New Pollution Challenges in Groundwater and Wastewater Due to COVID-19

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WATER is considered one of the most important components of life, alongside atmospheric air. Its pollution represents a serious threat not only to human health but also to the surrounding ecology. Water pollution problems were aggravated in the era of COVID-19. Approximately 80% of global diseases are waterborne, and polluted aquatic environments have been linked to the SARS-CoV-2 virus, which causes the disease COVID-19. Understanding the fate of this virus in aquatic environments like water and wastewater is critical. SARS-CoV-2 may be adsorbed on charged colloidal particles and this process probably depends on the pH of the medium. Other parameters that may influence this process include sorptive interaction with solid particles in soils, aquatic environments and sewage sludge. There are several areas of research that need to be investigated regarding the relationship between SARS-CoV-2 and the transmission of COVID-19 to aqueous environments, including indirect relationships between different aquatic environments (e.g., groundwater, drinking water and wastewater) and outbreaks of COVID-19. Different pathways and the fate of SARS-CoV-2 in water, wastewater and groundwater and subsequent human exposures also need to be determined. These issues will be explored in this review.

Keywords: Environmental pollution; Coronavirus; SARS-CoV-2; Groundwater; Drinking water; Human health; Disease

Introduction
The global coronavirus disease 2019 (COVID-19), a disease caused by the severe acute respiratory syndrome coronavirus (SARS-CoV-2), represents a great challenge for countries worldwide (Wang and Su 2020). Habib et al. (2021) stated “The way the COVID-19 pandemic has halted normal life has no precedent in modern history”. This pandemic is probably one of the worst to face humanity in modern history due to the high death toll, interruptions in human activities and negative impacts on the global economy when compared to other pandemics like HIV, polio, Spain flu, severe acute respiratory syndrome (SARS), the Middle East respiratory syndrome (MERS), and Ebola.
(Saqr and Wasson 2020). The environmentally destructive impacts of COVID-19 have been recorded in important life sectors such as food security, agriculture, and livelihoods (Lal et al. 2020; Workie et al. 2020), animal health (Gortázar and de la Fuente 2020), air pollution (El-Ramady et al. 2020; Mostafa et al. 2021), energy domains (Mofijur et al. 2021), solid wastes (Urban et al. 2021), NOx emissions (He et al. 2021), food-energy-water-waste nexus (Zhao and You, 2021), the global economy and ecosystems (Ibn-Mohammed et al. 2021), global metal supply (Habib et al. 2021), forest fires (Paudel, 2021), food wastes (Brizi and Biraglia, 2021), energy grid dynamics (Werth et al. 2021) and the entire environment (Espejo et al. 2020; Lokhandwala and Gautam 2020; Juan-Reyes et al. 2021).

Pollution is considered a serious challenge facing the whole world, particularly in developing countries (Verma, 2020). Due to intensive anthropogenic activities, several deleterious effects on the environment, including aquatic systems, and its resources have occurred (Siddiqa and Faisal, 2020). The freshwater ecosystem includes aquatic habitats that are highly prone to pollution due to the intensive interactions between these habitats and humans (Verma, 2020). Heavy metals (HMs) are of special concern, being important inorganic pollutants that cause many problems through their toxicity as well as being non-degradable and therefore persistent in nature (Aitta et al. 2019; Verma 2020). The presence of organic pollutants and pathogens can also cause major problems (Brevik et al. 2020). These pollutants, when present in aquatic environments, may have negative implications for cultivated plants, domesticated animals, humans and the food chain (Yan et al. 2019).

One of the major water quality issues of our day is the COVID-19 pandemic (Fig.1). More than 200 countries worldwide have engaged in the fight against COVID-19 since January 2020. This struggle has become the top priority in many of these countries. Thus, the scientific community has published over a million articles (according to Google Scholar, searching “COVID 19” on November 26, 2020) on COVID-19. These studies have covered a wide range of COVID-19 topics, with focus on the perspectives of different disciplines such as medicine, biology, tourism, socioeconomics and environmental studies (Casado-Aranda et al. 2020). Torres-Salinas (2020) reported that the number of scientific articles on COVID-19 have doubled every 15 days since the pandemic’s outset. A pressing question involving the COVID-19 outbreak is whether aquatic environments have direct or indirect roles in spreading this disease, and if they do, under

![COVID-19](image)

**Fig. 1.** A summary of selected major aquatic challenges related to COVID-19. These challenges may include the transmission of COVID-19 to groundwater or from the wastewater to different sources of water like drinking water or to the human. Several confirmations concerning this transmission among water resources still are needed.
what conditions? Few studies have addressed this problem (Kumar et al. 2020a). Therefore, this work investigated the potential relationship between polluted wastewater and COVID-19 and its impact on aquatic environments.

