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Show us the Data: Global COVID-19 Wastewater Monitoring Efforts, Equity, and Gaps

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Abstract (200 words)

A year since the declaration of the global coronavirus disease 2019 (COVID-19) pandemic there have been over 110 million cases and 2.5 million deaths. Using methods to track community spread of other viruses such as poliovirus, environmental virologists and those in the wastewater based epidemiology (WBE) field quickly adapted their existing methods to detect SARS-CoV-2 RNA in wastewater. Unlike COVID-19 case and mortality data, there was not a global dashboard to track wastewater monitoring of SARS-CoV-2 RNA worldwide. This study describes the development of the "COVIDPoops19" dashboard to disseminate information regarding sites, universities, research institutions and private laboratories in countries that are involved in WBE for SARS-CoV-2. Methods to assemble the dashboard combined standard literature review, direct submissions, and daily, social media keyword searches. Over 200 universities, 1,000 sites, and 50 countries with 59 dashboards monitor wastewater for SARS-CoV-2 RNA. However, monitoring is inequitably distributed in high-income countries and data are not widely shared publicly or accessible to researchers to inform public health actions, meta-

analysis, better coordinate, and determine equitable distribution of monitoring sites. For WBE to be used to its full potential during COVID-19 and beyond, show us the data.

1. Introduction

In one year, the coronavirus disease 2019 (COVID-19) pandemic has resulted in 110 million cases and 2.5 million deaths worldwide (Dong et al., 2020). When the novel coronavirus strain (SARS-CoV-2) that causes COVID-19 emerged in late 2019, environmental virologists began rapidly adapting their methods from other pathogens wastewater survey work (https://www.pathogens.org/) including use of public health elements to address concerns associated with monitoring SARS-CoV-2 in wastewater. Some of the first major monitoring efforts for SARS-CoV-2 in wastewater were in the Netherlands (Medema et al., 2020a), Australia (Ahmed et al., 2020), Italy (La Rosa et al., 2020), and the United States (Sherchan et al., 2020). A global coordination effort was proposed to share and standardize sampling strategies, virus methodologies and data for WBE for SARS-CoV-2 (Bivins et al., 2020). COVID-19 Wastewater Based Epidemiology (WBE) is now being used to describe this effort and has grown from just a few countries in March 2020 to at least 50 countries and over 200 universities a year later (https://arcg.is/1aummW).

Both the growth and recognition of WBE for SARS-CoV-2 monitoring has been rapid and widespread. Wastewater monitoring to address epidemiological questions has been used historically to track enteric viruses and other pathogens (Waterpathogens.org) including the poliovirus vaccine and wildtype strains (Ranta et al., 2001), norovirus, and others (Li et al., 2019; Schmidt, 2020) and drugs such as opioids (Burgard et al., 2014) but at generally smaller scales. Due to the COVID-19 pandemic, at least six countries (Finland, Hungary, Luxembourg, Netherlands, Spain, Turkey) have nationalized wastewater monitoring for SARS-CoV-2 (Terveyden ja hyvinvoinnin laitos, 2021, Nemzeti Népegészségügyi Központ, 2021, Luxembourg Institute of Science and Technology, 2021, Rijksoverheid, 2021, VATar COVID-19, 2021, Kocamemi et al., 2020). The United States and Canada have established national coordination networks/systems (CDC, 2021a, Canadian Water Network, 2020). At least five countries have regional level monitoring (Australia, Brazil, France, South Africa, Switzerland, United Kingdom) (Victoria State Government, 2021, Queensland Government, 2021, ANA, 2020, Obépine, 2021, SAMRC, 2021, EAWAG, 2021a, EAWAG 2021b, SEPA, 2021). There have been numerous popular news stories in print, online, and on television as well as calls by politicians at all levels for widespread application of wastewater testing. However, while COVID-19 case and death data has been widely available globally, for example, through the Johns Hopkins University dashboard (Dong et al., 2020), even the locations of COVID-19 wastewater testing are less available and difficult to track.

