Environmental Network Research Center
GWCN

Environmental Network Journal (ISSN 2752-8294)
Volume 1, Article no. 1, December 2022

Climate Change, SARS-COV-2 Pandemic, Wastewater, what are the Implications and the Risks? A Systematic Review

Dr. Kouassi Julien Momou

To cite this article: Momou, K.J. (2022), 'Climate change, SARS-COV-2 pandemic, Wastewater, what are the implications and the risks? A systematic Review', *Environmental Network Journal*, 1:1

1. Abstract

Today, more than 304 million people globally in over 210 countries have been confirmed to have been infected and more than 5.4 million people have died of COVID-19. In this paper we provide a systematic review of the recent literature on the effects of climate on COVID-19's global expansion, also rapid review to map research evidence on the utilization of SARS-CoV-2 wastewater surveillance and risks assessments. The results of the statistical and modeling techniques considered in the listed papers have been included in this review. The results of several studies, considering climate change and/or the seasonality of respiratory tract viruses, reported that both humidity and temperature affect the pattern of the worldwide spread of the COVID-19 pandemic, but there is a lack of consensus in the conclusions about the roles of temperature, humidity and other meteorological factors on the transmission dynamics of COVID-19. Furthermore, the presence of SARS-CoV-2 has been demonstrated in faeces and, in some cases, urine of infected people, as well as in wastewater and in sewage sludge. The possibility of faecal-oral transmission of SARS-CoV-2 resulting from these findings, has many implications, especially in regions with poor sanitation infrastructure, considering entering of SARS-CoV-2 into the sewage and wastewater treatment plants. This review takes stock 55 listed articles between December 2019 and January 2022. This paper would be useful as one of the tools for early health warning and to prioritize emergency response plans for water and sanitation operators during COVID-19 and future pandemics. Further research is needed on the assessment of health risks for communities near sewage treatment plants or for communities that simply do not have a wastewater collection system.

Keywords

SARS-CoV-2; Climate Change; Seasonal Variation; Surveillance; Wastewater; Risk Assessment

2. Introduction

Coronavirus disease 2019 (known as Covid-19), which is caused by an infectious virus, Severe Acute Respiratory Syndrome Coronavirus 2 (known as SARS-CoV-2) (Daughton, 2020), has spread across the world and gets people infected in almost all countries worldwide, with some countries with a high level of cases and deaths. As of 9 January, over 304 million cases and over 5.4 million deaths have been reported globally in COVID-19 by World Health Organization (WHO) Weekly Epidemiological Update (WHO, 2022).

Several studies have so far examined the relationship between COVID-19 and weather factors such as temperature (Ma et al., 2020), humidity (Liu et al., 2020) and air pollution (Zhu et al., 2020).

For some, climate, conditions are classified as top predictors of coronavirus illnesses (Dalziel et al., 2018) as wind speed, humidity, temperature are critical in the transmission of infectious diseases (Yuan et al., 2006). Understanding the strong seasonal pattern of respiratory viruses could help anticipate subsequent waves of SARS-CoV-2.

The primary mechanism of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) transmission is via respiratory droplets that people cough, sneeze or exhale (Kumar et al., 2020; Domingo et al., 2020). However, recent studies reported that live SARS-CoV-2 can be isolated from the excrement and urine of COVID-19 patients (Holshue et al., 2020), and viral nucleic acid of patients remained positive in stool samples even after viral clearance in respiratory tract, indicating the risk of fecal-oral transmission of SARS-CoV-2 should be of concern (Xiao et al., 2020).

According to Bogler et al. (2020), entry of the virus into the sewer system results in a variety of potential transport pathways that must be considered in the context of faecal–oral transmission.

Indeed, potentially serious health risk is faecal–oral transmission in low-income countries where communities with inadequate sanitation infrastructure (for example, open sewers and direct discharge into the environment) could be infected by untreated wastewater or faecal waste. Water transmission routes of SARS-CoV-2 should also be taken into account. Coronavirus can enter into a system of distribution of potable water if the residual amount of disinfectant is at a low concentration (García-Ávila et al. 2020). In addition, a significant advantage of the detection of SARS-CoV-2 in wastewater is to allow environmental surveillance of SARS-CoV-2 in these waters. Indeed, wastewater surveillance for SARS-CoV-2 could provide an unbiased opportunity to track its epidemiology in countries having limited resources for clinical diagnosis. The presence of SARS-CoV-2 in wastewater may also have consequences for public health in developing countries with poor water and sewage infrastructure, inadequate institutional and technical disinfection capabilities, and lack of financing. Wastewater-related exposure to SARS-CoV-2 remains a significant possibility in such vulnerable communities (Usman et al., 2020).

Globally, sub-Saharan Africa has the highest proportion of the population sharing toilets (Rheinländer et al., 2015; WHO/UNICEF, 2014). In densely populated urban areas, communal or shared toilets are common (Morella et al., 2008). Events related to climate change such as extreme weather events (floods) can damage or destroy sensitive water treatment systems and cause overflow of untreated sewage (WHO, 2019). Moreover, the rainy season is associated with the increase in the overflowing of pit latrines (Nakagiri et al., 2016). Owing to the impacts of climate change, sub-Saharan Africa has been identified as a vulnerable region with emphasis on weather-related extremes such as floods (Carabine et al., 2014). This will further compound increasingly overburdened wastewater systems. Season change and differing climate regions have pronounced effects on wastewater surveillance and may affect the persistence of SARS-CoV-2 in wastewater (Hart & Halden, 2020).

This work presents and summarizes the observed environmental effects of COVID-19 as reported in the literature for different countries worldwide. Otherwise, this paper examines how the seasonal variation and/or climate change influence the transmission of this novel virus across many areas. The purpose of this review is to evaluate available literature on the association between weather variables including temperature, humidity, wind speed or rainfall and COVID-19 incidence over a wide climate range, to provide useful information for predicting seasonality and early warning for future outbreaks.

Given that in large parts of the world, measures for the protection of water resources, controls on the treatment and supply of drinking water and the treatment and discharge of waste water may be substandard in accordance with the guidelines by the WHO (2017) or not in place, the current paper has also, the following two major aims: firstly, to investigate the potential of water and waste water to operate as transmission routes for the Sars-CoV-2; secondly, to assess the risks and threats to both public health and the geoenvironment posed by a potential entry of the virus in water and waste-water-treatment systems.

3. Methodology

3.1 Information Sources and Literature Search

PubMed, Google Scholar, and the World Health Organization (WHO) library databases for relevant studies were searched. The key search terms included “Coronavirus”, “Covid-19,” “SARS-CoV-2”, “wastewater”, “epidemiology”, “surveillance”, “Climate Change”; “Seasonal Variation” all database searches were conducted until 9 January 2022.

