Discussion

Indirect effects of COVID-19 on the environment: How deep and how long?

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ABSTRACT

Although the World Health Organization (WHO) announcement released in early March 2020 stated there is no proven evidence that the COVID-19 virus can survive in drinking water or sewage, there has been some recent evidence that coronaviruses can survive in low-temperature environments and in groundwater for more than a week. Some studies have also found SARS-CoV-2 genetic materials in raw municipal wastewater, which highlights a potential avenue for viral spread. A lack of information about the presence and spread of COVID-19 in the environment may lead to decisions based on local concerns and prevent the integration of the prevalence of SARS-CoV-2 into the global water cycle. Several studies have optimistically assumed that coronavirus has not yet affected water ecosystems, but this assumption may increase the possibility of subsequent global water issues. More studies are needed to provide a comprehensive picture of COVID-19 occurrence and outbreak in aquatic environments and more specifically in water resources. As scientific efforts to report reliable news, conduct rapid and precise research on COVID-19, and advocate for scientists worldwide to overcome this crisis increase, more information is required to assess the extent of the effects of the COVID-19 pandemic on the environment. The goals of this study are to estimate the extent of the environmental effects of the pandemic, as well as identify related knowledge gaps and avenues for future research.

1. Introduction

The indirect effects of the COVID-19 pandemic on the environment, such as an increase in waste production, could negatively affect water resources (Zambrano-Monserrate et al., 2020; Petrosino et al., 2021). Although there is no direct evidence that the SARS-CoV-2 virus—the virus that causes COVID-19—can survive in drinking water or wastewater, the presence of SARS-CoV-2 RNA in municipal sewage has been reported in different locations around the world (Medema et al., 2020; Wu et al., 2020; Wurtzer et al., 2020; Gonzalez et al., 2020; Kumar et al., 2020a, 2020c, 2021b). Wastewater surveillance has been identified as a promising tool for tracking virus circulation because it correlates the reported prevalence of COVID-19 cases with the SARS-CoV-2 RNA detected in sewage (Bhattacharya et al., 2021).

Containing a global pandemic is difficult and ensuring that people have access to safe water is a vital step in decreasing viral spread among populations and in the aquatic environment (Habibi et al., 2020). As documented by many scientists and organizations worldwide, the emphasis since the start of the pandemic has been to provide the public with realistic reports of COVID-19 and counteract unrealistic/unfounded information. In early March 2020, the World Health Organization (WHO) disclosed that there was a lack of information on the survival and potential transmission of the COVID-19 virus in drinking water and sewage (WHO and UNICEF, 2020). The first paper confirming the presence of SARS-CoV-2 RNA in municipal wastewater came shortly after that statement (Medema et al., 2020).

Considering the lack of available information, even if drinking water can be considered safe, the potential transmission of SARS-CoV-2 or its genetic information in wastewater remains mostly unknown and is worth further study. There are significant knowledge gaps that need to be addressed, such as the strength and duration of SARS-CoV-2 spread in wastewater, as well as the difference between SARS-CoV-2 and other viruses and pathogens found in wastewater. SARS-CoV-2 is considered "not robust" and less stable in the environment and more susceptible to inactivation. Nevertheless, according to some previous studies, enveloped viruses like

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coronavirus are known to persist in water bodies for several weeks (Kumar et al., 2020c).

The goals of this work are to provide a critical analysis of the potential of SARS-CoV-2 to spread in the aquatic environment, evaluate the risks and challenges of potential viral spread, and identify knowledge gaps and avenues for future research.

2. The potential spread of SARS-CoV-2 in the aquatic environment

The technical report released by WHO in collaboration with UNICEF (WHO and UNICEF, 2020) revealed that the morphology and chemical structure of SARS-CoV-2 are similar to those reported for synonymous human coronaviruses. Because of these similarities, McLellan et al. (2020) found that the current processes at wastewater treatment plants (WWTPs) can prevent the spread of SARS-CoV-2 in treated water effluents and comply with regulations during the treatment process. Based on previous experience with the Middle East respiratory syndrome (MERS) and other SARS-CoV-type viruses, the risk of coronavirus reaching drinking water is considered low (WHO and UNICEF, 2020), which has been confirmed as information on COVID-19 has progressively increased.

Global efforts are needed to delineate the risk of SARS-CoV-2 spreading through water bodies (Bhattacharya et al., 2021) and a more detailed investigation is needed to assess the activity and fate of the genetic components of SARS-CoV-2 during wastewater treatment processes to determine its potential removal.

