RESEARCH ARTICLE

REVISED Stakeholder Interviews to Inform Best Practice for Public Facing COVID-19 Wastewater Dashboards

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Abstract

Background

Wastewater (WW) -based epidemiology is the detection of pathogens and chemicals from wastewater, typically sewage systems. Its use gained popularity during the COVID-19 pandemic as a rapid and non-invasive way to assess infection prevalence in a population. Public facing dashboards for SARS-CoV-2 were developed in response to the discovery that RNA biomarkers were being shed in faeces before symptoms. However, there is not a standard template or guidance for countries to follow. The aim of this research is to reflect on how currently available dashboards evolved during the pandemic and identify suitable content and rationale from these experiences.

Methods

Interviews were carried out with implementers and users of dashboards for SARS-CoV-2 WW data across Europe and North America. The interviews addressed commonalities and inconsistencies in displaying epidemiological data of SARS-CoV-2, clinical parameters of COVID-19, data on variants, and data transparency.

Results

The thematic analysis identified WW dashboard elements that can facilitate standardization, or at least interoperability. These elements emphasise communication among developers under the same organization, open access for identified stakeholders, and data

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summarized with a time-intensive graphic analysis through normalizing at least by population. Simultaneous communication of clinical surveillance is recommended. More research is needed on flow and faecal indicators for normalization of WW data, and on the analysis and representation of variants.

Discussion

WW dashboard development between 2020-2023 provided a 'real-time' iterative process of data representation, and several recommendations have been identified. Communication of data through dashboards has the potential to support early warning systems for infectious diseases.

Keywords
SARS-CoV-2, COVID-19, wastewater, dashboards, thematic analysis, qualitative, communication

This article is included in the Coronavirus (COVID-19) collection.

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REVISED **Amendments from Version 1**

1) Clarification was provided for some methods, 2) additional quotes were added to support statements, 3) reference to broader design principles were included in Discussion, 4) improved clarity on use of definitions associated with wastewater, 5) additional references included.

Any further responses from the reviewers can be found at the end of the article

Introduction

WW-based epidemiology (WBE) is the detection of pathogens and chemicals from wastewater, typically sewage systems[1]. Indicators of presence/absence, or pathogen quantity are often measured using real-time qPCR, and provide a method for monitoring infection in a population. The basic mechanism behind this is that many infections replicate in the gut and so genetic material can be detected from environmental material with faecal contamination, especially within sewers. While WW data and analysis continues to be a developing field of public health, it has been used to detect pathogens since at least the 1930s[2]. The best known 'use-case' is in polio eradication, where poliovirus can be detected in sewage from infected communities, and if local transmission is thought probable, timely vaccination responses can prevent poliomyelitis cases, such as that reported in Israel in 2013[3].

Today, WBE is being applied to detect levels of illicit drug use, pharmaceutical consumption, antimicrobial resistant microbes, chemical exposures, and infectious diseases[4–6]. WW data can provide additional critical information that can be used in conjunction with other methods of surveillance, such as clinical surveillance. A concern with exclusively relying on clinical records for surveillance is that the data collected from health centres may be underreported and biased, and will not detect asymptomatic infections[7]. A promise afforded by WBE is that when reported and analysed with clinical data, researchers are provided with health information that *fills in the gaps* regarding how a virus moves through the population while also analysing variants.

In April of 2020 it was found that SARS-CoV-2 (the causative agent of COVID-19) could be detected in the stool of active COVID-19 cases[8]. In fact, RNA biomarkers of SARS-CoV-2 were being shed in faeces days before COVID-19 symptoms developed. Researchers in the Netherlands reported the first example of WW tracking that same April[9]. Several studies have illustrated a positive correlation of viral concentration in WW with the number of SARS-CoV-2 cases, and many settings have established WBE to approximate the disease burden of COVID-19 in communities[9–11]. This development has been especially useful while health systems were overwhelmed, and documented examples of public health actions based on WW data are now emerging[11–15].

During the COVID-19 pandemic there was a demand for countries to rapidly develop and communicate surveillance data via online dashboards[16]. Dashboards are a public facing display, typically an online webpage, that provides a data summary for stakeholders. While many disease-specific[17,18] and general dashboards[19] existed prior to the COVID-19 pandemic, engagement with dashboards was typically limited to subject experts. That COVID-19 was an pandemic which affected everyone and was a rapidly evolving situation, meant that there was a demand for real-time information that would indicate community spread and contextualise mitigating actions[20]. With reference to dashboards designed specifically for WW data, dashboards were developed without a unifying organizing body and there was no template, leading to variability in reported results, data standards, meta data requirements, and quality assurance. An analysis of dashboards present on the COVIDPoops19 site emphasised the distinctions: in 2022, 49% of the dashboards represented data in the form of graphs while 48% presented maps[21]. How data is represented, and variabilities in data visualisations, may shape how evidence comes to be known and understood among different stakeholders, both among the scientific community, policy makers and community members. The public communication of science in the COVID-19 pandemic was at times characterised by multiple and contested interpretations of visually represented data, emphasising the complexities of translating data in early warning efforts and emergencies[22]. The swift implementation of WW tracking may have caused uncertainties in the reliability of the data. As argued by Rhodes and Lancaster[23], the methods of presenting data may be as important as the data itself and can thus be considered as a form of evidence making. Consequently, an understanding of how dashboards were developed is an important part of public health.

The aim of this research is to reflect on how currently available dashboards evolved during the pandemic to understand stakeholder and implementer perspectives on the preferred content and rationale for SARS-CoV-2 WW dashboards. Further, we are interested specifically in whether such preferences align in ways which enable the standardization of SARS-CoV-2 WW dashboards.