3.2 Information Sources and Literature Search

Reports, reviews, research articles and primary observational studies (case-control, case-crossover, cross-sectional) were searched. The review included studies from Africa, Asia, Europe, the United States, Canada and Latin America.

3.3 Eligibility Criteria

Manuscripts that evaluated the effects of different climatic conditions of temperature, humidity etc. on the spread of COVID-19 were included, SARS-CoV-2 prevalence, wastewater surveillance and risk assessment. The search strategy was defined based on the PECOS format as follows: Population (P): Humans diagnosed with COVID-19; Exposition (E): risks, different weather conditions: humidity, temperature etc. Comparison (C): comparison between the effects of different parameters on the spread of SARS-CoV2; Outcome (O): Spread of SARS-CoV-2 (COVID-19), description of SARS-CoV-2 prevalence and wastewater surveillance methods; Study design (S): Observational studies, prospective or retrospective, case reports, case-series. The exclusion criteria involved studies that evaluated other upper and lower respiratory tract infections, such as Middle East Respiratory Syndrome Coronavirus (MERS-CoV) and influenza, opinion articles, animal or laboratory studies. Only English manuscripts have been included.

3.4 Screening Process

An a priori selection criterion was developed for each of the three stages: title, abstract and full text. Differences in screen results at the full-text stage were resolved by discussion. Covidence, an online tool for conducting various types of reviews (www.covidence.org), was used to review the titles and abstracts for inclusion/exclusion based on the criteria described in the modified PICO framework. Next, articles were single screened during full text using the same inclusion/exclusion criteria.

3.5 Data Abstraction and Synthesis

A data abstraction form was developed and reviewed a priori. Data extraction was performed using the following endpoints: (1) country; (2) purpose of the study; (3) study design (if applicable); (4) utility/description effects of different climatic conditions of temperature, humidity etc. on the spread of COVID-19, SARS-CoV-2 prevalence, wastewater surveillance and risk assessment; (5) any other significant findings. Data from included studies were extracted. To collate, summarize and report the results, the content of the articles was reviewed. Second, the findings reported in the articles were grouped into categories based on the findings reported, and a narrative was provided.

4. Results

4.1 Coronavirus and Climate Change

Is Climate Change affecting variation in COVID-19 cases across the globe? Can the climate be used as a tool for predicting the emergence or not of COVID-19 cases? Many researchers around the world are asking themselves these questions. This review aims to select and summarize a number of currently available literature on the association between weather and the incidence of COVID-19 in order to contribute to the development of a weather-based early warning system for COVID-19 transmission.

4.1.1 Effects of Climate on COVID-19

Sarkodie & Owusu (2020) examined the effect of weather factors on the health outcomes of COVID-19. According to these authors, there is a very strong causality between meteorological factors and the results of COVID-19. They observed that a percentage increase in temperature decreases confirmed cases and deaths by 0.13% (p-value <0.01) and ~ 0.11% (p-value <0.01), respectively, but improves cure cases by 10% (p-value <0.01). According to the same authors, the maximum temperature increase of 1% decreases confirmed cases by 0.13% (p-value <0.01) and deaths by 0.11% (p-value <0.01), but increases cure cases by about 10% (p-value <0.01). In contrast, a percentage increase in minimum temperature increases both confirmed cases and deaths by about 10% (p-value <0.01) but decreases cure cases by 0.10% (p-value <0, 01).

4.1.2 Effects of Atmospheric Pollution on COVID-19

Some authors have combined climate data and air pollution data to see if they were affecting the emergence of COVID-19 cases. Thereby, in this research, Sarwar et al. (2021) focused on the meteorological and climatic factors of the spread of COVID-19, the main parameters including daily new cases of COVID-19, emissions of carbon dioxide (CO_2), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), PM2.5, ozone (O_3), average temperature and humidity which are examined to understand how different weather parameters influence the spread of COVID-19 in Canada? The results of the graphical quantitative analysis indicate that CO_2 emissions, air quality, temperature and humidity have a direct negative relationship with COVID-19 infections. Quantile regression analysis revealed that air quality, nitrogen and ozone significantly induce the spread of COVID-19 in Canadian provinces. The results of Sarwar et al. (2021) show that the higher amount of sulfur dioxide in the atmosphere can increase the number of new daily cases of COVID-19. Their results are consistent with the results of the study by Pansini & Fornacca (2021) and oppose the results of Xie and Zhu (2020). In addition, their results suggest that the higher amount of particulate matter (poor air quality) could increase daily cases of COVID-19 in Canada. This result is similar to the results of the recent study Xie & Zhu (2020). In addition, Shakoor et al., (2020) and Shahzad et al., (2020) came to similar conclusions for their research on the United States, China, Turkey and Spain respectively. Thus, for their part, Jiang and Xu (2021) collected the number of COVID-19 deaths, the air quality index (AQI), the concentrations of pollutants in the ambient air and the data of weather variables from Wuhan between January 25 and April 7, 2020. Pearson and Poisson regression models were used to understand the association, between deaths from COVID-19 and each risk factor. Daily deaths from COVID-19 were positively correlated with AQI (slope = 0.4 ± 0.09, $R2 = 0.24$, $p < 0.01$). In detail, PM2.5 was the only pollutant with a positive association (relative risk (RR) = 1.079, 95% CI 1.071-1.086, $p < 0.01$) with deaths from COVID-19. PM10, SO2, and CO were all also significantly associated with deaths from COVID-19, but in a negative pattern ($p < 0.01$). Among them, PM10 and CO had the highest and lowest RR, which were equal to 0.952 (95% CI 0.945–0.959) and 0.177 (95% CI 0.131–0.24), respectively. Additionally, Jiang and Xu (2021) found that temperature was inversely associated with deaths from COVID-19 (RR = 0.861, 95% CI 0.851-0.872, $p < 0.01$). In contrast, the daytime temperature range was positively associated with deaths from COVID-19 (RR = 1.014, 95% CI 1.003 to 1.025, $p < 0.05$). Data suggests that PM2.5 and the daytime temperature range are closely associated with increased deaths from COVID-19.

4.1.3 Effects of Climate on COVID-19: implication of socio-demographic factors

Sociodemographic factors play a key role in whether COVID-19 cases are transmitted. In the study Chong et al. (2021), they assessed the extent to which the variability in COVID-19 activity is attributable to city-level sociodemographic characteristics, weather factors, and imposed control measures. They obtained the daily incidence of COVID-19, city-level characteristics and weather data from a total of 102 cities located in 27 provinces / municipalities outside of China's Hubei Province from January 1, 2020 to March 8, 2020, which largely covers almost all the first wave of the epidemic. According to the results obtained by Chong et al. (2021), including the effects of the control measure in a model significantly increased the explained variance to 45%, which increased by more than 40% compared to the null model which did not include any covariant. In addition to this, the inclusion of temperature and relative humidity in the model could only result in a <1% increase in explained variance, even though meteorological factors showed a statistically significant association with the rate of incidence of COVID-19.

