of extracellular enzymes (Gundy et al. 2009). Meanwhile, other microorganisms can also affect the survival of viruses in wastewater because, in wastewater, other microorganisms accelerate the inactivation of viruses (Achak et al. 2021). Thus, solar UV availability is cited as a primary factor for the survival of pathogens in solar stills. It should be pointed out that the wavelength of UVC (The UVC wavelength range for inactivating SARS-CoV-2 is 100-279 nm) is effective and strong enough to damage (Zahmatkesh et al. 2022b) viruses.

In contrast, the most prevalent solar UV on Earth (UVA) does not have an overwhelming effect on viruses. A well-known method of reducing the concentration of pathogens in contaminated water is solar water disinfection (SODIS). Finally, pH also affects the survival of viruses in wastewater. SARS-CoV-2 can survive pH ranges between 3 and 10 for at least 1 hour without showing significant stability loss (Tran et al. 2021).

Water is transported to treatment plants, treated, and then discharged into the environment in the sewage system. A wastewater and WBE monitoring program are critical for infectious disease surveillance and control (Fig. 2). Prevent and control the spread of the disease in the community; continuous monitoring of the prevalence of SARS-CoV-2 is fundamental. However, SARS-CoV-2 can be detected in sewage or wastewater by monitoring the genetic material RNA and screening the entire community for the presence of the virus. Consequently, the presence of SARS-CoV-2 in wastewater can be predicted since the virus can be shed through the stools of patients.

2. SARS-CoV-2 impact on municipal wastewater treatment

Previous reports suggest SARS-CoV-2 is found in human feces and can be transmitted by animals able to excrete it (Lesimple et al. 2020). Although stomach acidity can destroy viruses, it can be protected by meals or compounds that resist acidity. As a result, it can pass through the intestine. Also, it can be caused by the replication of the virus within the intestinal cells (Stanifer et al. 2020). Although, Despite the lack of diarrhea and other gastrointestinal symptoms, SARS-CoV-2 positivity can also be detected in patients' feces; for example, A live version of SARS-CoV-2 was found in the stool of two infected people who did not