Methods

Ethics

Written informed consent was obtained from all participants as part of study sign up, and all analyses were performed on anonymized data. This study was approved by the ethics committee of the London School of Hygiene and Tropical Medicine (approval number: 28778, granted 15th June 2023).

Research on a sample of online SARS-CoV-2 WW dashboards was conducted to develop research themes and interview questions. Both the EU Sewage Sentinel System for European Dashboards[24] and COVIDPoops19[25] were used to identify specific WW dashboards. These websites were put together by research stakeholders to act as a hub for stakeholders view independent dashboards. Our initial review of dashboards focused on the granularity and presentation of WW data and the inclusion of clinical data. This gave

rise to questioning how and what epidemiological data should be hierarchized in dashboards. We therefore proposed a qualitative interview study of stakeholder perspectives on this question.

Participants were recruited from organizations with dashboards included in the COVIDPoops website, through informal networks, and via social media. We adopted a purposive sampling approach to include a variety of backgrounds and forms of expertise, including among researchers, health providers, public health workers, government employees, and academics across Europe and North America. There were no prior relationships with the study participants and the interviewer.

Participants were asked to fill out a consent form, including questions on demographics and basic information to help with interviews. Demographic questions included gender, country of work, country where WW data are collected. To help with interviews, we requested a link to the dashboard used in their country of work, their profession, how long they have worked in this role, and if they identified as a Developer/Implementer of dashboards or as a User/Stakeholder. The interviews were conducted over Zoom and were transcribed by a transcribing software (Zoom v 5.16.0). In preparation, a pilot interview was carried out, in which it was identified that a PowerPoint presentation would be useful to guide the interviewees through the questions.

Interviews consisted of a 30–45-minute semi-structured interview, carried out throughout August 2023 by DM, who was carrying out this study as part of her MSc, and this was explained to all study participants. Only the interviewer and interviewee were present at the call. The interview guide was separated into three sections:

1) Participants were asked about the experience and process of creating the dashboard. The question was designed to explore how often dashboards were accessed and analyse the strengths/weaknesses of current design.

2) Participants were asked how epidemiological information should be hierarchized for the purpose of standardization. The second part of this question focused on what WW units are preferred to represent RNA copies of SARS-CoV-2.

3) Participants were asked about the content that should be included alongside WW data and the transparency of this data. Participants were asked for insights on clinical data and variant surveillance, how accessible dashboards should be and for whom.

Following the transcription of the audio, the transcriptions were uploaded into NVivo, a qualitative coding software. Codes were developed based on the Braun and Clarke Thematic Analysis[26]. More specifically, a theoretical thematic approach was used to code sections that were relevant to the original objectives, and an open coding process was used to allow for modification. Transcripts were not returned to the interviewee for comment.

The original parent codes included: experience with dashboards, process of development, gaps of knowledge regarding the content within a dashboard, epidemiological hierarchization of the graphic, and epidemiological hierarchization of WW units of measurement. Within these parent codes, sub sections were created based on the frequency and importance of a section.

Results

Demographics of study participants

A total of 32 people were contacted via email, with 14 interviews conducted, resulting in a response rate of 43.8%. Reasons for non-participation were non-response or not being able to participate (interviews took place in August, a vacation period). No repeat interviews were required. Participants were based across Europe and North America, and worked in 10 countries, but collected WW data from 15 countries, including within Africa and Asia. Seven participants identified as both a User/Stakeholder and Developer/Implementer while five identified as just a Developer/Implementer and 2 as just a User/Stakeholder (Table 1). Participants had worked with WW data for an average of 12 years.

There were three identified themes from the coding process (Table 2): the development of WW dashboards, the content of WW dashboards, and the challenges of implementation.

Theme 1: Development of WW dashboards

1.1 SARS-CoV-2 experiences

While some countries did not begin investing in WW tracking until the COVID-19 pandemic many others already had WW tracking in place and were able to transition their equipment from a previous different target to SARS-CoV-2. Only four participants mentioned WW tracking that were already conducted in their countries, with applications including polio, illicit drug use, faecal contamination of bathing waters, and specific bacterial/viral projects conducted through academic institutions. Eight participants did not start working with projects focused on WW tracking until 2020. One participant mentioned that while dashboards had existed pre-COVID-19, *"…the technical reason for why we didn't develop more, was that we didn't have a good reason for deploying them*". In fact, when the Scottish government decided to conduct routine monitoring of SARS-CoV-2 in June of 2020 this was the first national surveillance system for a pathogen that had been done independently of the UK.

1.2 Strengths of WW dashboards

During the initial days of the pandemic, WW tracking systems were put together very quickly. A developer explained that,

> "*The WW surveillance was novel because while it did exist before for polio or other applications, it was novel in its bipartisan approach because it brought in research and academia".* (3)

Table 1. Demographics of study participants.

Country of Work	Participants	Interaction with WW dashboards			Mean years worked with WW data
		User/Stakeholder	Developer/Implementer	Both	
Austria	2	0	0	2	2
Finland	1	0	1	0	20
Ireland	2	0	1	1	14
Italy	1	0	0	1	25
Netherlands	1	1	0	0	21
Norway	1	0	1	0	3
United Kingdom	4	1	1	2	7
United States of America	2	0	1	1	3
Total	**14**	**2**	**5**	**7**	**12**

Table 2. Themes from the Braun and Clarke Thematic Analysis coding process.