The efficacy of wastewater treatment processes in removing SARS-CoV-2 is a significant knowledge gap related to the readiness of WWTPs in dealing with novel waterborne illnesses. For example, very little information is available on the role environmental conditions play in the purification of water bodies potentially contaminated with SARS-CoV-2 (Chen et al., 2021). It is relatively well-known that the persistence of enveloped viruses (e.g., influenza or herpes simplex viruses) in water may reach up to 200 days at 4 °C. The time required for the initial viral titer to decrease by 90% in wastewater ranges from 20 to 40 days for enveloped viruses, whereas the same value for human coronavirus can vary between 200 and 400 days at 4 °C. However, the effects of climate change stressors such as increases in temperature and ionic strength, as well as changes in pH on these values are unknown (Kumar et al., 2020c).

The indirect effects of this pandemic on our lives and its adverse environmental results are also poorly understood. The drastic decrease in traffic and other global anthropogenic/economic activities during the mandatory pandemic lockdown substantially improved air and water quality (Somani et al., 2020). Nevertheless, a remarkable peak in the generation of municipal solid waste and an increased production of biomedical waste and used protective gears has been observed in the past months (Bandala et al., 2021; Petrosino et al., 2021). Because the long-term effects of the COVID-19 pandemic are yet to be determined, assessing its current effects on our daily lives is an interesting avenue of future research that is worth exploring to develop technology to alleviate long-term effects and provide decision makers with valuable information to address similar or related events in the future. Furthermore, the long-term effects of the COVID-19 pandemic on global water bodies is another critical knowledge gap that needs to be addressed. It is clear that we need a better understanding of the survival of SARS-CoV-2 in water and wastewater, as well as its source and dispersion potential in aquatic environments (Kumar et al., 2021c). Very little information is available on these topics, which is another significant knowledge gap that needs attention considering the potential consequences for water security and reliability.

3. SARS-CoV-2 in water environments

The lipid membrane envelope surrounding coronaviruses makes them more fragile than non-enveloped viruses (Walls et al., 2020), and therefore more susceptible to disinfection processes. The schematic in Fig. 1 shows the intact (a), incapacitated (b), and degraded (c) stages of SARS-CoV-2.

In several locations around the world without a wastewater treatment plant or sewer network, untreated sewage is known to drain into surface water bodies or infiltrate into groundwater (Abbaszadegan et al., 2003; Fout et al., 2003; Bhattacharya et al., 2021; Kuroda et al., 2021; Elsaid et al., 2021; Longobardi et al., 2020). Groundwater, which is a vital water resource, has been historically reported to have lower pathogen loads than surface water because of the natural purification that occurs during natural adsorption and inactivation processes. The physical characteristics of porous media (i.e., soil geological and hydrogeological properties) play a key role in the dynamics of the pollutants released into the environment (Hart and Casper, 2004; Bivins et al., 2020; Paleologos et al., 2020). Some authors (Craun et al., 2010) have suggested that almost all waterborne disease dispersion is related to polluted groundwater and that pathogens can be transmitted from wastewater to groundwater through septic tanks, leaky sewers, and weak well nets. Many of these outbreaks may come from wells or small water systems that do not include disinfection.

Because water treatment is time and resource demanding, preventing groundwater contamination is a more logical approach than disinfection. Regardless of state and national borders, groundwater can transmit diseases through the water cycle. The presence of chemical pollutants can also modify the characteristics or fate of pathogens in groundwater. For example, past studies on coronaviruses (human coronavirus 229E) found that detergents remove the viral envelope and eventually inactivate the virus (Wang et al., 2005; Gundy et al., 2009; Welch et al., 2020). Therefore, the presence of detergents in wastewater has been proposed to help to reduce virus pathogenicity to approximately 0.1% of the initial pathogenicity within 24 to 72 h. However, detergents also pose a threat to ecosystems because
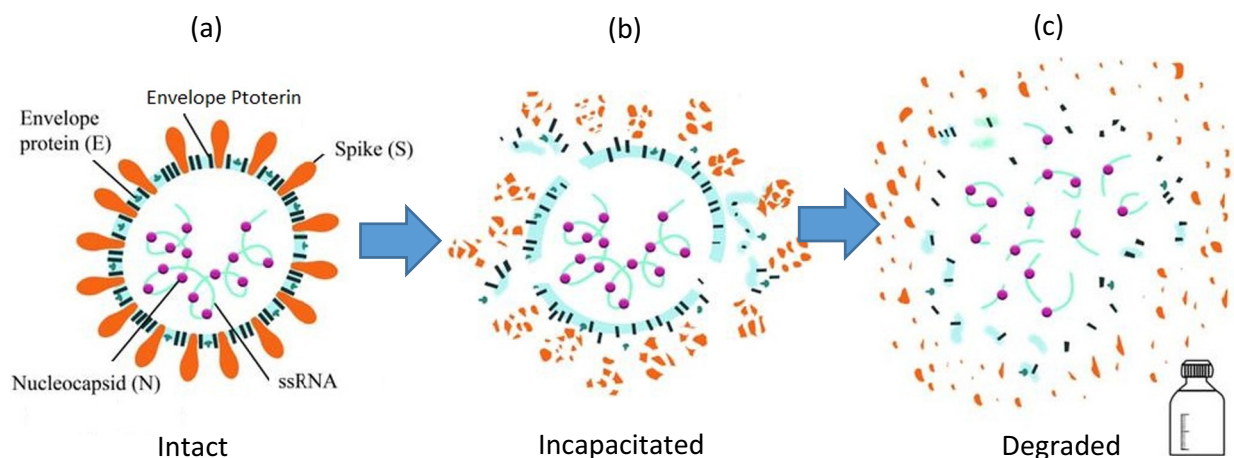