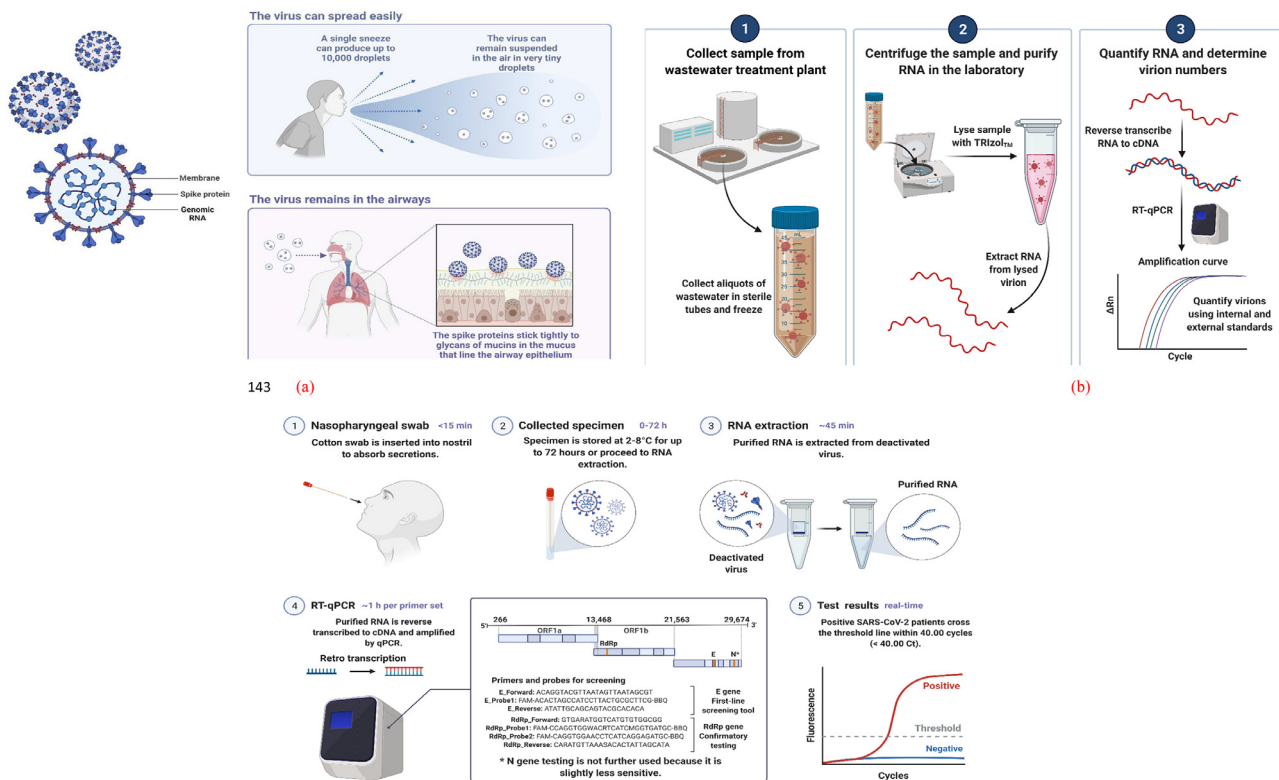


Fig. 2. RT-qPCR analysis for epidemiology of SARS-CoV-2 in wastewater: (a) Spread of SARS-CoV-2 (b) detection of SARS-CoV-2 viruses in wastewater (c) COVID-19 diagnostic test through RT-PCR.

experience diarrhea symptoms (Foladori et al. 2020). SARS-CoV-2 has been confirmed in urine samples of patients (Essler et al. 2021). Despite this, SARS-CoV-2 genetic material in the stool does not necessarily imply illness or infection (Yuen et al. 2020). Finally, A coronavirus virus concentration of 104–108 copies/liter was found in the feces of infected individuals who tested positive (Foladori et al. 2020). Nevertheless, feces dilution reduces viral loads in sewage by about 102 to 106.5 copies/L (Ahmed et al. 2020).

The spread of viruses is a primary concern due to polluted water and populations. On the one hand, humans contaminate water; on the other hand, water becomes a potential source of human infection. Due to the fact that wastewater contains viruses that everyone repels, regardless of health status, measuring viruses in the wastewater and other waters that receive effluent from wastewater treatment plants (WWTPs) can provide information on how common and dangerous gastroenteritis viruses to human health (Tran et al. 2021).

3. Coronavirus removal at wastewater treatment

Three main phases are needed to clean infected water from coronaviruses to safe water for recycling or reusing (Teymoorian et al. 2021). Firstly, before reclaimed water can be used, it is crucial to prevent the virus from spreading in the surrounding environment. Physical activities such as screening, grit chambers, and initial sedimentation are part of the first phase of wastewater treatment to remove the suspended solids (Ji et al. 2021). Secondly, approximately half of the treatment is achieved by biological treatment, while the other half involves physicochemical treatment to reduce turbidity, remaining organics, heavy metals, and pathogens such as Coronavirus (Teymoorian et al. 2021). Finally, many factors such as pH, temperature, sunlight, and solids strongly affect SARS-CoV-2, as with other coronaviruses (Anand et al. 2022). Despite the need for more research on these methods for SARS-CoV-2, regular monitoring of their efficacy in actual water treatment to consider all factors affecting virus survival

and environmental influences to determine which technology is most effective.

3.1. Effect of physical treatment on Covid-19

One of the methods used to remove volatile and fixed solids suspended in sewage is physical separation (Espinoza-Quiñones et al. 2009). As the leading and first mechanism in the treatment phase for removing viruses, virus adsorption onto large suspended solids in sewage is accompanied by gravitational sediment (Teymoorian et al. 2021). However, according to available data, gravitational sedimentation is not enough to eliminate viruses from wastewater. Secondary and tertiary wastewater treatment processes remove coronavirus RNA, and tertiary treated wastewater is used for irrigation and the public domain (Randazzo et al. 2020).

3.2. Effect of Biological process on Covid-19

Biological methods such as membrane bioreactors activated sludge and extended aeration in wastewater treatment plants are used mainly during secondary treatment phases (Randazzo et al. 2020). According to past studies, the secondary treatment process eliminates more intestinal viruses than the first treatment process (Naidoo et al. 2014). According to other studies, coronavirus resistance and survival are also higher in primary treatment than in secondary treatment due to the higher levels of organics in the primary treatment stage that protect viruses (Wang et al. 2005).