Key Theme Area	Definition
1. Development of Wastewater Dashboards	**The process of developing WW dashboards from the initial start of the pandemic to today.**
	1.1 SARS-CoV-2 experiences
	1.2 Strengths of WW dashboards
	1.3 Identifying stakeholders
	1.4 Process of developing Dashboards
	1.5 Current Use
	1.6 Termination of program or future applications
2. Content of Wastewater Dashboards	**Stakeholder preference and reasoning for sections within a WW dashboard.**
	2.1 Epidemiological hierarchization of graphic
	2.2 Epidemiological hierarchization of units
	2.3 Clinical surveillance
	2.4 Variant surveillance
	2.5 Data transparency
3. Challenges of Implementation	**The challenges behind adoption and implementation of WW dashboards.**
	3.1 Communication and Trust
	3.2 Acceptability
	3.3 Ethic concerns
	3.4 Security concerns

One participant described how their team discussed and promptly executed initial research without securing funding. These unprecedented circumstances were new territory for countries and a stakeholder described it as if "*Everybody was trying to invent the wheel*", and many others expressed that there were no standardization or protocols for countries

to follow. Nevertheless, experts were communicating between countries, and the European Commission supported member states. Two participants working in government appointed health roles shared that until the intervention of the EU many governments were not interested in WW epidemiology.

1.3 Identifying stakeholders

The first step that developers took when designing dashboards was to identify the audience and stakeholders. For example, an epidemiologist might prefer exportable data to create models themselves, while government/health policy makers require a plain explanation of the data. All participants reported that the dashboards were not originally designed for the general audience, and instead for professionals such as national health security and safety agencies, local health authorities, researchers, and policy makers. Initially WW tracking was driven by academics, but as the pandemic continued public health officials, policy makers and the public became increasingly interested in WW tracking, meaning that the audience widened. Additionally, initiatives such as the EU WISH (https://www.eu-wish.eu/) were developed to enable collaboration on cross order health threats by improving disease surveillance. One participant commented, "*I think [EU WISH is] really good because it's the public health institutes that are that are involved in this. And I said before at the start of the pandemic and wastewater surveillance, it was really driven by academics. And there's a disconnect. So I think this will be really good because it is the public health institutes plus their affiliated academic partners*."

1.4 Dashboard development

All participants expressed the common theme of dashboard creation following an iterative process. As one developer stated, "*The dashboard had to be correct in all regards so to reduce the corruption, or the possibility for corruption*". Each developer explained that the ideal process was done in stages with user feedback present at each stage, and four developers credited team collaboration for success. Only one developer mentioned the use of specific guidelines that were followed, and this was the Government Design Principles[27]. In brief, these are eleven principles that have been developed for UK governmental services where the user and their needs are identified, any project should be simple, translatable, easy to use, accessible, and meets the needs of the user. Two developers mentioned using the ONS coronavirus survey carried out in the UK as an exemplar for data communication[28]. One user expressed that their dashboard could not succeed until statistical support was sought out for analysis of the data. Two developers stated that a major improvement was simply having more data points, one of them stated, *"…we first only had qualitative data detected and not detected, and later on we were able to solve for trends and quantitative results*".

Challenges were encountered during dashboard development, such as balancing data privacy and clarity, "*What should be the resolution? So the provinces that was in the end allowed, but not the communities*." The presentation of data evolved during the pandemic, alongside there being more data to display. Several participants commented that explanations of the data, and guides for users of the dashboards were included in the later stages,

> "*There are more information now than at the beginning, more data points, more information in general [and] more explanations. ...What the data means and how to use the data*" (1)

1.5 Current use

As users were engaging with the data, use varied from checking the dashboards weekly, to not at all. Three users explained that they rely more on weekly reports provided to health officials instead of checking the physical dashboard. A stakeholder explained that the Center for Disease Control (USA) dashboard provides automated updates for users so even if the dashboard is not checked daily, it will still contact stakeholders. Provision of dashboards to a wide audience also presented research opportunities,

> "*…there are so many interesting people who are starting to ask questions, and these questions are helping us to see and consider different things. Having this feedback helps a lot, especially in the beginning. When we were developing, no one had done it prior*" (8)

1.6 Future use

As of August 2023, some countries have either started to switch off their dashboards, terminate programs, or have taken a hiatus in the use of WBE. In fact, a couple of weeks before the interviews, the Welsh government discontinued the development of the dashboard and stopped clinical surveillance of SARS-CoV-2 (although some moderate data collection has since resumed). The discontinuation of SARS-CoV-2 WW data collection has encouraged researchers to think beyond COVID-19, for example by expanding towards a multi pathogen surveillance system including seasonal respiratory and gastroenteritis diseases[29,30], as well as interest in monitoring for antimicrobial resistance.

Theme 2: Content of WW dashboards

2.1 Presentation of WW data and associated metrics

When asked about how users would prioritise graphical illustration of epidemiological data, eight stakeholders explained that the dashboard of the country that they worked in favoured virus quantification over time. These same stakeholders considered this the most valuable information to include. The most popular reason for this preference was that they valued seeing how the virus load changed over time. One user stated that,

> "*I'd say most users derived most benefit from looking at it in a line graph and looking at the fluctuations in the data…It was easier to tell a story with the line graph"*. (2)

The only challenge described was that sometimes line graph representations can be over too much time. One user expressed that,

> "*The problem of this graph for me at least, is that it is for a very long time, so most often the stakeholders are interested in the last couple of weeks"*. (4)