According to Sera et al. (2021), there is conflicting evidence on the influence of weather conditions on the transmission of COVID-19. Their study aimed to estimate time-dependent signatures in the early phase of the pandemic, while controlling for socio-economic factors and non-pharmaceutical interventions. Sera et al. (2021) identified a modest nonlinear association between mean temperature and effective breeding number (Re) in 409 cities in 26 countries, with a decrease of 0.087 (95% CI: 0.025; 0.148) for an increase of 10 °C. Early interventions have a larger effect on Re, with a decrease of 0.285 (95% CI 0.223; 0.347) for an increase from the 5th to 95th percentile of the government response index. The variation in the effective number of reproductions explained by government interventions is 6 times higher than the average temperature.

4.2 Coronavirus and Wastewater

4.2.1 SARS-CoV-2 in Wastewater, implication of environmental surveillance

As part of the epidemiological surveillance of the coronavirus, the coupled detection of SARS-COV-2 strains in wastewater and the detection of clinical cases in the target population gives a more accurate idea of the progression of the pandemic (Shah et al., 2022). It allows response measures to be quickly put in place. Thus, in the current COVID-19 pandemic, to determine if SARS-CoV-2 RNA was present in sewage during the emergence of COVID-19 in The Netherlands, sewage samples of six cities and the airport were tested by Medema et al. (2020) using four qRT-PCR assays, three targeting the nucleocapsid gene (N1−N3) and on the envelope gene (E). No SARS-CoV-2 RNA was detected on February 6, 3 weeks before the first Dutch case was reported. On March 4/5, one or more gene fragments were detected in sewage of three sites, in concentrations of 2.6−30 gene copies per mL in Amersfoort, N3 was detected in sewage 6 days before the first cases were reported. As the prevalence of COVID-19 in these cities increased in March, the RNA signal detected by each qRT-PCR assay increased, for N1−N3 up to 790−2200 gene copies per mL. This increase correlated significantly with the increase in reported COVID-19 prevalence.

Similarly, other studies have been carried out around the world. Thus, in the study by Hata et al. (2021), presence of SARS-CoV-2 RNA in wastewater samples was investigated and was compared with the number of the confirmed COVID-19 cases in the study area during COVID-19 outbreak in Japan. In total, 45 influent wastewater samples were collected from five wastewater treatment plants in Ishikawa and Toyama prefectures in Japan. During the study period, the numbers of confirmed COVID-19 cases in these prefectures increased from 0.3 and 0 to >20 per 100,000 people. SARS-CoV-2 ribonucleic acid (RNA) in the samples was detected by Hata et al. (2021) using several PCR-based assays. Of the 45 samples, 21 were positive for SARS-CoV-2 according to at least one of the three quantitative RT-PCR assays. The detection frequency increased when the number of total confirmed SARS-CoV-2 cases in 100,000 people exceeded

10 in each prefecture; however, SARS-CoV-2 could also be detected at a low frequency even when the number was below 1.0.

Other studies have been more precise by highlighting mutations in SARS-CoV-2 genes during COVID-19 epidemics. This is the case of Dharmadhikari et al. (2022). Dharmadhikari et al. (2022) used wastewater as a valuable resource for analyzing SARS-CoV-2 mutations circulating in the wastewater of Pune region (Maharashtra; India), one of the most affected during the COVID-19 pandemic. They conducted the study in open wastewater drains from December 2020–March 2021 to assess the presence of SARS-CoV-2 nucleic acid and further detect mutations using ARTIC protocol of MinION sequencing. The analysis revealed 108 mutations across six samples categorized into 39 types of mutations. Dharmadhikari et al. (2022) report the occurrence of mutations associated with Delta variant lineage in March-2021 samples, simultaneously also reported as a Variant of Concern (VoC) responsible for the rapid increase in infections. The study also revealed four mutations; S: N801, S:C480R, NSP14:C279F and NSP3:L550del not currently reported from wastewater or clinical data in India but reported worldwide. Further, a novel mutation NSP13:G206F mapping to NSP13 region was observed from wastewater. Notably, S: P1140del mutation was detected in December 2020 samples while it was reported in February 2021 from clinical data, indicating the instrumentality of wastewater data in early detection. This is the first study in India to demonstrate the utility of sequencing in wastewater based epidemiology to identify mutations associated with SARS-CoV-2 virus fragments from wastewater as an early warning indicator system.

Wastewater surveillance at the institutional level as specific geographic areas / populations with emerging cases can be tracked, and immediate action can be taken in the event of a positive wastewater signal. This aspect was highlighted in the study carried out by Ahmed et al. (2022). In fact, Ahmed et al. (2022) conducted a study aimed to establish whether the surveillance of aircraft wastewater can be used to provide an additional layer of information to augment individual clinical testing. Wastewater from 37 long-haul flights chartered to repatriate Australians was tested for the presence of SARS-CoV-2 RNA. Children 5 years or older on these flights tested negative for coronavirus disease 19 (COVID-19) (deep nasal and oropharyngeal reverse-transcription (RT)- PCR swab) 48 h before departure. All passengers underwent mandatory quarantine for 14-day post arrival in Howard Springs, NT, Australia. Wastewater from 24 (64.9 %) of the 37 flights tested positive for SARS-CoV-2 RNA. During the 14-day mandatory quarantine, clinical testing identified 112 cases of COVID-19. Surveillance for SARS-CoV-2 RNA in repatriation flight wastewater using pooled results from three RT-qPCR assays demonstrated a positive predictive value (PPV) of 87.5 %, a negative predictive value (NPV) of 76.9 % and 83.7% accuracy for COVID-19 cases during the post-arrival 14-day quarantine period. The study successfully demonstrates that the surveillance of wastewater from aircraft for SARS-CoV-2 can provide an additional and effective tool for informing the management of returning overseas travelers and for monitoring the importation of SARS CoV-2 and other clinically significant pathogens.

4.2.2 SARS-CoV-2 in Wastewater, Risk and Risk Assessment

The coronavirus viral concentration in feces of infected people who tested positive were exhibited in the range of almost 104–108 copies/L (Teymoorian et al. 2021). However, in sewage, feces dilution is caused to reduce the viral load between almost 102–106.5 copies/L (Zhou et al. 2017). Foladori et al. (2020) reported that concentration of SARS-CoV-2 in sewage entering a WWTP may vary from 2 copies.100 mL−1 to 3 × 103 copies·mL−1.Wu et al. (2020) and Y. Wu et al. (2020) quantified viral titer of SARS-CoV-2 in sewage from a major urban treatment facility in Massachusetts (USA) and suggested approximately 100 viral particles per mL of sewage.