3.2.1. Effect of Activated sludge and membrane from Biological Process Covid-19

As a powerful and essential mechanism for removing viruses from wastewater treated with activated sludge, the uptake of viral particles on the organic biomass and their elimination by sedimentation

through the secondary clarifier has been shown (Kiser et al. 2010, Teymoorian et al. 2021).

As part of the secondary treatment phase of wastewater, membrane bioreactors are used to remove considerable amounts of viral particles. These processes consist of membrane filtration and suspended growth. Membrane technology is economical and environmentally friendly; the relatively little chemical is involved, the size of the equipment is reduced, and it is easy to use (Obotey Ezugbe et al. 2020). Recent studies show that this technology is severely limited by its high energy requirements, ranging between 0.45 and 0.65 kWh·m⁻³ for the highest performance (Shen et al. 2020). Activated sludge processes are designed with membrane bioreactor systems with longer retention times of solids, resulting in different treatment performances and other outcomes (Abu Ali et al. 2021). Compared to activated sludge, membranes have more significant operational difficulties and complexity. In the Biological process, the membrane bioreactor achieved log removal values of 6.8, 6.3, and 4.8 for enteroviruses, adenoviruses, and noroviruses, respectively (Simmons et al. 2011).

3.3. Effect of advanced process (UV, chlorination, ozonation and Membrane) on Covid-19

Treatment operations in the third phase include coagulation, filtration, ultraviolet (UV), chlorination, ozonation, etc. (Gerba et al. 2019). The aim of viral disinfection (such as UV, chlorination, ozonation, etc.) was to influence one of these parts by applying environmental stress (Pinon et al. 2018). Viruses in sewage have been inactivated and eliminated with nanomaterials, including titanium dioxide, zero-valent iron, and carbon nanotubes (CNTs) (Lesimple et al. 2020). Covid-19 contains a genome and a protein capsule, either without or with an envelope. Viral envelopes can be disrupted more easily. As a result, non-enveloping viruses demonstrate a higher resistance to inactivation and less susceptibility to adverse circumstances (Fitzgibbon et al. 2008). However, according to a recent study by Nasseri and colleagues, SARS-CoV-2 was detected in 5 out of 6 water outlet samples from UV disinfection and detected in 1 out of 4 water outlet samples from chlorine disinfection from WWTPs in southern Tehran, Iran, according to this report showed only chlorine disinfection samples remain positive (Nasseri et al. 2021). Hence, UV disinfection has been more effective than chlorine, so WWTP operators should enhance free residual chlorine concentrations to ≥ 0.5 mg·L⁻¹.

4. Reduces and prevents the spread of SARS-CoV-2 in wastewater treatment

Coronaviruses rely on the temperature, light exposure, organic matter, and antagonistic microorganisms to survive in water (Corpuz et al. 2020). Although solar or UV light and temperature above 23°C, however, cause the virus to be inactivated, organic matter provides an adsorbent surface, thereby increasing their survival. Hence, It is imperative to ensure that people who work in the vicinity of untreated wastewater follow safe work practices and wear protective gear (Heilingloh et al. 2020).

4.1. Effect of Solar, UV, and Chlorination on SARS-CoV 2

The implementation of UV disinfection devices for disinfecting surfaces that are frequently touched and streams of circulating air is currently being considered by different public environmental settings worldwide, including health care facilities, hospitals, airports, and shopping centers. However, the advantages of UV treatment for water treatment include the fact that it is a clean disinfectant, effective against most waterborne pathogens, including several pollutants that are relatively resistant to the treatment (Hijnen et al. 2006). Under UV light, the viral particles lose their ability to infect and replicate as the phosphodiester bonds and links with molecules are broken, which results in

the breakdown of the viral genome and protein (Wigginton et al. 2012). Moreover, UV light is considered one of the most effective methods for disinfecting biologically contaminated water (Parsa et al. 2021). It does not generate harmful by-products during the process compared to other methods like chlorination and controls the growth of microorganisms in any medium. Three types of UV Light exist based on their wavelengths: UVA (315-400 nm), UVB (280-315 nm), and UVC (100-280 nm) (Fig. 3). These types of UV light are abbreviated as UVA, UVB, and UVC, respectively (UVA photons have shallow energy, while UVC photons have enough energy to damage bacteria's DNA) (Darnell et al. 2004, Parsa et al. 2021). Among the three types of UV, only the UVA wavelength reaches the surface of the earth and a small part of the UVB wavelength.