Only two participants preferred the use of a geographical map. The reason for the geographic preference was that these stakeholders preferred to look at the bigger picture, a stakeholder expressed that, "*… we have an eagle's eye view. We look from the top, so, we are interested in the occurrence of the presence of the virus*". Although it was common for participants to compliment the design of the map, they admitted that it was not realistic globally, a stakeholder explained that, "*It depends on the infrastructure that is there, in the European regions, there's nice coverage of networks, but that is not the case in all locations of the world*". For many countries the information that needs to be included in a geographical display is either not public data or not part of a public system. In fact, many challenges were expressed about the design of a map and the most common being that the data changed too much depending on population level leading to changing boundaries. It is very difficult to show this data in one graphic especially in large countries, a developer explained that,

> "*Our problem with the map is that in […] we have a huge diversity in the size of our treatment plants. So, they range from serving from 1000 people up to 5 million and when you have that kind of diversity these numbers are no longer comparable"*. (9)

When stakeholders were asked about measuring the units of SARS-CoV-2 in WW, even with varying levels of expertise, every stakeholder emphasized the importance of normalizing the data ie. at least accounting for population size in the units of measurement reported. Accounting for the population served by the sampling location enables comparison of data between locations, assuming that the methods of data collection are identical. Thus, each of the stakeholders ranked the SARS-CoV-2 gc/L as the lowest priority, and one developer stated that, "*I wouldn't be very comfortable showing non normalized data at all, because of misinterpretation*". Five stakeholders identified normalizing by population as their top priority, and in fact it was the most common unit used throughout each of the dashboards. However, it was identified as a challenge when the population is not mapped against a sewer shed and it might not work with diverse or temporally changing population sizes. After normalizing by population, stakeholders preferred normalizing by WW flow. This was identified as beneficial because it corrects for rainfall and other contaminants in sewer systems. Next, it was preferred to normalize by a faecal indicator. However, there were mixed responses on the reliability of this method. While three stakeholders prioritized this unit in their dashboards, others countered the benefits and one stated that,

> "*There are several options for these [faecal] indicators, and the current challenge is that there is no global gold standard. So that it seems that any indicator might be good, but there are different options that different groups are using and that's the main challenge at this point.*" (4)

another stakeholder said,

> "*We know that correction improves the statistical scattering, and it compensates, but none of the current faecal indicators are really capturing the picture as it should, presumably because you may need a whole range of faecal indicators to cover it"*. (3)

Nevertheless, the most common faecal indicators mentioned were the pepper mild mottle virus (PMMOV), ammonia, and crAssphage. Lastly, two stakeholders valued the importance of the qualitative metric. One of these stakeholders expressed why they chose this method by explaining,

> "*It is robust enough to be interpretable overtime at different states, whether concentrations are high or low. And it's interpretable across our jurisdictions, so that's what we use for our sort of initial like just how the jurisdiction is doing? qualitative is the answer"*. (9)

One developer explained that their dashboard compares by percent change metrics instead to discourage comparisons among sites.

2.3 Clinical surveillance

The question of including clinical surveillance in dashboards was unanimously described as valuable. In fact, the only reason that it was not included in certain dashboards was due to a lack of funding. Most stakeholders claimed that clinical surveillance aided in validating the WW data and would prefer to be able to plot the case data alongside. In fact, one participant emphasized the fact that,

> "*WW based surveillance is always additional information. Don't use it stand alone. I mean, even if you have a dashboard, it doesn't mean it is the solution to all your problems…the first rule in [WBE], it is always supplementary"*. (3)

Nevertheless, it was frequently stated that under-reporting from clinical surveillance has increased in recent months, this has resulted in WW data becoming the early warning system it was originally proposed to be, and in some circumstances the sole source of information.

2.4 Variant surveillance

When users were asked about their opinion on variant surveillance, users unanimously mentioned the importance of conducting the research, however, they were divided on including this information on a dashboard. The answers were dependent on identifying the audience of the dashboards. Nine users prioritized the importance of it, while five expressed concerns with including this type of data. Many users shared that they thought variant data was more academic than informative, others claimed that genomic sequencing is not advanced enough to validate the data, and others

said that they are not sure about including this data. One developer explained their hesitancy by explaining, "*You're not treated any differently based on what variant you have. Your doctor's making the same decisions. We're recommending the same protective actions*." Regardless of these reservations, every stakeholder in support of including variant surveillance emphasized the importance of communicating the information to the users in an accessible language to avoid confusion.

2.5 Data transparency

The topic of open dashboards versus restricted dashboards had varied opinions among participants. Overall, stakeholders emphasized the importance of having open data transparency for everyone. It was frequently mentioned across interviews that if taxpayers are paying for the program, then they should have access to the data. Although no stakeholder explicitly mentioned restricting data, many stakeholders described having to be cautious with sharing data openly. Some stakeholders cited government hesitancy and confidentially concerns and explained that they have restrictions with sample size. For example, a stakeholder explained,

> "*We have a certain rule that there needs to be enough people in these WW sample locations. Usually, it is more than 20,000 persons before we publish the data. Also, if the case numbers are lower than five cases per community, we are not publishing those small number of cases"*. (4)

Similarly, in the European dashboard the site is restricted because of data agreements with member states. In this case the data provider remains the owner of the data. One stakeholder explained that the raw data is restricted because "*You don't want someone taking your data and doing open manuscript and publishing before you actually get the chance to do it*". Two stakeholders mentioned having to separate the data into an internal dashboard and a public dashboard. The internal dashboard included a data download option and identifiable information for specific WW samples sites. In fact, a developer explained this separation by stating, "*One of the big failings initially was we tried to make a website that would work for everyone, and it worked for no one*". Regardless of the current dashboard status, most of these data transparency perspectives can be summarized by the following comparison stated by a stakeholder,

> "*In case of SpaceX, they give the public the information they need to understand what's going on, and then there's a lot of technical data underneath and unless you're an expert, it doesn't really inform you at all. Or even worse, it might muddle the waters"*. (7)