Though challenges exist to standardize wastewater testing methods and data normalization (Medema et al., 2020b), public health departments, utilities, scientists and engineers have an ethical obligation, especially during a pandemic, to provide this information to the public (Canadian Water Network, 2020). The goal of this study is to provide a global dashboard and analysis of SARS-CoV-2 wastewater testing to inform the public (general population, public health departments, municipalities, and researchers) where this type of testing is taking place and provide links to available data for decision making and better coordination. This study uses the "COVIDPoops19" dashboard to identify gaps in wastewater monitoring, to make recommendations for science communication of wastewater data and as a call to action for more forthcoming and transparent open data sharing.

2. Materials and Methods

To create a global dashboard of reported wastewater monitoring efforts, six different data sources were used (see Figure 1): (1) the COVID-19 WBE website (COVID19 WBE Collaborative, 2021), (2) webinars, (3) Google form submissions, (4) literature searches, (5) Twitter keyword searches, and (6) Google keyword searches. ArcGIS Online Dashboards was chosen as the host platform (ESRI Online, 2020). First, points were added from the COVID-19 WBE collaborative publication map as country points (COVID-19 WBE Collaborative, 2021). A link to a Google form was made available at the bottom of the COVIDPoops19 dashboard for users to submit public data points. A Twitter account (@COVIDPoops19) was created for the dashboard and the UC Merced co-authors performed key word searches daily for 'wastewater based epidemiology' and six combinations of 'wastewater' or 'sewage' and 'COVID19' or 'COVID-19' or 'SARS-CoV-2'.

From advertisements on Twitter and the United States National Science Foundation (NSF) COVID-19 WBE Research Coordination Network (RCN), the co-authors regularly attended webinars to learn about different monitoring efforts. Only publicly reported locations and data from websites and news articles were added to the dashboard. Google was used to check for missing U.S. states and territories. For example, a combination of "South Dakota" and "wastewater", "sewage", "monitoring" and "COVID-19" and "SARS-CoV-2" keywords were used to see if there were missing articles that were not found by the daily keyword searches on Twitter.