Aquatic environments and their pollution
Water is the main source of life; without water life as we know it would not exist. Aquatic environments occupy more than 70% of Earth’s surface, including oceans, rivers, lakes, wetlands, and springs (Li et al. 2020). These aquatic environments may suffer from pollution due to intensive human activities, which may increasingly result in the deterioration of food chains and, ultimately, deterioration of the aquatic life cycle. The three main sources of water pollution are urban wastewater, agricultural development, and industrial effluents (Kiani and Rahimpour 2020). Polluted aquatic environments are considered a human health threat that cause a lot of environmental problems (e.g., Martins et al. 2014; Farkas et al. 2020; Kiani and Rahimpour, 2020). This pollution has been monitored and assessed by researchers in a plethora of studies including occurrence, detection methods, fate, ecological toxicity and removal methods (Li et al. 2020). Several approaches have been adapted to decontaminate polluted aquatic environments from HMs and organic pollutants (Ajiboye et al. 2021) using techniques such as biochar (Yang et al. 2021), nano zero valent iron (Sliješčević et al. 2021), and clays (Elshazly et al. 2019). Other pollutants may cause serious threats to human health and ecosystems when they reach aquatic environments, including nanoparticles (Turan et al. 2019; Souza et al. 2021), antibiotics (Li et al. 2020; Xu et al. 2021), micropollutants (Ma et al. 2020; Tang et al. 2020; Pan et al. 2021; Wang et al. 2021), bisphenols (Liu et al. 2021; Šauer et al. 2021), retinoic acids (Yeung et al. 2020), perfluoroalkylated acids (Groffen et al. 2021), heavy metals (Aitta et al. 2019; Karaozuras et al. 2021), personal care products (Zhou et al. 2020; Lu et al. 2021), antineoplastic agents (Yadav et al. 2021) and COVID-19 (Kumar et al. 2020a; Steffan et al. 2020; Lachrich et al. 2021). On the other hand, during lockdowns to combat COVID-19, the quality of surface water (Yunus et al. 2020) and air (Guatam, 2020) are expected to improve.

Polluted groundwater and COVID-19
Water scarcity is a major global issue, particularly in arid and semi-arid regions. Preserving sources of clean and safe drinking water is critical for nations all over the world. Groundwater is the main source of drinking and irrigation water in many countries (Cai et al. 2020) and is important in sustaining native terrestrial ecosystems (Huang et al. 2019). In general, groundwater-dependent ecosystems are divided into three types based on their ecological function: (1) aquifers and cave ecosystems, (2) wetlands, springs, rivers, estuaries and nearshore marine ecosystems and (3) terrestrial vegetation ecosystems (Huang et al. 2019). Due to global climate changes, which includes increasing temperatures and redistribution of precipitation, groundwater recharge has decreased in many places while salinity has increased (El-Ramady et al. 2017, 2019). Groundwater pollution problems have gained global attention in recent decades due to their frequent occurrence and potentially adverse effects on aquatic ecosystems and human health (Kuroda and Kobayashi 2021). Many studies have focused on the pollution of groundwater and its remediation (e.g., Haris et al. 2020), which may depend on advanced technologies and its sustainability. Recent reports that address these issues include:

1- A global review on pollution of domestic groundwater systems by verotoxigenic Escherichia coli (Chique et al. 2021),

2- Global sources of groundwater and their security as well as scarcity and sustainability issues (Mukherjee et al. 2021). These issues are being documented in many countries, such as Australia (Maheshwari 2021), Bangladesh (Ahmed 2021), Brazil (Sahoo et al. 2021), China (Huang et al. 2021; Jia 2021), Pakistan (Masood et al. 2021), and the USA (Schreiber 2021),