Theme 3: Challenges of the implementation of dashboards

3.1 Communication and trust

The main challenge identified across every interview was minimizing the risk of misinterpretation. Developers needed to report the data in a language that everyone who had access to the dashboard could understand, and a developer stated that,

> "*Not everybody's going to have expertise in WW data interpretation. So even when sharing it within public health it needs to be clear, and even when communicating to our senior management, we need to make everything very clear as to what the signals are saying, and what we can't say from the signals"*. (5)

One stakeholder explained that dashboards have global interest however, for a long time their dashboard was only in the national language and translations were included to meet the demand of international interest. Another communication challenge was updating dashboards. Dashboards need to explain a potential lag in data reporting or other delays, and one developer stated that "*We'll occasionally get questions from health departments about why our internal dashboard shows one thing, while the COVID Data tracker is showing something different*".

A concern with communicating data based on geographical locations is an issue of provenance, if that catchment falls over multiple different health boards or different geographies of interest, the information is diluted which limits interpretation. The representativeness of a site for a specific locality and the coverage achieved was difficult to communicate for many audiences. A developer stated that,

> "*People will look at this measure and say in my big, 4 million town, my WW is currently measuring 100,000 particles per 100,000 people. And in this tiny little town, it's also 100,000 per 100,000 people, what are they doing wrong?"*. (9)

Interest from clinicians or in public health specialists was challenging in some settings. A developer explained this hesitancy by stating that "*This happens every time you have something new and innovative...you have to prove the value*".

3.2 Acceptability

Initial development of WBE perhaps lacked engagement with people working in public health. One stakeholder stated that, "*The link or collaboration with public health was missing and very few of the people at the monthly meetings were from public health backgrounds*". Instead, many of the original stakeholders were people with environmental backgrounds and many participants claimed that these two worlds were not communicating effectively. A common theme identified was that WBE only works if the health sector is the implementor. This theory was exemplified by a stakeholder stating that, "*The WW people, they are very helpful, but they are scared that they have to do the job, so in other words that they would have to pay…*", suggesting that there is a reluctance for those involved in WW tracking to directly pay for the tracking itself.

In the case of acceptability many stakeholders explained that there was discourse between clinical and WW teams,

and one implementor stated "*There is also a lobby of the medical sector, who want to maintain their unique position in society for doing disease surveillance*". Overall, stakeholders mentioned that initially the health sector was not willing to accept this different type of surveillance. A stakeholder explained their frustration by claiming that, "*There are too few doctors anyways and they don't have time, and they don't need to have this bureaucratic burden...This additional burden*".

During the pandemic many practitioners were not utilizing dashboards because they did not understand what dashboards added to their practice. A stakeholder explained that the practitioner's perspective was that,

> *"I already know there's COVID here and I already know what's going on, how is knowing that going to help? and that's not untrue, for someone in a hospital, I don't know that they need to include WW as part of their thinking and diagnosis".* (9)

While that perspective was for COVID it was stated that as WW tracking moves to other pathogens the perspective of WBE and dashboards may change because of the potential to inform clinical care.

3.3 Ethical and security concerns

A common theme across the interviews was that with WW sequencing individual cases should not be identifiable, a developer stated that,

> "*This information can be abused very easily, so the decision of what goes to the public and how it goes to the public, and how you're communicating it is a very sensitive one, you have to protect vulnerable groups".* (3)

Privacy concerns were stated to be more of an issue with small catchment areas such as with university monitoring.

In the United States, since 9/11 it was reported that sewerage systems have been identified as a potential target of a biothreat. As a result, geolocated data is considered a privacy concern, potentially preventing WW information being public data. Another stakeholder specified that there are legal implications behind releasing WW data, for instance "*Who owns that WW and consequently the information encoded?*" The conclusions that can be drawn from WW are advanced enough to be able to infer health-related risks, and stakeholders expressed concern that interest from the private sector could affect life insurance or healthcare insurance.

Discussion

WW dashboards for SARS-CoV-2 became an integral part of communicating information during the COVID-19 pandemic, and as individual testing reduces in frequency, WW dashboards have become the only regularly updated information on COVID-19 in many countries. To our knowledge this is the first attempt to interview developers and stakeholders of WW dashboards for COVID-19. We identified that the use of WW dashboards were in many cases unprecedented and so much was being learnt during the development process. The intended audience for dashboards were stakeholders involved in public health across a wide spectrum, where viewing time trends was the most useful output. While dashboards were not initially intended for a general audience, it became apparent that the public were broadly interested in the information displayed. A recognised challenge is identifying the most appropriate units of virus quantification for WW data, as there is currently no consensus on the minimum data required. Appropriate methods for flow normalization and accounting for different measurement methods are needed to improve interpretation of time trends and to support comparison across multiple sites and locations.

From a broader infectious disease surveillance perspective, the use of and reflections about dashboard design and development expanded during the COVID-19 pandemic. Concurrently, several reviews have provided insight on dashboard design principles[31–34]: considering aims and target users, appropriate content, interface, data analysis and presentation types and infrastructure. These broad principles align well with the themes identified in the current study. It was clear that the principles for WW dashboards evolved during a relatively short period of time, for example focussing initially on displaying information for policy makers and gradually expanding the intended audience and the need for data sharing. We also identified some themes not included in the broader design principles that were specific to data generated for WW.