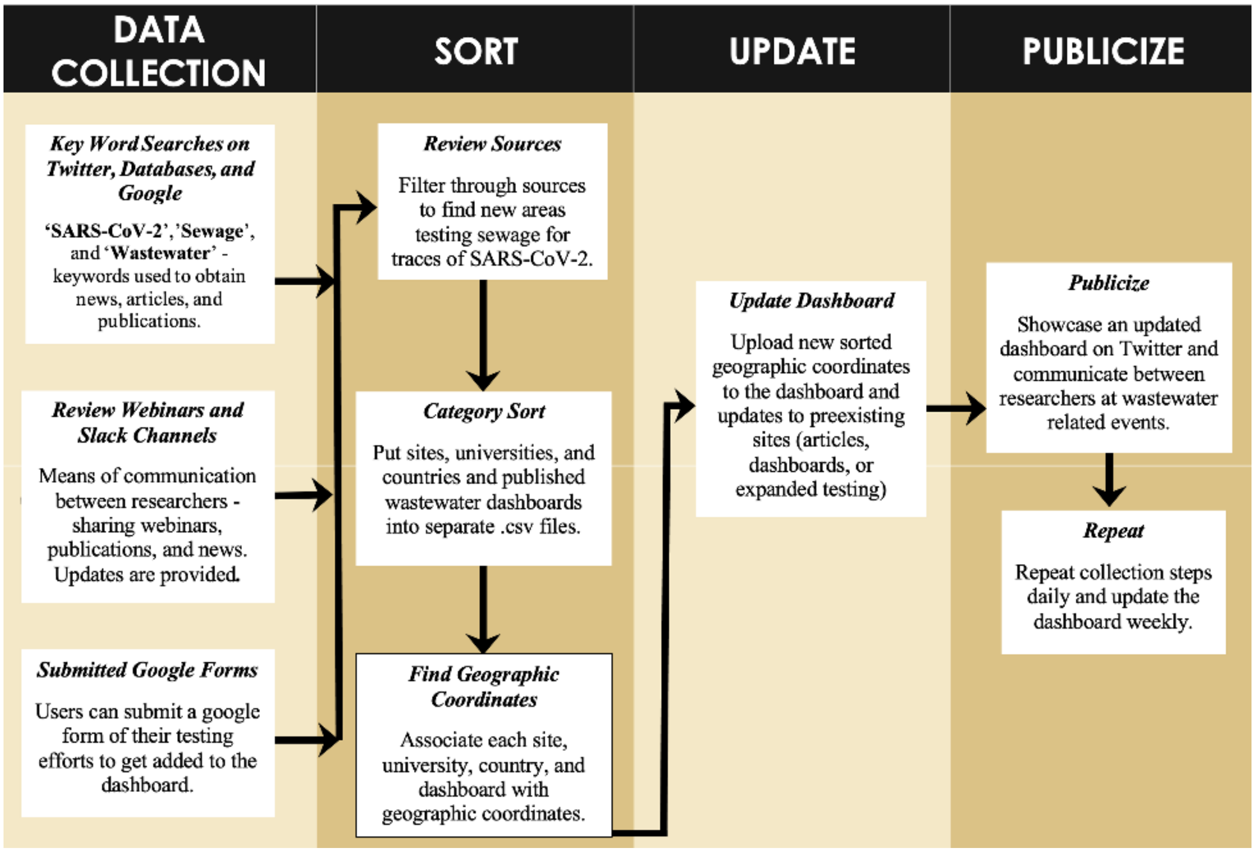

Figure 1. COVIDPoops19 dashboard data workflow

After collection of reported wastewater monitoring locations for SARS-CoV-2, news articles, publications, Google form submissions, dashboard/data and other web links were sorted into four categories: (1) dashboard/data, (2) university, (3) country, and (4) sites to post on the dashboard with their geographic location. GPS coordinates in WGS 84 coordinate system for the dashboard were either directly extracted if provided or approximated from the location mentioned in the source. If a city, county, or country were found testing their wastewater for SARS-CoV-2 without specific sampling sites mentioned, a point was placed near the centroid of the mentioned area tested to associate the testing site with a location. When public dashboards for wastewater testing efforts provided coordinates for their sampled sites, those were downloaded and utilized as site points on the dashboard. The dashboard was usually updated weekly depending on the number of points gathered and submitted.

Although keyword and literature searches are predominantly in English, the dashboard team includes English, French, and Spanish speakers and the dashboard had a broad submission from international stakeholders via the Google form as well as engagement during international webinars. Many researchers in other countries also publish in and post in English.

After the collection of sites, universities, countries, the spatial distribution of wastewater monitoring was analyzed. Countries were sorted based on the World Bank income classifications (high-income, upper middle income, lower middle income, and low income) (World Bank, 2021). ArcGIS Pro 2.6.1 was used to map the number of sites and universities monitoring wastewater for SARS-CoV-2 globally. With a large number of sites and universities monitoring SARS-CoV-2 in the wastewater, the United States was chosen to further classify based on the fifty states and five inhabited territories. The U.S. Centers for Disease Control and Prevention (CDC) rankings based on COVID-19 cases, hospitalization, and deaths were compared to entities without wastewater monitoring for SARS-CoV-2 (CDC, 2021b).

Dashboards were categorized based on their presentation, communication style, and data availability. Results of SARS-CoV-2 testing in wastewater were presented as maps, graphs, a small written description or solely by color (demonstrating an increase or decrease of trend). Dashboard communication style categories were: video, FAQ page, a short written format (less than three paragraphs), longer descriptions (three or more paragraphs), and no form of written communication. The simplicity of the communication was also determined by whether the description given was: (1) technical, more specifics on the science behind SARS-CoV-2 wastewater testing (included information on lab processes), (2) a simpler form of communication that would be understandable to the general public (used general vocabulary to inform as to why wastewater is being used to test for SARS-CoV-2). Dashboards were checked if they provided downloadable data, the file type, and variables available.