A study conducted by Wang et al. (2005) showed that SARS-CoV could survive in wastewater for 14 days at 4oC and for 2 days at 20oC. During these times, the SARS-CoV can be infectious by fecal-oral transmission. It is very likely possible that SARS-CoV-2 can be infectious by fecal-oral transmission. A study done by Zaneti et al. (2021) showed that wastewater treatment plants could be a transmission pathway for the SARS-CoV-2.

Wang et al. (2022) used the model simulated the spatial and temporal distribution of the viral pRNA concentrations in the surface water of the Elbe watershed from March 2020 to January 2021. The results show that the WWTPs with the maximum capacity of >10,000 population equivalents were responsible for 95% of the viral load discharged into the surface water. They estimated the pRNA concentrations in surface water to be 1.33 × 10−2 copies·L−1 on average in the watershed based on the model simulation on viral transmission. It had considerable variations in spatial and temporal scales, which are dominantly controlled by epidemic situations and virus transport with decay in water, respectively. A quantitative microbial risk assessment was conducted to estimate the viral infection probability from surface water ingestion with consideration of the influence of toilet usage frequency and gender/age population groups. The individuals aged 15–34 years had the highest infection probability of 4.86 × 10−9 on average from surface water ingestion during swimming activities. Regarding the population groups, men had a comparable infection probability with a spatio-temporal median of 4.30 × 10−9 (95% CI: 3.74 × 10−12–2.73 × 10−7) compared with the infection probability of women (3.66 × 10−9, 95% CI: 3.74 × 10−12–2.32 × 10−7). Similarly, Zaneti et al. (2021) conducted the first study that investigates the potential health risks of SARS-CoV-2 in sewage to wastewater treatment plant (WWTP) workers. A quantitative microbial risk assessment (QMRA) is applied for three COVID-19 scenarios (moderate, aggressive and extreme) to study the effects of different stages of the pandemic in terms of percentage of infected population on the probability of infection to WWTP workers. A dose-response model for SARS-CoV-1 (as a surrogate pathogen) is assumed in the QMRA for SARS-CoV-2 using an exponential model with k = 4.1 × 102. Literature data are incorporated to inform assumptions for calculating the viral load, develop the model, and derive a tolerable infection risk. Results reveal that estimates of viral RNA in sewage at the entrance of WWTPs ranged from 4.14 × 101 to 5.23 × 103 GC·mL−1 (viable virus concentration from 0.04 to 5.23 PFU·mL−1, respectively). In addition, Zaneti et al. (2021) have estimated risks for the aggressive and extreme scenarios (2.6 × 10−3 and 1.3 × 10−2, respectively) were likely to be above the derived tolerable infection risk for SARSCoV-2 of 5.5 × 10−4 pppy, thus reinforcing the concern of sewage systems as a possible transmission pathway of SARS-CoV-2. These findings are helpful as an early health warning tool and in prioritizing upcoming risk management strategies, such as Emergency Response Plans (ERPs) for water and sanitation operators during the COVID-19 and future pandemics.

4.2.3 SARS-CoV-2 in Wastewater, sanitation measures

Da Silva et al. (2020) conducted an ecological study, using spatial analysis tools, on COVID-19 cases registered in the 27 federative units of Brazil until May 28, 2020, and assessed the correlation of COVID-19 distribution with access to water and sewage. Three indices, i.e., water supply, sewage service, and treated sewage index, were used as independent variables. Interestingly, analysis of absolute data revealed a significant negative correlation between the number of cases and the sewage treatment index (ρ = -0,5269; p-value = 0,0047) and a significant weak positive correlation between the number of cases and population density (ρ = 0,4542; p-value = 0,0173).

Similarly, the authors demonstrate the absolute number of deaths showed a moderate negative linear relationship with the sewage treatment index (ρ = -0,6118; p-value = 0,0007) and a weak positive linear relationship with population density (ρ = 0,4497; p-value = 0,0186). The incidence and mortality rates showed a significantly negative correlation with the total water service index (ρ = -0,6319; p-value =

0,0004 and ρ = -0,4641; p-value = 0,0148, respectively). Moreover, the lethality rate presented a moderate negative relation with the sewage treatment index (ρ = -0,5284; p-value = 0,0046).

The incidence and mortality rates of COVID-19 increase significantly with a decrease in the total water utility index, and that the case fatality rate increases significantly with a decrease in the water treatment index.

It is possible that stormwater could serve as an environmental reservoir and transmission pathway for SARSCoV-2. Bernard et al. (2022) investigated whether SARS-CoV-2 could be detected from 10 storm sewer outfalls each draining a single, dominant land use in Columbus, Xenia, and Springboro, Ohio (USA). Of the 25 samples collected in 2020, at minimum one SARS-CoV-2 target gene (N2 [US-CDC and CN-CDC], and E) was detected in 22 samples (88%). A single significant correlation (p = 0.001), between antecedent dry period and the USCDC N2 gene, was found between target gene concentrations and rainfall characteristics. Potential hazards may arise when human fecal contamination is present in stormwater and facilitates future investigation on the threat of viral outbreaks.

5. Discussion

Bashir et al. (2020) used secondary data published by the New York City Health Services and the United States National Weather Service. The Kendall and Spearman rank correlation tests were chosen by these authors for data analysis. They found that average temperature, minimum temperature, was significantly associated with the COVID-19 pandemic. Sajadi et al. (2020) concluded in their study that humidity and temperature also play an important role in the seasonal spread of coronaviruses. Along the same lines, Wang et al. (2020) also reported similar results for the case of China. The COVID-19 outbreak in Wuhan has shown a strong association between the spread of the disease and weather conditions, with forecasts that the warming of the weather will play a significant role in virus removal. Other weather indicators such as wind speed and humidity also affect the spread of infectious diseases. In addition, air temperature also contributes to the transmission of the virus (Chen et al., 2020). Like many authors, some of whom have been cited above, Ma et al. (2020) have suggested that humidity and temperature will play an important role in the COVID-19 death rate as climate indicators and temperature correlate with the spread of COVID-19 (Poole, 2020).

McClymont and Hu (2021) gave an overview of research related to the effect of climate on the emergence of COVID-19 cases. Indeed, McClymont & Hu (2021) in their review showed that temperature was reported as significant in the greatest number of studies, with COVID-19 incidence increasing as temperature decreased, and the highest incidence reported in the temperature range of 0–17 ◦C. According to McClymont & Hu (2021), humidity was also significantly associated with COVID-19 incidence, though the reported results were mixed, with studies reporting positive and negative correlation. A significant interaction between humidity and temperature was also reported. Weather variables including temperature and humidity can contribute to increased transmission of COVID-19, particularly in winter conditions, through increased host susceptibility and viability of the virus. While there is less indication of an association with wind speed and rainfall, these may contribute to behavioral changes that decrease exposure and risk of infection.

Kerr et al. (2021) showed in their study, the lack of consensus in the conclusions on the roles of temperature, humidity and other meteorological factors on the dynamics of transmission of COVID-19. They discussed in their paper how several aspects of the study methodologies can challenge direct comparisons between studies and inflate the importance of weather factors on COVID-19 transmission.