(a)   (b)   (c)

Intact   Incapacitated   Degraded

Fig. 1. Intact (a), incapacitated (b), and degraded (c) SARS-CoV-2 virus in wastewater (modified from Hill et al., 2020).

surfactants are degraded through microbial activity. Depending on their concentration in the ecosystem, surfactants can bioaccumulate in organisms (although their effects are not adequately studied) and affect soil, which leads to groundwater contamination (Hassan et al., 2017). Furthermore, detergents are adsorbed on particulate material in the water column and in sediment, which plays a significant role in their fate.

Limited studies show that coronaviruses might survive in groundwater for more than a week (John and Rose, 2005; Gundy et al., 2009). Gundy et al. (2009) demonstrated that coronaviruses are extremely sensitive to temperature and can be deactivated in high-temperature water. Coronavirus Inactivation is ten times faster when water temperature increases from 4 °C to 23 °C, suggesting that RNA fragments of SARS-CoV-2 (the original active or inactive coronavirus) would be inactivated more quickly in higher temperature environments. However, many other parameters are also known to contribute to the inactivation of pathogens and/or damage to the DNA/RNA structure in surface water, such as ultraviolet (UV) radiation or the presence of reactive oxygen species (ROS). UV radiation, ROS, and thermal inactivation threaten cells by inducing DNA and protein damage (Tran et al., 2021). None of these parameters are usually present in groundwater, which has been identified as a receptacle of untreated wastewater where the COVID-19 virus has been reported to survive for long periods of time and has been found to accurately reflect changes in the number of COVID-19 cases in nearby communities (Mahlknecht et al., 2021).

A recent study identified the high vulnerability of the Arctic to virus contamination (Benediktsdóttir et al., 2020) because the viral degradation process is slow in low-temperature environments, which suggests the virus can persist in Arctic waters for years. Therefore, the survival of SARS-CoV-2 at groundwater temperature in the Arctic (between 3 °C and 6 °C) is highly likely, which highlights the need for more studies about this claim. This topic is another interesting avenue for further research. Although some authors have reported the natural decay of SARS-CoV-2 pathogenicity after eight days of release into raw wastewater and river water based on the reduction of SARS-CoV-2 viral RNA (Rimoldi et al., 2021), water resource monitoring should be continued until more robust results are available from studies on the survival of SARS-CoV-2 in recipient water bodies (Annalaura et al., 2020).

Several studies have been conducted to assess the presence of SARS-CoV-2 in municipal raw wastewater (Bhattacharya et al., 2021) in the Netherlands (Medema et al., 2020), the United States, (Wu et al., 2020), Australia (Ahmed et al., 2020a), France (Wurtzer et al., 2020), India (Kumar et al., 2020a, 2020b, 2020c), Turkey (Kocamemi et al., 2020), the United Arab Emirates (Hasan et al., 2021), and Bangladesh (Ahmed et al., 2020b, 2021; Jakariya et al., 2021). The results from these studies reveal a more comprehensive image of the outbreak by identifying SARS-CoV-2 genetic materials in raw wastewater contaminated by coronaviruses and, in some cases, effluents from inefficient sewage treatment plants released into water bodies (Chen et al., 2021). A recent study by Kumar et al. (2021a) reported a significant reduction of SARS-CoV-2 RNA materials in the upflow anaerobic sludge blanket (UASB) system and the aeration polishing/detention ponds. Kumar et al. (2021c) compared the effectiveness of root zone treatment (RZT) and conventional activated sludge (CAS) for virus removal during a two-month evaluation of the process with weekly intervals in forty-four wastewater surveillance data samples. These authors suggested that WWTP effluents are not always free of SARS-CoV-2 RNA and the reported inconsistencies in the experimental results are another significant knowledge gap that requires additional research to evaluate various WWTP processes to ensure SARS-CoV-2 removal.