3- Groundwater pollution in Japan as a result of the Kumamoto earthquakes in 2016; artificial sweeteners and acesulfame were used as tracers to evaluate sewer exfiltration to groundwater (Ishii et al. 2021),

4- Investigating multi-isotopic and molecular source tracking methods in nitrate pollution identification in groundwater based on the 91/676/CEE regulation of the European Nitrate Directive (Carrey et al. 2021),

5- Studying the health risks posed by groundwater polluted with various nitrogen forms (nitrate, nitrite and ammonium) (Adimalla and Qian 2021; Cameira et al. 2021; Wu et al. 2021; Li et al. 2021),

6- Assessing the public health risks associated with the geochemical evolution of groundwater polluted with nitrate and fluoride (Nawale et al. 2021),

7- Investigating the effects of drought on the environmental health risks posed by polluted groundwater, including both cancerogenic and non-cancerogenic threats (Kubicz et al. 2021),

8- Assessing pesticides and nitrogen pollution sources using stable isotopes in a complex multi-stressed catchment. Nitrate in groundwater may result totally or partially from NH$_4^+$- mineralization and nitrification from organic sources (i.e., manure or sewage sludge) or may originate from inorganic fertilizers (Postigo et al. 2021),

9- Studying the hazardous effects of microplastics in natural water resources. Effects were found to depend on the sources, origins, pathways and receptors of the microplastics (Selvam et al. 2021),

10- Studying polyfluoroalkyl substances in groundwater to understand their occurrence, sources and related health risks (Zhou et al. 2021),

11- Investigating groundwater-dependent ecosystems as transfer vectors of nitrogen from groundwater to surface waters in agricultural basins (Balestrini et al. 2021) and

12- Assessing how the use of plastic in farming processes may affect water quality; accordingly, aquifers and drinking water supplies should be protected from plastic and pesticide contaminants and thus reduce potential human health hazards (Wanner, 2021).

On the other hand, very few studies have been published concerning COVID-19 and groundwater. Patni and Jindal (2020), Núñez-Delgado (2020), and Steffan et al. (2020) addressed potential indirect impacts of COVID-19 on groundwater. Patni and Jindal (2020) presented potential positive impacts. More precisely, Patni and Jindal 2020 found that groundwater stores increased and quality improved during the COVID-19 pandemic due to the reduction of many human activities. Núñez-Delgado (2020) and Steffan et al. (2020) both noted potential negative impacts of COVID-19 on the groundwater system, primarily the introduction of the SARS-CoV-2 viral pathogen into groundwater through contaminated wastewater. There are several open questions concerning the relationship between groundwater and COVID-19, such as what are the direct and indirect impacts of COVID-19 on the global groundwater resource? Does groundwater play any role in propagating the COVID-19 pandemic? What are the positive and negative impacts of COVID-19 on global groundwater? And how much protection does the overlying soil “filter” provide groundwater against contamination with SARS-CoV-2?

COVID-19 and polluted wastewater

Wastewater is defined as “all the water from homes and urban public facilities like hospitals, schools, and others as well as from certain industries if it does not require specific treatment” (Lahrich et al. 2021). Wastewater may be a source of pathogens, as occurs in hospital effluents and household sewage. Nearly 80 % of global human diseases are waterborne according to WHO. Unhygienic water is attributed to approximately 1.5–12 million deaths per year due to waterborne diseases such as cholera, diarrhea, typhoid, and viral hepatitis (Bhatt et al. 2020). Lethal viral diseases include hepatitis, gastroenteritis, and respiratory illnesses like the present COVID-19 pandemic, which is caused by SARS-CoV-2 (Cao 2020). The presence of COVID-19 in wastewater has been demonstrated by recent studies (Mallapaty 2020; Lodder and Husman 2020; Ahmed et al. 2020; Wu et al. 2020; Bhatt et al. 2020). It has been suggested that both surface and groundwater represent SARS-CoV-2 control points through addition of effluents and possible contamination from health care facilities, sewage and drainage water (Kumar et al. 2020a). Therefore, the different possible transmission pathways of SARS-CoV-2 to water sources should be identified to prevent further rapid spread of such a disease (Bhatt et al. 2020). SARS-CoV-2 may enter water bodies through different routes such as feces, sewage and on surfaces according to WHO. Because SARS-CoV-2 is known to transmit through the air and has been found in water sources, the possibility that COVID-19 could be spread through both aquatic and non-aquatic environments needs to be strongly considered (Bhatt et al. 2020).