Kerr et al. (2021) specifies that at the current stage of the pandemic, efforts to characterize the environmental sensitivity of COVID-19 are based on surveillance data, but this data is heterogeneous and impacted by bias in the time series of deaths, cases and cures (Smit et al. 2020; Angelopoulos et al. 2020; Jagodnik et al. 2020). Even for a fixed location with almost homogeneous interventions, human behavior and demographics, there are regular changes in test, which could result in a different proportion of cases detected over time (Flaxman et al. 2020). As with the number of cases, the basic and effective breeding numbers (R0 and Re or Rt, respectively) may be affected by the characteristics and mobility of the population and depend on the time varying sensitivity (Smit et al., 2020) but if the surveillance biases are systematic, R0 and Re provide more reliable alternatives for a number of raw cases. According to Kerr et al. (2021), true environmental sensitivity of COVID-19 may exist, but its impact has likely been minimal so far in the pandemic, compared with influences from non-pharmaceutical interventions and behavior Carlson et al. (2020). If studies claiming to have found a sensitivity of COVID-19 to weather factors are presented to policymakers and the public without adequate scientific verification or without proper context, the release of such results presents potentially dangerous and even deadly misinformation and may erode credibility of scientific data (Zaitchik et al., 2020). Global transmission of COVID-19 implies that seasonal variation cannot be seen as just a propagation modifier; however, the warmer climate could moderately limit the spread of COVID-19. No evidence has advised that the warmer weather would limit the power of the spread of COVID-19 to result in less needed additional actions to restrict transmission.

In Brazil, in their study, Neto & Melo (2020) demonstrated that population density had a strong positive correlation with the number of COVID-19 cases in Brazilian capitals. They point out that population density, which is linked to higher human mobility, and poorer socio-economic environments that have poor sanitary conditions contribute to the spread of the virus. According to da Silva et al. (2021), although some studies have addressed studies examining the relationship between weather variables and COVID-19, some results appear inconsistent. On the one hand, temperature and humidity, for example, have been reported to have a significant impact on the majority of studies. On the other hand, the correlation was positive in some cases and negative in others. These observations suggest that the link between weather characteristics and the number of COVID-19 cases is complex and difficult to generalize. According to Neto & Melo (2020) there is some evidence that meteorological variables contribute to increased transmission of COVID-19, but the effect of these relationships should be studied locally, as other factors such as human mobility and public health measures (containment, for example) also have a strong influence on the number of COVID-19 cases.

Sera et al. (2021) found little evidence that weather conditions influenced the early stages of local epidemics, and concluded that population behavior and government interventions are more important drivers of transmission.

The secondary transmission potential via sewage should not be underestimated, especially in low-income and developing countries with weak wastewater treatment technologies. Therefore, the risk of transmission and infection can be increased into sewage by the fecal-oral way, mainly in some parts of the globe with a high amount of open defecation. The existence of the virus is confirmed in the stool of a human until 33 days when the infected person's test is negative for SARS-CoV-2 (Quilliam et al. 2020). The risk of infection increases in some parts of the globe and with a high amount of open defecation. According to UNICEF, 892 million people around the world still use open defecation (UNICEF, 2018). For example, statistical data on November 2019 demonstrated that in India, about 28.7% of rural people still do not have access to any type of toilet (Kataki et al. 2020). Hence, a considerable amount of viruses would be expected in sewage from the number of diagnosed infected individuals, which has been exhibited in studies from many countries affected by this crisis.

There is a high risk for transmission of SARS-CoV-2 through the air when wastewater operators clean the screens manually or when wastewater treatment tanks are not covered (Figure 1).

Figure 1. The possible pathways of different contamination in water during the COVID-19 pandemic according to Teymoorian et al. (2021).

Successful detection of SARS-COV-2 in wastewater suggests the potential utility of wastewater-based epidemiology for COVID-19 community surveillance. While wastewater surveillance cannot replace large-scale diagnostic testing, it can complement clinical surveillance by providing early signs of potential transmission for more active public (Shah et al.,2022). Institutional level wastewater surveillance may, also, serve well for early warning purposes because specific geographic areas/populations with emerging cases can be tracked, and immediate action can be executed in the event of a positive wastewater signal health responses.

SARS-CoV-2 RNA SARS-CoV-2 is present in two matrices: stool and wastewater for two main reasons: (i) they are problematic matrices due to the high concentration of microorganisms which can affect the performance of viral culture in cell lines; and (ii) isolation of SARS-CoV-2 should be performed at least in a BLS-3 laboratory using BSL-3 good practice and most environmental laboratories do not have such facilities and protocols in place. At least two studies have investigated the infectivity of SARSCoV-2 detected in the stools of infected patients with conflicting results. While Xiao et al. (2020) were able to detect infectious viral particles in the stool of an infected patient, using the Vero E6 cell line, Wölfel et al. (2020) were unable to isolate infectious viral particles, using the same cell line, in two separate laboratories, despite the high viral RNA load detected by RT-qPCR.

According to Street et al. (2020) in sub-Saharan Africa, wastewater systems may have large numbers of unlawful connections such as illegal discharge into storm water drains (UN Water, 2015; Levin et al., 2020). Little is known about the impact of dysfunctional sewer systems, as have been reported throughout Africa, on capacity to detect SARS-CoV-2 RNA in wastewater. Extreme weather events such as floods can damage or destroy wastewater treatment systems and cause overflow of untreated sewage (WHO, 2019). Moreover, the rainy season is associated with the increase in the overflowing of pit latrines (Nakagiri et al., 2016; Sengupta et al., 2018). Owing to the impacts of climate change, sub-Saharan Africa has been identified as a vulnerable region with emphasis on weather-related extremes such as floods (Carabine et al., 2014). This will further compound increasingly overburdened wastewater systems. Season change and differing climate regions have pronounced effects on wastewater surveillance and may affect the persistence of SARS-CoV-2 in wastewater (Hart & Halden, 2020). According to Hart and Halden (Hart and Halden, 2020) temperature effects may influence virus detectability and if such factors are not taken into account, wastewater temperature may lead to under or over estimating COVID-19 prevalence and thereby misinform the public health response. This is a key consideration when planning a national wastewater surveillance in expansive countries like Algeria, Nigeria and South Africa which have national climatic diversity. However, if properly used, the EWS could detect COVID-19 hotspots brought on by such extreme climate events (Kitajima et al., 2020).