In SODIS, UV content, temperature, and time are critical parameters. Moreover, UVC wavelengths are entirely absorbed by the Ozone layer, which means that pathogens, including viruses, can be damaged by the direct effect of UV on genomes as well as indirectly by endogenous or exogenous factors (Parsa et al. 2021). Despite this, Sunlight intensity (i.e., the UV content available) is more critical than temperature or time of exposure in viral disinfection since high temperatures only affect capsid proteins but have minimal effect on the structure of the genome. Temperatures above 40°C can produce thermal-optic synergy, meaning that more viruses are inactivated with each photon. Thus, secondary treatment benefits residual protection followed by UV and ensures redundant microbial protection (Parsa et al. 2021).

Several studies showed that The UVA method is ineffective enough to eliminate the SARS-CoV-1 virus (Darnell et al. 2004), whereas UVC eliminated the virus (Parsa et al. 2021). Another study, however, failed to complete the inactivation of the SARS-CoV-1 virus using UVC, so study results are not conclusive (Kariwa et al. 2006). Numerous studies have investigated the effectiveness of UV irradiance in eliminating the SARS-CoV-2 virus, focusing primarily on using UVC. The UVC wavelength was strong enough to eliminate SARS-CoV-2 on various surfaces (Hadi et al. 2020). Kitagawa et al. reported that UVC (222 nm) decreased the concentration of SARS-CoV-2 on various surfaces by 88.5–99.7% (Kitagawa et al. 2021), while (Heilingloh et al. 2020) showed that UVC at a dose of 1048 mg/cm² is the minimum dose for inactivating SARS-CoV-2. The influence of various types of UV on SARS-CoV-2-virus solutions remains unknown. Seeing that UVC is entirely absorbed by the atmosphere, and UVB reaches the earth at only 5%, UVA reaches the earth in the most amounts; however, UVA has only a tiny effect on deactivating SARS-CoV-2 according to. A viral nucleic acid absorbs most of the ultraviolet radiation at 260 to 265 nanometers (the UVC range) within the germicidal wavelength range, the most effective and optimum (Kowalski 2010). The UV wavelength below 320 nm is considered actinic, and at wavelength >320 nm, the virus nucleic acid absorbs a smaller amount of the UVA, so this wavelength does not appear germicidal. Wavelength reverses the relationship between germicidal action and wavelength, which means the germicidal increases by decreasing wavelength (Pozo-Antonio et al. 2018).

Thermal energy is essential in solar disinfection, but its importance varies during different seasons. As the structure and activity of enzymes are affected by thermal stress above the optimum temperature for microorganism growth, thermal stress has significant consequences. For example, most fecal bacteria can survive between 20 and 45°C (Hartz et al. 2008). Inactivation of bacteria is more sensitive to temperatures above 45°C; the temperature does not significantly affect bacterial inactivation below 45°C (Ross et al. 2008). Thus, solar disinfection can remove microorganisms in winter with a severely limited ability. The thermal effect is determined by volume, turbidity, and environment. Thermal stress facilitates DNA damage, inhibiting DNA repair mechanisms (McGuigan et al. 2012). As a result, there is increased cell wall permeability (Theitler et al. 2012), cutting down on enzyme activity, and protein denaturation leading to the death of cells (García-Gil et al. 2020). The fact that thermal and optical inactivation can enhance the performance of solar disinfection in temperatures beyond