Several investigations have addressed the fate and transmission of COVID-19 in wastewater, important topics covered include:
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1- Emphasis on detection methods and prevalence of the SARS-CoV-2 virus in wastewater (Lahrich et al. 2021),

2- The role of water, sanitation and hygiene in spreading COVID-19 through the fecal-oral route, particularly in low-income countries (Table 1). The spread of COVID-19 is currently premised on respiratory and contact transmission; however, a fecal-oral pathway has been suggested for the transmission of SARS-CoV-2 from the human gut to stools and wastewater (Bhatt et al. 2020; Gwenzi 2021),

3- The occurrence and persistence of SARS-CoV-2 in the environments and conditions favorable for the survival of this virus in water/wastewater/sewage has not yet been established, despite evidence of the transmission of the infective virus to the community (Ihsanullah et al. 2020; Mohan et al. 2021),

4- Potential secondary transmission of SARS-CoV-2 via wastewater; reducing risks of transmission could contribute to limiting COVID-19 resurgence and future research should focus on the virus in different aquatic environments (Liu et al. 2020),

5- Implications for SARS-CoV-2 in river water in countries that do not have good sanitation; including important viral loads of SARS-CoV-2 from urban streams and how the degree of wastewater treatment may affect COVID-19 risks (Guerrero-Latorre et al. 2020),

6- SARS-CoV-2 surveillance using wastewater-based epidemiology can be an effective technique in the early detection of COVID-19 within a population, but an effective concentration method is needed for recovery of SARS-CoV-2 RNA from wastewater (Al Huraimel et al. 2020; Bhatt et al. 2020; Corpuz 2020; Kitajima 2020),

<table>
<thead>
<tr>
<th>Country/ region</th>
<th>COVID-19 and wastewater</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>The first study and detection of COVID-19 trends in wastewater in Canada. Provided a quantitative analysis of this virus from wastewater solids during low incidence of viral load.</td>
<td>D’Aoust et al. (2021)</td>
</tr>
<tr>
<td>Global study</td>
<td>Hand hygiene could protect from the transmission of COVID-19 via the fecal-oral route. Viral occurrence in wastewater can estimate its ability to spread.</td>
<td>Elsamadony et al. (2021)</td>
</tr>
<tr>
<td>China</td>
<td>Studied the potential modes of COVID-19 transmission in health care facilities, which occur via multiple routes like potential fecal-oral transmission in the toilet and in sewage pipes.</td>
<td>Feng et al. (2021)</td>
</tr>
<tr>
<td>Global study</td>
<td>SARS-CoV-2 transmission could potentially be linked to wastewater and biomedical wastewater disposal risks; this creates a widespread public concern.</td>
<td>Kataki et al. (2021)</td>
</tr>
<tr>
<td>Global study</td>
<td>Wastewater irrigation systems may have a high risk of COVID-19 transmission.</td>
<td>Lahrich et al. (2021)</td>
</tr>
<tr>
<td>Global study</td>
<td>The occurrence of COVID-19 has been shown in stool samples from symptomatic and asymptomatic people as well as in municipal wastewaters worldwide.</td>
<td>Langone et al. (2021)</td>
</tr>
<tr>
<td>Italy</td>
<td>COVID-19 was already circulating in northern Italy at the end of 2019; wastewater (sewage) monitoring could contribute to the early detection of this viral circulation.</td>
<td>La Rosa et al. (2021)</td>
</tr>
<tr>
<td>Global study</td>
<td>COVID-19 in wastewater treatment, sanitation status and health-care infrastructure from middle- and low-income countries was correlated with risk associated with the fecal-oral transmission route.</td>
<td>Pandey et al. (2021)</td>
</tr>
<tr>
<td>Sweden</td>
<td>COVID-19 was detected in wastewater treatment plants and was correlated to hospitalized patients.</td>
<td>Saguti et al. (2021)</td>
</tr>
<tr>
<td>Africa</td>
<td>SARS-CoV-2 can transmit in water systems (mainly wastewater) and could potentially be removed by integrating chlorination, coagulation, UV irradiation, and NaClO treatment techniques.</td>
<td>Sunkari et al. (2021)</td>
</tr>
<tr>
<td>Germany</td>
<td>The first investigation that reported the detection of COVID-19 in wastewater (wastewater treatment plants) was in Germany using RT-qPCR.</td>
<td>Westhaus et al. (2021)</td>
</tr>
<tr>
<td>Brazil</td>
<td>The first study that investigated the potential health risks of SARS-CoV-2 in sewage to wastewater treatment plant workers; the dose of this virus was estimated in workers whose were exposed during their job.</td>
<td>Zaneti et al. (2021)</td>
</tr>
<tr>
<td>Japan</td>
<td>SARS-CoV-2 was detected in wastewater samples collected from wastewater treatment plants.</td>
<td>Hata et al. (2020)</td>
</tr>
<tr>
<td>Global study</td>
<td>There is a possibility for SARS-CoV-2 to become widespread through the wastewater network.</td>
<td>Naddeo and Liu (2020)</td>
</tr>
</tbody>
</table>
7- The seasonality of SARS-CoV-2 and its environmental fate, transport, inactivation and antiviral drug resistance issues; wastewater treatment plants are the main reservoirs of antiviral drugs; SARS-CoV-2 may be transmitted as a fecal virus in wastewater, water and groundwater, leading to human exposure (Kumar et al. 2020b), and