6. Conclusion

Weather is a significant contributing factor to COVID-19 transmission, particularly temperature and humidity. The relationship between temperature and humidity was addressed in more studies than wind speed and rainfall, but the evidence was not consistent across studies. In conclusion, even though meteorological factors were associated with COVID-19, stringent control measures are necessary to control COVID-19 regardless the meteorological conditions of an area, the post-pandemic era can be a place where social hygiene is more practiced, where crisis management can be managed more effectively, and where technology plays a greater role in human life. Looking toward the future, studies combining SARS-CoV-2 molecular detection in sewage and viral isolation in cell culture to validate infectivity, as well as epidemiological studies, are needed. Another urgent research need is the risk assessment for communities bordering WWTPs or for communities that simply do not have sewage collection. This is a common situation in underdeveloped countries, which may be subject to routes of exposure to the virus by direct ingestion and inhalation of bioaerosols.

References

Ahmed, W., Bivins, A., Simpson, S. L., Bertsch, P. M., Ehret, J., Hosegood, I., Metcalfe, S. S., Smith, W. J., Thomas, K. V., Tynan, J., & Mueller, J. F. (2022). Wastewater surveillance demonstrates high predictive value for COVID-19 infection on board repatriation flights to Australia. *Environment International*, *158*, 106938.

Angelopoulos, A., Pathak, R., Varma, R., & Jordan, M. I. (2020). Identifying; and Correcting Bias from Time- and Severity- Dependent Reporting Rates in the Estimation of the COVID-19 Case Fatality Rate. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3556644

Araujo Neto, R. A., & Melo, G. C. (2020). Correlation between weather, population size and COVID-19 pandemic: a study of Brazilian capitals. *Journal of Health & Biological Sciences*, *8*(1), 1.

Bashir, M. F., Ma, B., Bilal, Komal, B., Bashir, M. A., Tan, D., & Bashir, M. (2020). Correlation between climate indicators and COVID-19 pandemic in New York, USA. *Science of The Total Environment*, *728*, 138835.

Bernard, K., Davis, A., Simpson, I. M., Hale, V. L., Lee, J., & Winston, R. J. (2022a). Detection of SARS-CoV-2 in urban storm water: An environmental reservoir and potential interface between human and animal sources. *Science of The Total Environment*, *807*, 151046.

Bogler, A., Packman, A., Furman, A., Gross, A., Kushmaro, A., Ronen, A., Dagot, C., Hill, C., Vaizel-Ohayon, D., Morgenroth, E., Bertuzzo, E., Wells, G., Kiperwas, H. R., Horn, H., Negev, I., Zucker, I., Bar-Or, I., Moran-Gilad, J., Balcazar, J. L., . . . Bar-Zeev, E. (2020). Rethinking wastewater risks and monitoring in light of the COVID-19 pandemic. *Nature Sustainability*, *3*(12), 981-990.

Carabine, E., Lemma, A., Dupar, M. (2014). *The IPCC's Fifth Assessment Report: What's in it for Africa*. Climate & Development Knowledge Network (CDKN).

Carlson, C. J., Gomez, A. C. R., Bansal, S., & Ryan, S. J. (2020). Misconceptions about weather and seasonality must not misguide COVID-19 response. *Nature Communications*, *11*(1).

Chen, B., Liang, H., Yuan, X., Hu, Y., Xu, M., Zhao, Y., Zhang, B., Tian, F., & Zhu, X. (2020). Predicting the local COVID-19 outbreak around the world with meteorological conditions: a model-based qualitative study. *BMJ Open*, *10*(11), e041397.

Dalziel, B. D., Kissler, S., Gog, J. R., Viboud, C., Bjørnstad, O. N., Metcalf, C. J. E., & Grenfell, B. T. (2018). Urbanization and humidity shape the intensity of influenza epidemics in U.S. cities. *Science*, *362*(6410), 75-79.

da Silva, T. T., Francisquini, R., & Nascimento, M. C. (2021). Meteorological and human mobility data on predicting COVID-19 cases by a novel hybrid decomposition method with anomaly detection analysis: A case study in the capitals of Brazil. *Expert Systems with Applications*, *182*, 115190.

Daughton, C. G. (2020). Wastewater surveillance for population-wide Covid-19: The present and future. *Science of The Total Environment*, *736*, 139631.

Dharmadhikari, T., Rajput, V., Yadav, R., Boargaonkar, R., Patil, D., Kale, S., Kamble, S. P., Dastager, S. G., & Dharne, M. S. (2022). High throughput sequencing based direct detection of SARS-CoV-2 fragments in wastewater of Pune, West India. *Science of The Total Environment*, *807*, 151038.

Domingo, J. L., Marquès, M., & Rovira, J. (2020). Influence of airborne transmission of SARS-CoV-2 on COVID-19 pandemic. A review. *Environmental Research*, *188*, 109861.

Flaxman, S., Mishra, S., Scott, J., Ferguson, N., Gandy, A., & Bhatt, S. (2020). Reply to: The effect of interventions on COVID-19. *Nature*, *588*(7839), E29-E32.

Foladori, P., Cutrupi, F., Segata, N., Manara, S., Pinto, F., Malpei, F., Bruni, L., & La Rosa, G. (2020). SARS-CoV-2 from faeces to wastewater treatment: What do we know? A review. *Science of The Total Environment*, *743*, 140444.

García-Ávila, F., Valdiviezo-Gonzales, L., Cadme-Galabay, M., Gutiérrez-Ortega, H., Altamirano-Cárdenas, L., Arévalo, C. Z., & Flores del Pino, L. (2020). Considerations on water quality and the use of chlorine in times of SARS-CoV-2 (COVID-19) pandemic in the community. *Case Studies in Chemical and Environmental Engineering*, *2*, 100049. https://doi.org/10.1016/j.cscee.2020.100049

Hart, O. E., & Halden, R. U. (2020). Computational analysis of SARS-CoV-2/COVID-19 surveillance by wastewater-based epidemiology locally and globally: Feasibility, economy, opportunities and challenges. *Science of The Total Environment*, *730*, 138875.

Hata, A., Hara-Yamamura, H., Meuchi, Y., Imai, S., & Honda, R. (2021). Detection of SARS-CoV-2 in wastewater in Japan during a COVID-19 outbreak. *Science of The Total Environment*, *758*, 143578.

Holshue, M. L., DeBolt, C., Lindquist, S., Lofy, K. H., Wiesman, J., Bruce, H., Spitters, C., Ericson, K., Wilkerson, S., Tural, A., Diaz, G., Cohn, A., Fox, L., Patel, A., Gerber, S. I., Kim, L., Tong, S., Lu, X., Lindstrom, S., . . . Pillai, S. K. (2020). First Case of 2019 Novel Coronavirus in the United States. *New England Journal of Medicine*, *382*(10), 929-936.

Jagodnik, M.K, Ray,F, Giorgi,M.F, Lachmann,A, Correcting Under-reported COVID-19 Case Numbers: Estimating the True Scale of the Pandemic, unpublished results, 2021, https://doi.org/10.1101/2020.03.14.20036178.