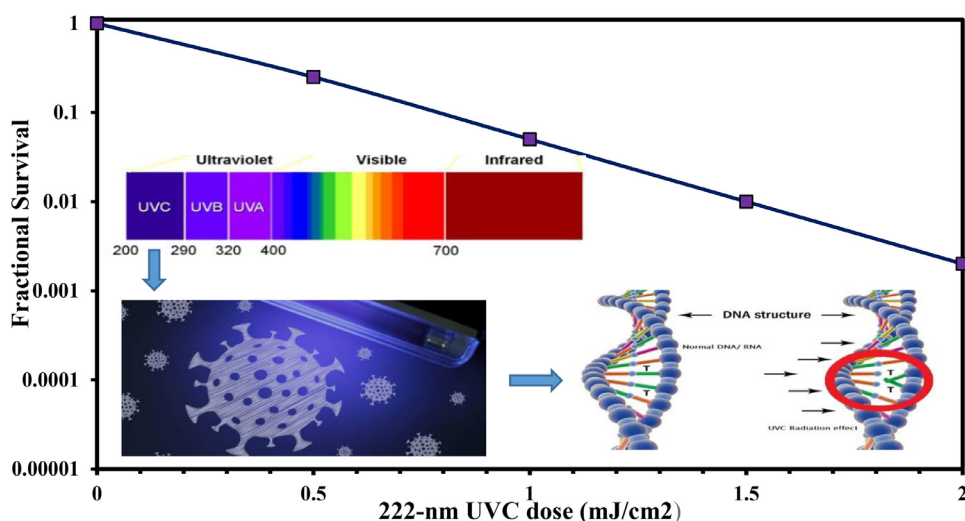


Fig. 3. The effect of UVC on SARS-CoV-2.

45°C is reported by many researchers. However, it is only effective in specific cases under specific conditions (McGuigan et al. 2012). Examining the effect of environmental conditions on removing E Coli using the SODIS method, they discovered that the water temperature during summer was no higher than 40°C (Sichel et al. 2007). The effect of temperature, turbidity, and optical irradiation was considered in a simulation of the SODIS process. The results showed that the water temperature needs to reach 55°C for the complete inactivation of pathogens (McGuigan et al. 1998). However, experiments in the field revealed water temperatures reaching only 45°C (Gómez-Couso et al. 2009). This study showed that water temperatures in SODIS with and without TiO₂ photocatalyst reached 39°C and 38.6°C, respectively, at 32.6°C and 36.6°C (Rincon et al. 2004). Additionally, the actual temperature of the water during winter and summer is within the range of 15-21°C and 25-30°C, respectively (Sichel et al. 2007).

Chlorine elements, chloramines, sodium hypochlorite, chlorine dioxide, calcium hypochlorite, and chloroisocyanurates are the primary sources of free chlorine released during disinfection. The most effective method to combat viral particles is using hypochlorous acid (HOCl) and hypochlorite ions (ClO⁻). The powerful oxidizing agent, hypochlorite, effectively oxidizes organic contaminants, while undissociated hypochlorous acid primarily acts as a microbicide (Pinto et al. 2003). A recent report suggests that the SARS-CoV was utterly inactivated after 30 minutes while a free residual concentration of ClO₂ was approximately 2.19 mg/L and chlorine was higher than 0.4 mg/L (La Rosa et al. 2020). Another recent report showed that the SARS-CoV-2 could be inactivated when tested in vitro on SARS-CoV-2 using 1:99 diluted household bleach within 5 minutes (Chin et al. 2020).

Ammonia is one of the most significant concerns and challenges in successful chlorination since it requires chlorine to deal with co-pollutants and pH. When Cl binds with Ammonia, it forms a chlorine compound (chloramine), which is not as efficient in combating viral particles as free chlorine is. Consequently, it is crucial to ensure that Cl is not absorbed by any of the different demanding substrates, including organic matter, ferrous ions, Ammonia, hydrogen sulfide, and nitrites. Chlorine-based materials are typically neutralized by organic materials, posing short-term risks to plants and soils (Teymoorian et al. 2021).

Based on preliminary research, the second and third wastewater treatments were reported to have coronavirus RNA in them. Approximately 11% of samples were positive for Coronavirus RNA after regular activated sludge treatment; On the other hand, after a third treatment, 100% of samples turned negative after disinfectant treatment with NaClO; on the other hand, disinfection was combined with ultraviolet (UV) (Randazzo et al. 2020). Zhang et al. demonstrated that in hospital sewage, sodium hypochlorite was used to disinfect SARS-

CoV-2; however, this method produced a large number of residual by-products, which had a considerable impact on the environment (Zhang et al. 2020).