3. Results and Discussion

As of March 8th, 2021, the COVIDPoops19 global dashboard for wastewater monitoring of SARS-CoV-2 included 235 universities, 59 dashboards, 1,488 sites in 50 countries. Between September 2020 and March 8th, 2021, there were 60 submissions on the Google form linked to the COVIDPoops19 dashboard. Since the dashboard was published publicly in September 2021, there have been 25,679 visits. The COVIDPoops19 twitter account has acquired over 2,000 followers between May 2020 and March 2021.

Of the 195 countries in the world (U.S. Department of State, 2021), 50 contain wastewater monitoring. Of these 50, 36 (72%) are in high-income countries, 10 (20%) are upper middle income, 6 (12%) are lower middle income, and 0% are low income countries. See Figure 2 for distribution of wastewater monitoring of SARS-CoV-2 globally. Similar to COVID-19 individual testing and Personal Protective Equipment (PPE) (Kavanagh et al., 2020; McMahon et al., 2020) and vaccination efforts (Lancet Commission, 2021), access to wastewater testing is also more widely available in High-Income Countries.

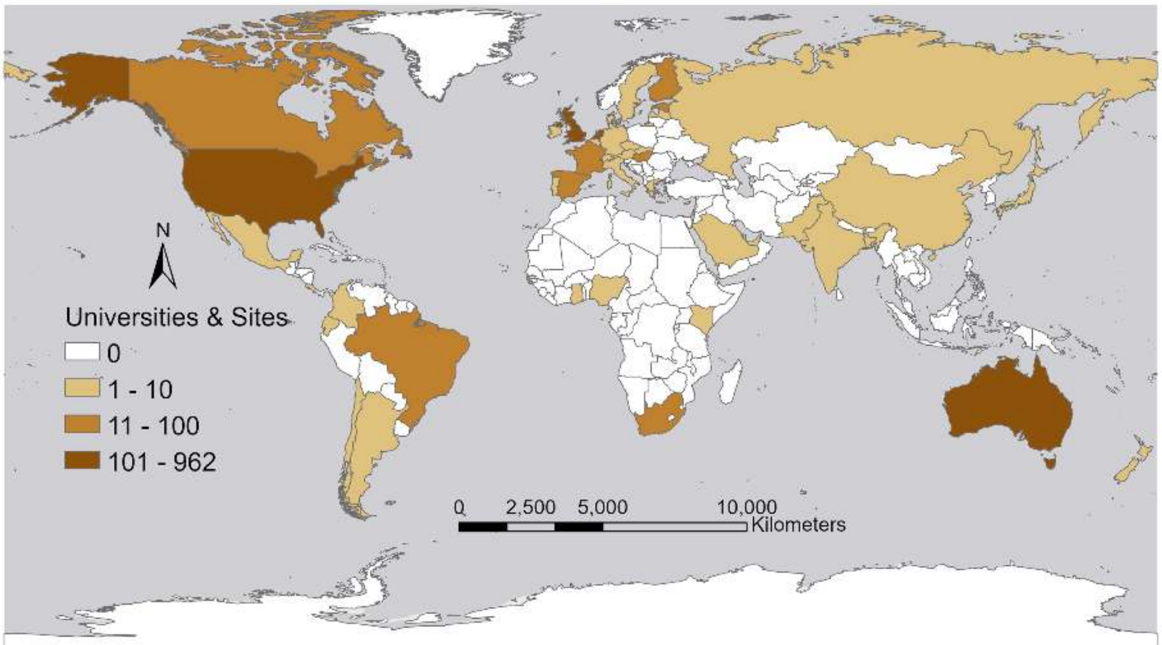

Figure 2: World map with countries using wastewater monitoring of SARS-CoV-2.