8- Environmental conditions that allow the transmission of SARS-CoV-2; humidity and temperature may control viability and survival of SARS-CoV-2 in droplets; the fecal-oral route may be a possible transmission route of COVID-19 from contaminated water bodies; while chlorination may not effectively and completely inactivate SARS-CoV-2 (Mohapatra et al. 2020).

Based on the research completed to date, two main aspects should be considered to control the fate of SARS-CoV-2, including survival and migration, in aquatic environments. One is the structure of the virus; enveloped viruses like SARS-CoV-2 may have significant mobility in sub-surface systems (e.g., groundwater). The second is the transport mechanism and its pathways affecting the water source and its interactions with soil properties such as infiltration rate, soil pH, ionic strength, and the adsorption of viruses onto the sub-surface system, all factors in establishing the soil “filter” that protects groundwater systems from contamination. (Kumar et al. 2020a).

Conclusions

A terrible struggle was initiated in January 2020, and combatting the SARS-CoV-2 virus became a top priority for more than 200 countries. The COVID-19 pandemic has put massive stress on many societal sectors including public administration and information, health care personnel, and the agricultural and industrial sectors. Because several viral diseases are water borne, COVID-19 may well be capable of transmission through aquatic environments. The presence of SARS-CoV-2 in systems such as wastewater has already been established, but further research is needed concerning the fate and transmission of SARS-CoV-2 in water systems. Pressing questions include: Is the water-based transmission of COVID-19 possible? How can the occurrence of SARS-CoV-2 in wastewater be minimized? What about the risks of transmission of COVID-19 in drinking water and its distribution systems? How much protection against SARS-CoV-2 does the soil “filter” give to groundwater?

There are several challenges facing the world in addressing aquatic environments and their relationship with COVID-19. Will lockdowns cause by the COVID-19 pandemic help in solving environmental problems like air and water pollution? Or will it aggravate these problems in the future? Questions and problems such as those discussed in this paper represent a serious challenge for all countries, but most particularly for developing countries. The most important question for developing countries is how to support and finance their water and sanitation systems to protect their citizens?

Ethics approval and consent to participate
This article does not contain any studies with human participants or animals performed by any of the authors.

Consent for publication
All authors declare their consent for publication.

Contribution of authors
This study was designed and implemented by all the authors, where all contributed to writing the manuscript, interpreting information presented and have read and agreed to the final version of the manuscript.

Funding
This research received no external funding.

Conflicts of Interest
The authors declare no conflict of interest.

Acknowledgement
The authors thank all the staff members in the Soil and Water Dept., Faculty of Agriculture, Kafrelsheikh University and the Soil Fertility and Plant Nutrition Lab, Soil and Water Dept., Faculty of Agriculture, Kafrelsheikh University for their help with and support of this work.

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A review.


He C, Yang L, Cai B, Ruan Q, Hong S, Wang Z

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