Innovation and experimentation

The WW tracking experience that countries had before the start of the SARS-CoV-2 pandemic impacted not only how quickly dashboards were developed but also the reliability and acceptability by policy makers. We found that until governmental bodies were convinced that WW tracking could be a valuable method many academic institutions were operating with their own resources. Even if funding was provided, researchers were operating on temporary support because the duration of the pandemic was unknown. The methods of data collection and the metrics included within these dashboards were fully dependent on the resources available to these teams. The lack of resources may have contributed to methodology gaps in sampling and analysis of WW data. Looking forward, we note that continued funding for infectious disease monitoring using WW varies across settings, with considerable investments in the USA[35] and the European Union[24], and an uncertain funding environment from charitable and governmental research funding bodies. Both the collection and presentation of WW data are important to improve and refine, both for endemic diseases and in advance of the next pandemic.

Data presentation

The data displayed on a dashboard is dependent on the question that stakeholders are seeking to answer, which may be stakeholder dependent. However, there was a strong preference to observe trends in time along with comparisons within a local and/or national area. The second preference for display

is through a geographical map. This graphic is dependent on the availability of catchment area data, how willing a country is to show sewer-catchment sites and the limits/boundaries of these systems. This information is crucial for policy makers that are interested in comparing the presence and intensity of the virus to other regions. There is a tension in the detail of information provided: on the one hand providing dashboards with up-to-date granular detail of infection trends has been described as a form of democratisation where failures in the social safety net can be seen and addressed[36], and in this study the open data approach facilitated innovation, and on the other hand this granular detail may be seen by some as a security risk and could have implications for healthcare access. Community, stakeholder and policy engagement is required to decide if the democratisation of data outweighs the perceived risks of making data available. As we gave interviewees a preference from just two options, we may have been over-simplistic in our questioning – additional variations in display options could give further granularity on how best to visualise information.

Even though stakeholders prioritize normalization of units, the specific factor of normalization is dependent on the data collected, and the technology available. Normalizing by population is recommended to compare across sites with differing catchment populations[37]. In some areas the size of the population fluctuates and the amount that the population travels (in and out of a catchment area) may affect the interpretation and requires methodological development. Normalizing by WW flow can be important in areas affected by heavy rainfall, or accounting for the effects of industrialisation, but again the precise data requirements and methods available to account for this require development and is an ongoing area of research. These conclusions assume that methods for data collection are identical across sites – a further challenge, beyond the scope of this study, is comparisons between data where methods differ.

If available, clinical surveillance is considered by the interviewees to be crucial to include in dashboards, and supports conclusions made elsewhere[37]. Clinical surveillance may include the number of cases, deaths, hospitalization, etc., which on their own will underestimate community burden or be less responsive to changes in incidence. Having both clinical and WW data, summarised and explained in an appropriate manner can provide a more informative appraisal of community burden which can be useful for departments of public health and have aided departments in communicating risks and preventive actions. However, if there is intense and frequent clinical sampling occurring in a population, WW data will show the exact same conclusions. As a result, WBE may not be an early warning system unless there is a significant uncertainty in clinical sampling or delays in accessing complete clinical data. Clinical data was less likely to be displayed on dashboards, due resource constraints while developing dashboards. Considerable support for the user would be required to aid interpretation of dashboards containing both information and should be the subject of future research.

The inclusion of SARS-CoV-2 variant surveillance is important only if it will influence health policy changes or clinical practice. For example, detection of new variants could indicate importation and emergence. Examples of where this may be epidemiologically important are if the variant corresponds to vaccine escape, if the community has a very low incidence (such as seen in Australia in 2020), or if variants indicate chronic carriage. These insights could offer information that changes a health officers' response or clinical practice, but concrete examples are currently limited. One overview from the USA provides some examples[34]. The interview participants expressed that while variant data is valuable, the information is perhaps more academic, although early indication of variants with additional vaccine resistance would be useful to know. The risk of misinterpreting variant analysis due to lack of understanding can be problematic, especially in public facing dashboards, and suitable guidance for data interpretation is needed.

Implications

From the three themes analysed in the present study certain recommendations can be made to facilitate development of dashboards that are interoperable. Access to displayed data on the dashboard should not be restricted and should ideally be openly accessible. The preferred time-intensive graphic needs to represent a pre-determined time, focussing on recent weeks. Based on all the analysed factors that may influence geographical representation the spatial design may not be practical currently, especially if there are concerns around security and identifiable factors that are dependent on sewer-catchment locations. However, if stakeholders regard geographical comparisons as important, investments should be made to develop a way forward that considers ethical and security concerns. Clinical surveillance should be included in a dashboard, especially because WW is still classified as supplementary to this data. Similarly, there needs to be more research done with variant surveillance because there remains hesitancy around the value of providing health policy makers with this data. Standardization of dashboards may not necessarily be a research or public health priority. Instead, evaluation of approaches helps to establish best practice, which may of course result in more uniformity is dashboards, but allows for innovation and adaptation.

A strength of the qualitative approach adopted in this study is the generation of data on the processes which shaped the development of dashboards in practice. This allows us to see the emergent and iterative nature of the innovation, as well as how the data translations afforded by different dashboards are subject to multiple interpretations on account of their data and use contexts. Qualitative interviews are inevitably oriented to the generation of accounts that are situated in their specific local contexts, and thus may not have generalisability beyond these and the perspectives of the

participants involved. In our study, interviews have generated findings of generic value when considering to what extent standardisation is possible and feasible when translating WW analyses into data presented via dashboards. A limitation of this study is that the initial coding of transcribed interview data informing the discussion of analytical themes were generated by one person (DM). As a rapid response study to an intervention development, the study was inevitably limited in its sample size and recruitment potential, and the purposive sampling may limit the representativeness of the findings. The participants of this study are all from high-resource settings in Europe and the USA whereas the WW tracking has utility across all settings. This bias is largely due to a majority (at the time of the study) of WW dashboards being for sites in high-resource settings and the purposive sampling led to a bias towards dashboards from Europe. Further research using a more representative sampling technique would be invaluable to determine whether dashboards differ in other settings, and the potential reasons for this.