5. Wastewater-based epidemiology provides a new tool for monitoring the effect of SARS-CoV-2 on wastewater treatment plants

SARS-CoV-2 has been detected, approximately half of the COVID-19 asymptomatic patients, and the feces can stay positive for up to five weeks (Mesoraca et al. 2020). WBE has been proposed as a cost-effective and powerful tool for assessing, monitoring, and managing the pandemic (Ahmed et al. 2020).

WBE is a new method for sampling and quantifying relatively stable environmental contaminants in the sewage system, and WBE is cheaper and faster than clinical screening. WBE in Fig. 4 has recently been proposed as an early detection method for viral outbreaks; It is also essential to determine whether viral indicators persist in aquatic environments (Murakami et al. 2020). The most common method used is high throughput RNA sequencing (RNA-Seq) rather than quantitative real-time PCR (qRT-PCR) (Sapoval et al. 2021). Moreover, as previously described, SARS-CoV-2 was found in stool samples and wastewater, which has led several authors to propose that WBE could be used as a tool in surveillance (Ahmed et al. 2020). According to their study, sewage surveillance could provide a sensitive and efficient method to monitor SARS-CoV-2 circulation in the population because symptoms could be detected in the community before the virus circulates (Dearlove et al. 2020). Sample storage of wastewater would detect an outbreak retroactively and provide historical information about the spread of the disease (Foladori et al. 2020). In order to concentrate SARS-CoV-2 in wastewater, various methods have been used, including ultrafiltration, PEG precipitation, and electronegative membrane adsorption, followed by direct RNA extraction (Dayan et al. 2021).

For instance, it was thought that the SARS-CoV-2 outbreak in France started at the end of January 2020 (Trottier et al. 2020); however, SARS-CoV-2 was detected in the samples of a patient admitted to intensive care in late December 2019. SARS-coVid-2 outbreak could manage if the first patients could have been identified, and the cities should have been placed under lockdown instead of a whole country being put under lockdown. However, monitoring and surveillance of COVID-19 and other outbreaks based on wastewater present an additional challenge for developing countries where most households do not have access to sewerage. As the current pandemic illustrates, developing countries should be investing in wastewater treatment facilities and sanitation. Meanwhile, with indirect markers of infection (e.g., by use of immunoassays,