The COVIDPoops19 dashboard is extensive but is likely an underestimate of the locations testing wastewater for SARS-CoV-2 RNA because it is limited to publicly available data. Many private companies who are monitoring wastewater for SARS-CoV-2 are limited by what their client(s) (e.g. public health department, municipality, etc.) allow to be shared. For example, Biobot Analytics is a private company that conducts WBE (Biobot, 2020). Biobot has processed wastewater from at least 300 sites in 42 states in the United States (Wiggins, 2020). Some Biobot sites were found and posted from news articles and publicly available dashboards (e.g. Eastern Massachusetts, Chattanooga, Nantucket, Delaware, etc.) (Biobot, 2021a, Biobot, 2021b, Town & Country of Nantucket, MA., 2021, Biobot, 2021) but the COVIDPoops19 dashboard is likely missing other sites. Similarly, universities do not publicly report all the sites they are sampling from.

The United States (U.S.) has the highest number of universities and sites (962) monitoring for SARS-CoV-2 globally. Of the 50 States and five inhabited territories of the USA and the District of Columbia, there is no record of wastewater testing for SARS-CoV-2 RNA in: (1) American Samoa, (2) Guam, (3) Puerto Rico, (4) U.S. Virgin Islands, (5) Northern Mariana Islands, and (6) South Dakota. See Figure 3 for the distribution of testing in the United States.

While the lack of wastewater monitoring may not be directly related to the number of cases and deaths within the state, WBE has potential as an early warning system and to identify hotspots to better target public health measures to prevent further COVID-19 cases (Ahmed et al., 2021). South Dakota has no record of wastewater monitoring for SARS-CoV-2 RNA and is ranked second highest for total cases per 100,000 people and seventh highest for deaths per 100,000 people within the U.S. as of February 15th, 2021 (CDC, 2021b). Iowa had no publicly disclosed wastewater testing until the University of Iowa added testing in February 2021 (University of Iowa, 2021). Iowa ranked eighth in cases per 100,000 people and sixteenth in deaths per 100,000 people in the U.S. (CDC, 2021b). There is no record of wastewater testing for SARS-CoV-2 RNA in any of the inhabited territories within the U.S. However, the U.S. territories all rank in the bottom 10 among U.S. states and territories with the least amount of cases and deaths per 100,000, based on available testing (CDC, 2021).