This study provides insight on how dashboards were developed during an acute period of a pandemic, and highlights best practice that were developed along the way. The varying experience of research groups and the initial reactions of governing bodies during the early days of the COVID-19 pandemic impacted the development of SARS-CoV-2 WW dashboards. Although in the beginning countries encountered varying degrees of challenges, today countries across Europe and North America remain focused on improving the future of WBE.

Data availability

Underlying data

The interview data generated and analysed during the current study cannot be sufficiently de-identified and therefore cannot be made publicly available, due to ethical considerations.

Extended data

Zenodo: Stakeholder Interviews to Inform Best Practice for Public Facing COVID-19 Wastewater Dashboards

https://zenodo.org/doi/10.5281/zenodo.11031718[38]

This project contains the following extended data:

A1 Interview Questions WW Dashboards.docx

Reporting guidelines

We adhere to the COREQ checklist for qualitative research, which are available via Zenodo (https://zenodo.org/doi/10.5281/zenodo.11031787)[39].

Acknowledgements

This project was undertaken as part of MSc study at the London School of Hygiene and Tropical Medicine in 2022–23. The authors are very grateful to the 14 participants that were willing to be interviewed and take time out of their busy schedules.

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Open Peer Review

Current Peer Review Status: ? ?

Version 1

Reviewer Report 09 October 2024

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Colleen Naughton
University of California Merced, Merced, California, USA

Dear Authors,

The manuscript entitled “Stakeholder Interviews to Inform Best Practice for Public Facing COVID-19 Wastewater Dashboards” reviews dashboards from Europe and the United States and those involved with them. The manuscript documents an important qualitative perspective and origin of these dashboards during the challenging times of the pandemic to learn from. The study did focus on more High Income Country regions though one dashboard had data from other regions so this is a limited perspective.
I appreciated the quotes and qualitative perspective from the manuscript. The manuscript could benefit from some further literature review and citations. I have some major, followed by minor comments.

MAJOR COMMENTS:

1. The authors used the COVIDPoops19 dashboard to find dashboards for their study and limited their selection to The United States and Europe. There were/are many dashboards in South America, one in South Africa, some in Asia, Canada, etc. Though there are more dashboards in the United States and Europe, it isn’t that there are not a lot of examples elsewhere. The authors should more clearly justify their focus on the U.S. and Europe and state the limitations of this perspective and recommend for similar analysis in other regions.
2. The manuscript makes a good point about the lack of consistency between presentation styles and units. There is a publication that reviewed 127 dashboards more quantitatively and found 96 different units of measure among other results that should be cited. https://iwaponline.com/jwh/article/21/5/615/94622/Online-dashboards-for-SARS-CoV-2-wastewater-data
3. There is a variety of terminology used for the method in the manuscript: Wastewater Based Epidemiology (WBE), Wastewater Surveillance, Environmental Surveillance, etc. Be more consistent or define in the beginning the different terms since in the interviews, the informants may have used various terminology. Also, the definition of WBE in the beginning

is more than just detection of pathogens (that can be done to assess wastewater treatment technology effectiveness), but usually more at the influent and for public health applications. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8499728/

4. 4th paragraph of the introduction should use “pandemic” and not “epidemic” when referring to COVID-19.
5. Last paragraph of Theme 1, it is stated that “many” countries have started to switch off their dashboards, terminate programs, or taken a hiatus in the use of WBE. Through COVIDPoops19, there are still many dashboards available though there is some drop off or change. Please change this to “some” unless you have more examples.
6. The authors had interviewers select their top preference for a number of different options but did not state in the methods which options were given (or can provide in supplementary information). Also, there can be more than one option included on dashboards. For example, maps can be a good complement to line data or a way to select line data. Shorter time period data can be good for recent trends but can also distort current trends and it is also good to have longer term data to compare the current data to past waves (you may want to adjust such a strong recommendation in implications for only shorter term data and overall based on the sample size of respondents).
7. 2.4 Variant surveillance and other mentions of variant inclusion on dashboards- Note that medical treatment can vary based on variant with certain types of mono-clonal antibodies that are only effective for certain strains. Mostly they are treated the same but not always the case. Variant monitoring was very useful at the beginning of the pandemic when there were more dominant variants like delta and the original omicron strains. It can help communicate to the public, that there is a more infectious strain. See CDC publication on this. https://www.cdc.gov/mmwr/volumes/71/wr/mm7103a5.htm In the future, variant monitoring maybe more important if there is a significant enough of a mutation that causes higher mortality for example. The manuscript may want to note this potential and not make as strong a recommendation against variant inclusion on wastewater dashboards. I agree with the authors, that variant information can be confusing to the general public if not presented carefully.
8. The manuscript emphasized the perspective from some informants that wastewater information was not useful to doctors. From my wastewater monitoring experience and others, the public health departments would communicate the wastewater levels to meetings with hospital management. This helped them plan for increases in cases especially in under resourced areas and early in the pandemic without a lot of emergency room beds. I think that section could benefit from elaborating on the differences between the usefulness of wastewater data to public health departments and doctors. Public Health Departments are separate from hospitals and doctors but interact. Public Health Departments may use the wastewater data more in communications to the general public about masking and vaccinations. I’m concerned, in the current form, about communicating such a strong perspective that the wastewater data is not useful to or can’t be used by doctors.
9. Last line of discussion and others. Ensure to note challenges with plant comparison even with same normalization method. There are still many differences in the wastewater surveillance methods (e.g., solids vs. liquid analysis, filtration, concentration, ddPCR vs RTqPCR, etc.) that can be challenging when comparing different plants. Wastewater surveillance is most useful at comparing one site/plant through time than to other plants. Sometimes with the exact same method, plants can be compared.