Jiang, Y., & Xu, J. (2020). The association between COVID-19 deaths and short-term ambient air pollution/meteorological condition exposure: a retrospective study from Wuhan, China. *Air Quality, Atmosphere & Health*, *14*(1), 1-5.

Kataki, S., Chatterjee, S., Vairale, M. G., Sharma, S., & Dwivedi, S. K. (2021). Concerns and strategies for wastewater treatment during COVID-19 pandemic to stop plausible transmission. *Resources, Conservation and Recycling*, *164*, 105156.

Kerr, G. H., Badr, H. S., Gardner, L. M., Perez-Saez, J., & Zaitchik, B. F. (2021). Associations between meteorology and COVID-19 in early studies: Inconsistencies, uncertainties, and recommendations. *One Health*, *12*, 100225.

Kitajima, M., Ahmed, W., Bibby, K., Carducci, A., Gerba, C. P., Hamilton, K. A., Haramoto, E., & Rose, J. B. (2020). SARS-CoV-2 in wastewater: State of the knowledge and research needs. *Science of The Total Environment*, *739*, 139076.

Kumar, M., Taki, K., Gahlot, R., Sharma, A., Dhangar, K., 2020. A chronicle of SARS-CoV-2: part-I - epidemiology, diagnosis, prognosis, transmission and treatment. Sci. Total En- viron. 734, 1–13.

Levin, R., Housh, M., & Portnov, B. A. (2020). Characterization of Localities with a High Likelihood of Illicit Connections between Runoff and Sewage Systems. *Environmental Management*, *65*(6), 748-757.

Liu, K., Hou, X., Ren, Z., Lowe, R., Wang, Y., Li, R., Liu, X., Sun, J., Lu, L., Song, X., Wu, H., Wang, J., Yao, W., Zhang, C., Sang, S., Gao, Y., Li, J., Li, J., Xu, L., & Liu, Q. (2020). Climate factors and the East Asian summer monsoon may drive large outbreaks of dengue in China. *Environmental Research*, *183*, 109190.

Ma, Y., Zhao, Y., Liu, J., He, X., Wang, B., Fu, S., Yan, J., Niu, J., Zhou, J., & Luo, B. (2020). Effects of temperature variation and humidity on the death of COVID-19 in Wuhan, China. *Science of The Total Environment*, *724*, 138226.

McClymont, H., & Hu, W. (2021). Weather Variability and COVID-19 Transmission: A Review of Recent Research. *International Journal of Environmental Research and Public Health*, *18*(2), 396.

Medema, G., Heijnen, L., Elsinga, G., Italiaander, R., & Brouwer, A. (2020). Presence of SARS-Coronavirus-2 RNA in Sewage and Correlation with Reported COVID-19 Prevalence in the Early Stage of the Epidemic in The Netherlands. *Environmental Science & Technology Letters*, *7*(7), 511-516.

Monteiro, S., Rente, D., Cunha, M. V., Marques, T. A., Cardoso, E., Vilaça, J., Coelho, N., Brôco, N., Carvalho, M., & Santos, R. (2022). Discrimination and surveillance of infectious severe acute respiratory syndrome Coronavirus 2 in wastewater using cell culture and RT-qPCR. *Science of The Total Environment*, 152914.

Morella E, Foster V, and Banerjee GS Climbing the Ladder: The State of Sanitation in SubSaharan A AICD June 2008

Nakagiri, A., Niwagaba, C. B., Nyenje, P. M., Kulabako, R. K., Tumuhairwe, J. B., & Kansiime, F. (2017). Assessing ambient and internal environmental conditions of pit latrines in urban slums of Kampala, Uganda: effect on performance. *Journal of Water, Sanitation and Hygiene for Development*, *7*(1), 92-101.

Nakagiri, A., Niwagaba, C. B., Nyenje, P. M., Kulabako, R. N., Tumuhairwe, J. B., & Kansiime, F. (2015). Are pit latrines in urban areas of Sub-Saharan Africa performing? A review of usage, filling, insects and odors nuisances. *BMC Public Health*, *16*(1).

Pansini, R., & Fornacca, D. (2021). COVID-19 Higher Mortality in Chinese Regions with Chronic Exposure to Lower Air Quality. *Frontiers in Public Health*, *8*.

Poole, L. (2020). Seasonal Influences On the Spread Of SARS-CoV-2 (COVID19), Causality, and Forecastabililty (3–15-2020). *SSRN Electronic Journal*.

Quilliam, R. S., Weidmann, M., Moresco, V., Purshouse, H., O'Hara, Z., & Oliver, D. M. (2020). COVID-19: The environmental implications of shedding SARS-CoV-2 in human faeces. *Environment International*, *140*, 105790.

Maria Dos Santos Silva, R., dos Santos Silva, L., Rocha Brito, D., Vieira Dos Santos, R. L., Raquel Santos Bezerra, I., & Lucas Cardoso Lima, L. (2019). Levantamento arbóreo da avenida Ceci Cunha e praças centrais do município de Arapiraca, AL. *Diversitas Journal*, *4*(2), 367-383.

Rheinländer, T., Konradsen, F., Keraita, B., Apoya, P., & Gyapong, M. (2015). Redefining shared sanitation. *Bulletin of the World Health Organization*, *93*(7), 509-510.

Sajadi, M. M., Habibzadeh, P., Vintzileos, A., Shokouhi, S., Miralles-Wilhelm, F., & Amoroso, A. (2020). Temperature and Latitude Analysis to Predict Potential Spread and Seasonality for COVID-19. *SSRN Electronic Journal*.

Sarkodie, S. A., & Owusu, P. A. (2020). Impact of meteorological factors on COVID-19 pandemic: Evidence from top 20 countries with confirmed cases. *Environmental Research*, *191*, 110101.

Sarwar, S., Shahzad, K., Fareed, Z., & Shahzad, U. (2021). A study on the effects of meteorological and climatic factors on the COVID-19 spread in Canada during 2020. *Journal of Environmental Health Science and Engineering*, *19*(2), 1513-1521.

Sera, F., Armstrong, B., Abbott, S., Meakin, S., O'Reilly, K., von Borries, R., Schneider, R., Royé, D., Hashizume, M., Pascal, M., Tobias, A., Vicedo-Cabrera, A. M., Hu, W., Tong, S., Lavigne, E., Correa, P. M., Meng, X., Kan, H., Kynčl, J., . . . Lowe, R. (2021). A cross-sectional analysis of meteorological factors and SARS-CoV-2 transmission in 409 cities across 26 countries. *Nature Communications*, *12*(1).

Shah S, Gwee SXW, Ng JQX, Lau N, Koh J, Pang J. Wastewater surveillance to infer COVID-19 transmission: A systematic review. Sci Total Environ. 2022 Jan 15;804:150060. doi: 10.1016/j.scitotenv.2021.150060. Epub 2021 Sep 8. PMID: 34798721; PMCID: PMC8423771.