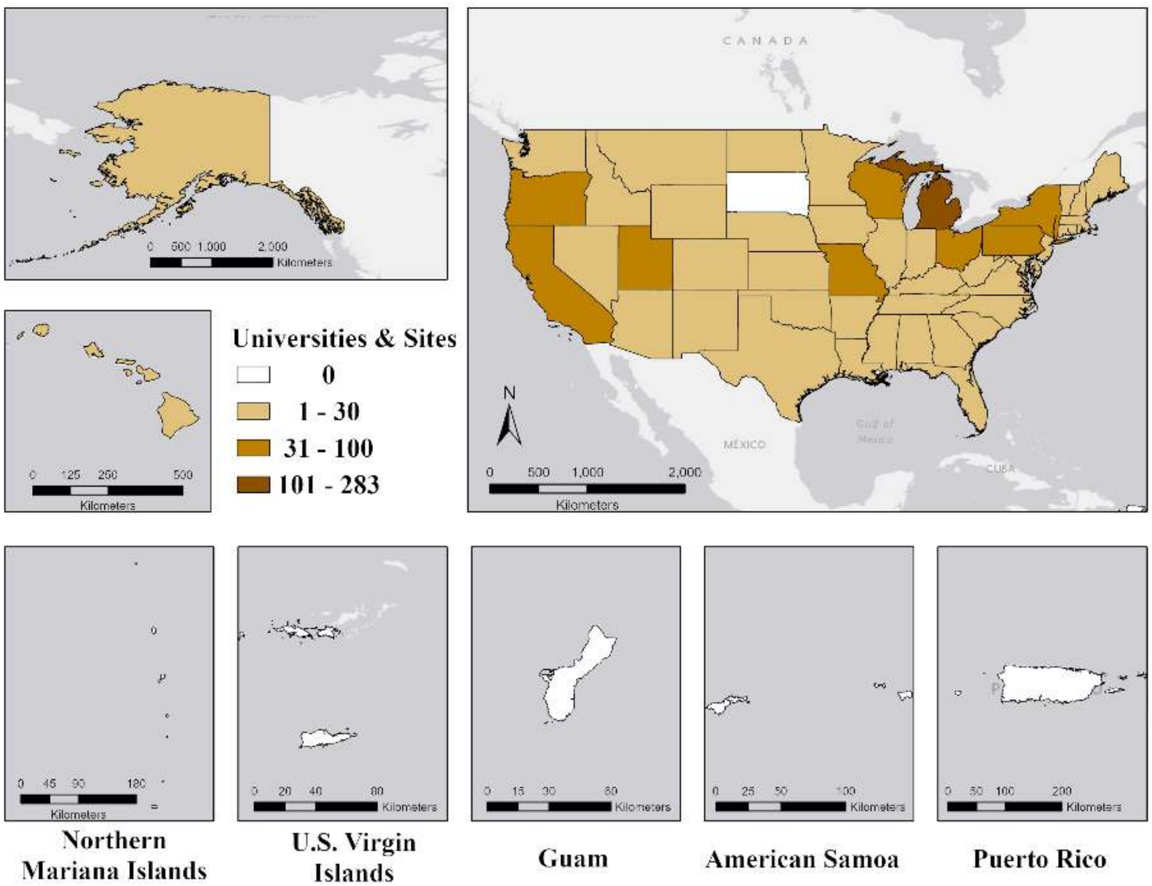

Figure 3: Map of the United States and inhabited territories testing wastewater for SARS-CoV-2 RNA.

Despite over 200 universities, 1,000 sites, and 50 countries with reported wastewater surveillance for SARS-CoV-2, there are a limited number of entities that make their data openly accessible with only 59 publicly available dashboards. Of these 59 dashboards, only eleven have downloadable data for further analysis (see Supporting Information Table 1). Data are downloadable as .csv, .xlsx, .rda, or .pitemx files depending on the dashboard. Typical data include flow rates, collection dates, coordinates, days since sampled, sample types, gene copy information, and if the virus was observed in the sample. Data available and units vary for each dashboard, as there is no visible common data standard followed among the different endeavors.

Fifty-nine dashboards were categorized on how their results were primarily presented. Twenty-eight (47%) presented their dashboards in the form of a map, 28 (47%) used graphs, 2 (3%) solely gave a written description of the results (Erie County, 2021, Lewis and Clark County, 2021), and 1 (2%) presented an image with a color to demonstrate the trend (Indiana Borough, 2021). Fourteen (24%) dashboards used both a graph and a map. Eighteen dashboards (30%) used colors to visually present results.

Fourteen of the 59 dashboards (34%) had no description of the data provided. Of the 45 dashboards that had some form of description, 25 (56%) dashboards used a short written format, 13 (29%) included more than three written paragraphs, nine (20%) included a Frequently Asked Questions (FAQ) page, three (7%) had videos. Five dashboards (13%) used a combination of communication styles. Valencia, Spain had a video and included multiple paragraphs (GoAigua, 2020). New Haven, Connecticut and Bozeman, Montana both had a video and a short written format to describe SARS-CoV-2 testing in wastewater (Yale University Environmental Engineering Program, 2020; Gallatin City-County Health Department, 2021), and the Luxembourg and Missouri dashboards have a short written format and a section with FAQ (Luxembourg Institute of Science and Technology, 2021; Missouri Department of Health and Senior Services, 2021). Lastly, of the dashboards that presented some form of communication, 34 (76%) were written in language that could be understood by the general public, while 11 (24%) had very specific and detailed scientific information. For example, the dashboard used for Valencia, Spain had a simple communication style for a general audience to understand how wastewater can be used as a tool to better understand COVID-19 trends in their area (GoAigua, 2020). In contrast, the dashboard used for Minas Gerais, Brazil went more in-depth with the scientific specifics of the lab results and was categorized as more technical (ANA, 2020).