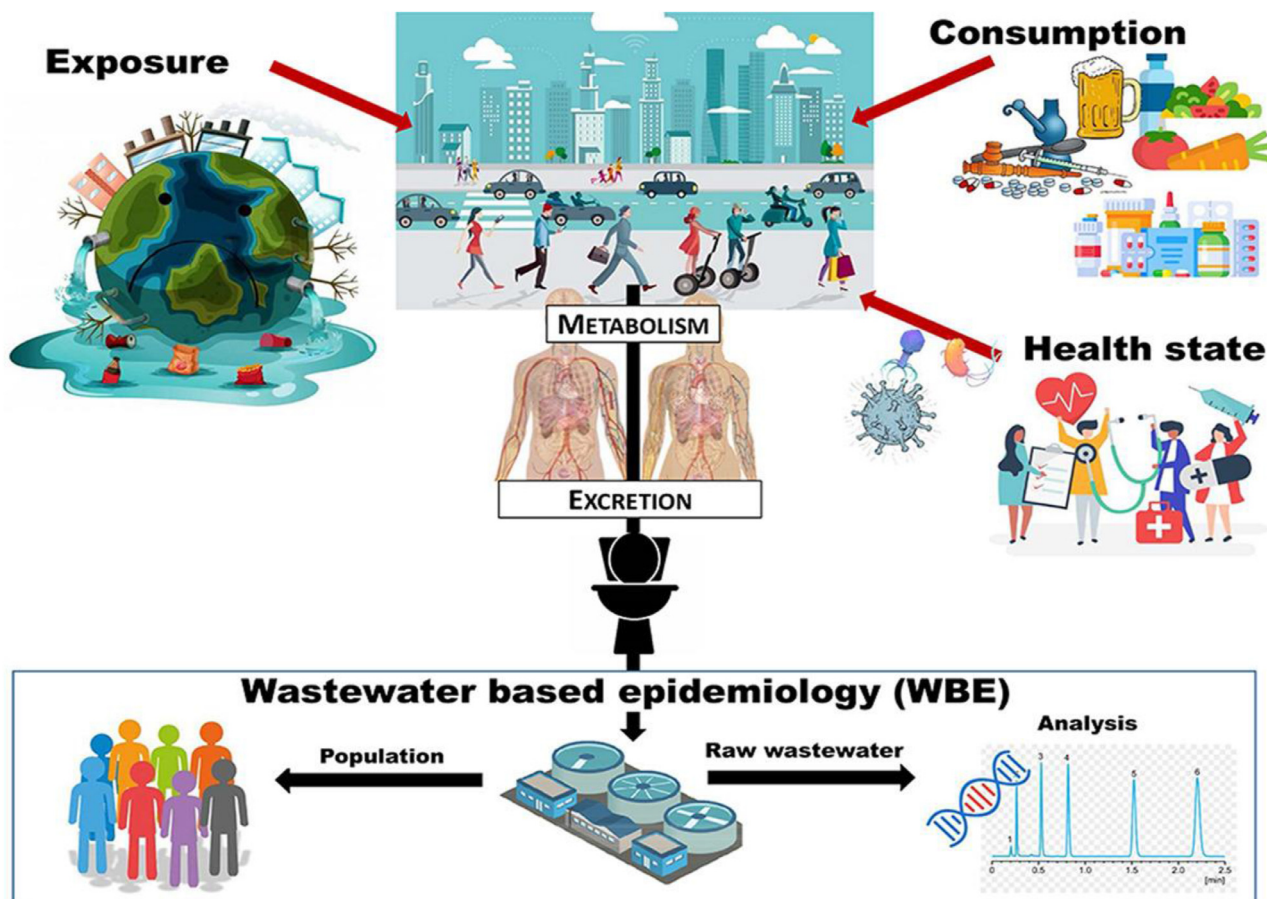


Fig. 4. The Potential of WBE for the Monitoring of the COVID-19 Pandemic (Vitale et al. 2021).

pharmaceuticals used in the treatment of COVID-19), WBE could become even more helpful in the future, improving availability and reducing costs while improving diagnostic accuracy (Foladori et al. 2020).

6. Conclusion

Numerous research projects were conducted during the SAR-CoV-2 pandemic in the water and Coronavirus transmission by untreated. They treated wastewater, each contributing to a description and definition of the role of water services in the virus's spread. This review focuses on the fact that the wastewater situation is problematic and challenging during a COVID-19 epidemic, so to prevent this virus from spreading to the environment and community, WBE and UV are vital techniques for wastewater treatment.

WBE has been applied as a complementary method of tracking coronavirus disease 2019 cases (COVID-19) among patients with severe acute respiratory syndrome Coronavirus 2 (SARS-CoV-2) and early warning of epidemics. Meanwhile, SARS-Co-2 is one of several new strains of highly pathogenic enveloped viruses in wastewater, providing a new challenge and opportunity to use WBE in its surveillance. Finally, A reliable WBE approach relies on representative sampling, viral concentrations in wastewater, population normalization, and ethical guidelines.

Furthermore, A wastewater-based epidemiology (WBE) approach as an additional instrument for COVID-19 prevention and control actions was developed following the detection of SARS-CoV-2 in feces and the rapid spread demonstrated by viral detection feces. WBE assumes that if humans excrete any stable substance in wastewater, the original concentration excreted by the serviced population can be back-calculated. Likewise, it is possible to use the same approach to examine pathogen circulation in sanitary sewers, mainly when excreted in the feces/urine

of infected individuals. This approach is beneficial when resources for clinical diagnosis are limited or reporting systems are not available.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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Consent to publish

This version has been approved by all other coauthors.

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Availability of data and material

The original contributions presented in the study are included in the article files, further inquiries can be directed to the corresponding author.

Code availability

Not applicable.

CRedit authorship contribution statement

Sasan Zahmatkesh: Collected the research articles, reviewed, and prepared first original draft, screened, and analyzed the key findings. **Mika Sillanpää:** Supervision, Writing-review & editing, Validation.

Ethics approval

Not applicable.

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