Despite all the above-mentioned results and facts, private well owners and those who use untreated public groundwater supplies have not been concerned about groundwater vulnerability to SARS-CoV-2. This lack of awareness is especially concerning considering higher pumping rates in private wells to ensure water security could expand the SARS-CoV-2 plume with unknown, undesirable consequences. Minor amounts of SARS-CoV-2 RNA fragments (the original active or inactive coronavirus) detected by PCR analysis have been reported in non-potable water of the Seine and the Canal de l'Ourcq (Leste-Lasserre, 2020). This undrinkable water is mainly used for street washing, watering parks, and feeding waterfalls and lakes in parks and forested areas. In these areas where highly polluted water is used, the dispersion of disintegrated genetic materials from wastewater is a greater risk. Water contaminated by viruses and virions in affected areas could be a factor that might cause significant health impacts and make these areas more susceptible to other viral diseases. Therefore, the spread of SARS-CoV-2 over an extended period of time has unveiled underlying vulnerabilities in many areas worldwide.

Unfortunately, water authorities make decisions from a local viewpoint while ignoring global water cycle integration. For example, people have extensively applied chlorine disinfectants to prevent coronavirus progression. Although there are benefits to the use of disinfectants and hand sanitizers against COVID-19, these germicidal agents penetrate porous media and pollute water resources directly and indirectly (Ghafoor et al., 2021; Bandala et al., 2021; Kumar et al., 2021b), which poses even more severe risks to aquatic ecosystems (Sedlak and von Gunten, 2011; Ghafoor et al., 2021; Bhattacharya et al., 2021). The continued release of these pollutants into the environment could potentially have catastrophic effects on aquatic ecosystems worldwide (Zhang et al., 2020). However, these crises are not a pretext for dropping scientific standards (London and Kimmelman, 2020). Providing safe, clean water for human consumption is critical to fighting off this pandemic, especially in countries that already face water scarcity issues that have been exacerbated by the transboundary nature of the pandemic (van der Voorn et al., 2021).

4. Potential threats and outlook

Although several studies have optimistically assumed that COVID-19 has not yet affected freshwater sources, the possibility of subsequent global environmental issues may exist (Barouki et al., 2021). Very limited studies have explored coronavirus contamination in water bodies and the current COVID-19 crisis makes a case for studying the virus's effect on the environment and the appropriate response to it (La Rosa et al., 2020). A study of the sewage system across the United States (Pennisi, 2015) revealed that each city has its own microbial character, showing local health levels and disease types. Similarly, COVID-19 can be considered an indicator of environmental vulnerability. The COVID-19 crisis has been an excellent opportunity to show our responsibility to our planet by preventing water overuse during handwashing and avoiding added pressure on the public sewage system and water supply (Sayeed et al., 2021). Once this crisis ends, the lessons learned should be remembered and applied to similar challenges in the future.

It is interesting that a tiny RNA particle revealed the need to find more sustainable wastewater treatments, but this lesson is far from being the ideal outcome of this pandemic. It is scientists' duty to report reliable news, conduct rapid and precise research on COVID-19, and advocate for scientists worldwide to overcome this crisis. It will be important not to forget that the price paid during the COVID-19 pandemic will help us handle future health crises. The scientific community must use its voice for increased transparency and cooperation on current and imminent issues. Increased transparency and the free of information will help avoid the tremendous costs of environmental contamination now and in the future. The day COVID-19 is under control, the environmental sciences in general and groundwater monitoring in particular should adapt to meet changing needs. Reaching this coordinated approach will save millions of lives and help the world prepare for another pandemic.

CRediT authorship contribution statement

Meysam Vadiati: Conceptualization, Methodology, Validation, Investigation, Writing - Original Draft; **Ali Beynaghi**: Conceptualization, Methodology, Investigation, Resources, Writing - Original Draft; **Prosun Bhattacharya**: Conceptualization, Validation, Resources, Writing - Review & Editing; **Erick R. Bandala**: Investigation, Resources, Writing - Original

Draft; **Masoud Mozafari**: Conceptualization, Investigation, Writing - Review & Editing, Supervision.

Declaration of competing interest

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