While offering detailed and technical information about the wastewater testing process/protocol is ideal, it is also important to communicate the benefits of wastewater testing for the general public. For this reason, successful communication styles should include more understandable vocabulary (e.g. less scientific jargon) with links to WBE case studies, while offering links to more detailed information for more technical audiences (e.g. researchers, other public health departments, and municipalities). Additionally, providing a video explanation gives another outlet to reach more visual learners.

It is essential to ensure appropriate public health surveillance systems and open data access in pandemic response (Canadian Water Network, 2020). The Canadian Water Network states, “During a public health emergency, it is imperative that all parties involved in surveillance share data in a timely fashion.” (Canadian Water Network, 2020) Providing open access to data collected from testing wastewater for SARS-CoV-2 RNA, along with effective communication and properly handling sensitive information, can better inform the public which will allow for a collective fight against the COVID-19 pandemic.

Increased access to wastewater testing data could provide other researchers, such as data scientists, the opportunity to further develop algorithms, compare between sites, and better analyze the data to make it more useful to inform public health decisions instead of keeping it internal. An ongoing challenge of WBE is the lack of normalization across datasets. This is a nascent research space with high variability in methods used to collect, process and analyze samples. Increased data sharing may allow for analysis across collection sites and methods to identify which methods work best in High-Income Countries (HIC) and Lower Middle Income Countries (LMIC) settings and should be adopted more widely. Greater open data would also facilitate better collaboration, coordination, and equity analysis. Most testing is concentrated in HICs. However, even within HICs there may be inequity in distribution to high-income, urban areas with less diversity, similar to disparities in individual testing (Hooper et al., 2020) and vaccination (KFF, 2021) in the U.S.

The U.S. National Wastewater Surveillance System (NWSS) currently only allows access to the wastewater data on their internal dashboard to public health departments (CDC, 2021a). The United States Health and Human Services (HHS) recently aimed to test 30% of the U.S. wastewater (genomeweb, 2020). HHS has yet to publicly release the locations where wastewater sampling is ongoing. Researchers, the media, and the general public have no way to determine if wastewater testing is equitably distributed among the 50 states, territories, and low-income, minority, and rural communities.

The United States has an OPEN (Open, Public, Electronic, and Necessary) Government Data Act that mandates federal agencies to make their data open (Data.gov, 2021). Fifty-three other countries that also have open data websites and policies are listed on Data.gov. The European Council prioritized the adoption of Open Science and reusability of research data, promoting FAIR (Findable, Accessible, Interoperable, and Reusable) data principles (Mons et al., 2017). COVID-19 case and death data has been invaluable during the pandemic to inform the public and policies. Wastewater data can be aggregated and de-identified similar to case, hospitalization, and death data to protect private health information. For WBE to be used to its full potential as a public health tool during and after the COVID-19 pandemic, data must be more openly shared with the public and among researchers. Wastewater monitoring and support for dashboard development must also be expanded to lower income countries and areas. Wastewater monitoring will remain important throughout vaccination efforts to monitor for outbreaks (Smith et al., 2021) and can be used to track the spread of variants at larger scales (Martin et al., 2021) only if they show us the data.

Conflict of Interest Disclosure

The authors declare no competing financial interest.

Supporting Information

Table of wastewater dashboards for COVID-19 and whether they included downloadable data.

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