Shahzad, K., Farooq, T. H., Doğan, B., Zhong Hu, L., & Shahzad, U. (2021). Does environmental quality and weather induce COVID-19: Case study of Istanbul, Turkey. *Environmental Forensics*, 1-12.

Shahzad, K., Shahzad, U., Iqbal, N., Shahzad, F., & Fareed, Z. (2020). Effects of climatological parameters on the outbreak spread of COVID-19 in highly affected regions of Spain. *Environmental Science and Pollution Research*, *27*(31), 39657-39666.

Shakoor, A., Chen, X., Farooq, T. H., Shahzad, U., Ashraf, F., Rehman, A., Sahar, N. E., & Yan, W. (2020). Fluctuations in environmental pollutants and air quality during the lockdown in the USA and China: two sides of COVID-19 pandemic. *Air Quality, Atmosphere & Health*, *13*(11), 1335-1342.

Silva, R. R. D., Santos, M. B. D., Santos, A. D. D., Tavares, D. D. S., & Santos, P. L. D. (2020). Coronavirus disease and basic sanitation: too early to be worried? *Revista da Sociedade Brasileira de Medicina Tropical*, *53*.

Smit, A. J., Fitchett, J. M., Engelbrecht, F. A., Scholes, R. J., Dzhivhuho, G., & Sweijd, N. A. (2020). Winter Is Coming: A Southern Hemisphere Perspective of the Environmental Drivers of SARS-CoV-2 and the Potential Seasonality of COVID-19. *International Journal of Environmental Research and Public Health*, *17*(16), 5634.

Street, R., Malema, S., Mahlangeni, N., & Mathee, A. (2020). Wastewater surveillance for Covid-19: An African perspective. *Science of The Total Environment*, *743*, 140719.

Teymoorian, T., Teymourian, T., Kowsari, E., & Ramakrishna, S. (2021). Direct and indirect effects of SARS-CoV-2 on wastewater treatment. *Journal of Water Process Engineering*, *42*, 102193.

Usman, M., Farooq, M., & Hanna, K. (2020). Existence of SARS-CoV-2 in Wastewater: Implications for Its Environmental Transmission in Developing Communities. *Environmental Science & Technology*, *54*(13), 7758-7759.

UNICEF (2018) United Nation Children's Fund. UNICEF's game plan to end open defecation. https://www.unicef.org/wash/files/UNICEF_Game_plan_to_end_open_defecation_2018.pdf. Accessed 12 Nov 2020

Wang, D., Hu, B., Hu, C., Zhu, F., Liu, X., Zhang, J., Wang, B., Xiang, H., Cheng, Z., Xiong, Y., Zhao, Y., Li, Y., Wang, X., & Peng, Z. (2020). Clinical Characteristics of 138 Hospitalized Patients with 2019 Novel Coronavirus–Infected Pneumonia in Wuhan, China. *JAMA*, *323*(11), 1061.

Wang, X. W., Li, J. S., Jin, M., Zhen, B., Kong, Q. X., Song, N., Xiao, W. J., Yin, J., Wei, W., Wang, G. J., Si, B. Y., Guo, B. Z., Liu, C., Ou, G. R., Wang, M. N., Fang, T. Y., Chao, F. H., & Li, J. W. (2005). Study on the resistance of severe acute respiratory syndrome-associated coronavirus. *Journal of Virological Methods*, *126*(1-2), 171-177.

Wang, Z., Yang, W., Hua, P., Zhang, J., & Krebs, P. (2022). Transmission risk of SARS-CoV-2 in the watershed triggered by domestic wastewater discharge. *Science of The Total Environment*, *806*, 150888. https://doi.org/10.1016/j.scitotenv.2021.150888

UN Water, 2015. Wastewater Management – A UN-Water Analytical Brief.

WHO 2022 Weekly epidemiological update on COVID-19 - 11 January 2022 Edition 74

https://reliefweb.int/sites/reliefweb.int/files/resources/20220111_Weekly_Epi_Update_74.pdf

WHO Climate, Sanitation and Health. (2019).

WHO 2017 Guidelines for Drinking-Water Quality. 4th edn. World Health Organization, Geneva.

WHO/UNICEF Joint Water Supply Sanitation Monitoring Programme, 2014

9789241507240_eng.pdf;sequence=1 (who.int)

Xie J, Zhu Y. Association between ambient temperature and COVID-19 infection in 122 cities from China. Sci Total Environ. 2020 ;138201.

Xiao, F., Tang, M., Zheng, X., Liu, Y., Li, X., & Shan, H. (2020). Evidence for Gastrointestinal Infection of SARS-CoV-2. *Gastroenterology*, *158*(6), 1831–1833.e3.

Wölfel, R., Corman, V. M., Guggemos, W., Seilmaier, M., Zange, S., Müller, M. A., Niemeyer, D., Jones, T. C., Vollmar, P., Rothe, C., Hoelscher, M., Bleicker, T., Brünink, S., Schneider, J., Ehmann, R., Zwirglmaier, K., Drosten, C., & Wendtner, C. (2020). Virological assessment of hospitalized patients with COVID-2019. *Nature*, *581*(7809), 465-469.

Yuan, J., Yun, H., Lan, W., Wang, W., Sullivan, S. G., Jia, S., & Bittles, A. H. (2006). A climatologic investigation of the SARS-CoV outbreak in Beijing, China. *American Journal of Infection Control*, *34*(4), 234-236.

Zaitchik, B. F., Sweijd, N., Shumake-Guillemot, J., Morse, A., Gordon, C., Marty, A., Trtanj, J., Luterbacher, J., Botai, J., Behera, S., Lu, Y., Olwoch, J., Takahashi, K., Stowell, J. D., & Rodó, X. (2020). A framework for research linking weather, climate and COVID-19. *Nature Communications*, *11*(1).

Zaneti, R. N., Girardi, V., Spilki, F. R., Mena, K., Westphalen, A. P. C., da Costa Colares, E. R., Pozzebon, A. G., & Etchepare, R. G. (2021a). Quantitative microbial risk assessment of SARS-CoV-2 for workers in wastewater treatment plants. *Science of The Total Environment*, *754*, 142163.

Zang, R., Castro, M. F. G., McCune, B. T., Zeng, Q., Rothlauf, P. W., Sonnek, N. M., Liu, Z., Brulois, K. F., Wang, X., Greenberg, H. B., Diamond, M. S., Ciorba, M. A., Whelan, S. P. J., & Ding, S. (2020). TMPRSS2 and TMPRSS4 promote SARS-CoV-2 infection of human small intestinal enterocytes. *Science Immunology*, *5*(47).

Zhu, Y., Xie, J., Huang, F., & Cao, L. (2020). Association between short-term exposure to air pollution and COVID-19 infection: Evidence from China. *Science of The Total Environment*, *727*, 138704.