MINOR COMMENTS:

1. I was told in a revision of my paper to also cite the other Netherlands research group that detected SARS-CoV-2 in wastewater at the same time in addition to your citation #7: https://www.thelancet.com/journals/langas/article/PIIS2468-1253(20)30087-X/fulltext
2. Last sentence of the first paragraph in the introduction, add comma between “probable” and “timely.”
3. In the methods for greater reproducibility, state which transcribing software was used.
4. Including the survey or question instrument or slides in supplemental information would help for reproducibility of and comparability to the study.
5. Table 2, the term “ES” is used without defining it as Environmental Surveillance in the table caption or as a footer to the table.
6. Theme 1 only has subsection 1.1 while theme 2 has more subsections that match Table 2. Were only the most prominent themes chosen? This can be confusing to the reader if they thought the subsections would align more with the table.
7. First quote in section 2.3 seems it may have been overly simplified with … then […].
8. Last paragraph of section 2.3, delete “has” before “becoming.” There are studies quantifying the amount of early waring and over different stages of the pandemic that you could cite.
9. The quote at the end of the first paragraph in section 3.2 is a little confusing to me. What are they scared to pay for? Pay for the monitoring? May want to expand the quote/explanation.
10. Consider adding a reference for statement on the systems as a biothreat or more formally stating from someone interviewed. We’ve found this issue for some plants in the U.S. but the EPA still has some databases with the addresses and such that are public along with other state agencies and cities. The statement “WW information is not public data.” is thus incorrect.
11. An important downside to flow normalization compared to a fecal indicator to note is that it does not account for industrial compared to municipal flow. Some plants have larger industrial flow than others.
12. Innovation and experimentation section of discussion, 2nd sentence, add a comma between “method” and “many.”
13. Third paragraph of data presentation, may want to add hospitalizations instead of or in addition to hospital beds as a clinical metric more frequently seen compared to wastewater data.
14. Last paragraph, change to the plural “best practices that were” instead of “best practice that was…”

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
No source data required

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Food-energy-water systems, Wastewater Based Epidemiology (WBE), Life Cycle Assessment (LCA), Geographic Information Systems (GIS)

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 14 September 2024

https://doi.org/10.21956/gatesopenres.16843.r37620

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David Larsen
Public Health, Syracuse University, Syracuse, New York, USA
Yifan Zhu
: Public Health, Syracuse University, Syracuse, New York, USA

This study reports the interview results regarding experiences in developing and maintaining SARS-CoV-2 wastewater surveillance dashboards. All interviewees are from developed countries in Europe and North America. The authors provided viewpoints from various perspectives and the interview questions covered a wide range of topics including dashboard development, data processing and visualization, clinical surveillance, funding source, data interpretability and acceptability, accessibility and transparency, and concerns over ethics and data privacy. By interviewing those who work with SARS-CoV-2 wastewater surveillance dashboards firsthand, this study provides valuable insights into the real-world challenges faced by them and their diverse approaches to questions without a standard answer. In addition, this study made some recommendations to improve interoperability and standardization. As wastewater surveillance continues to evolve, future projects with an interest in public health communication including the use of dashboards will benefit from this study. Other specific comments are listed below.

Specific comments:

1) There is a growing body of evidence around the use of dashboards to communicate public health information. We encourage the authors to place this study in the context of that evidence. We doubt the dashboard developers were experts in public health communication, and perhaps

they did not even review best practices from the literature before they developed their dashboards? We wonder if they arrived at similar conclusions to public health communication experts, or missed some of the best practices? For reference here are some articles that have examined public health communication using dashboards:[1],[3]

https://bmcpublichealth.biomedcentral.com/articles/10.1186/s12889-024-17841-2

2) The authors need to better describe how they selected dashboards for review. The list of dashboards on the COVIDPoops19 website would have allowed for a random sample of dashboards and therefore representative data. As written the article is unclear how representative the findings are across Europe and North America, and better description of the recruitment process and the connectedness of the participants would give more insight into how representative the findings are.

3) The authors have primarily interviewed dashboard developers. Only 2 of individuals interviewed did not describe themselves as developers. We are unsure whether that is the best audience for identifying best practices in dashboard development. Certainly some practice standards might be identifiedm but in our view users of dashboards should provide the feedback on which aspects of dashboards might be helpful and which might be confusing. In our view the fact that the authors primarily interviewed developers would warrant a change in title to reflect that these are standard practices from the developers' perspective, not the users' perspective. The authors should also note this in their limitations, and review Schulze et al. who identified this as a significant issue in studies of public health communication using dashboards.

4) Page 1, '*In April of 2020 it was found that SARS-CoV-2 (the causative agent of COVID-19) could be detected in the stool of active COVID-19 cases.*': a reference could be added here.

5) Page 4, Table 1: it would be better if some basic information regarding the dashboards they work on can be covered too. Also, all participants are from developed countries. Since wastewater surveillance has the advantage of being a low-cost surveillance option, it has huge potential in developing countries yet the viewpoints from those areas are not provided. This potential limitation should be mentioned.

6) Page 6, '*Only one developer mentioned the use of specific guidelines that were followed, and this was the Government Design Principles*': a brief introduction of these principles might give readers some ideas about the general rules to follow when designing dashboards.

7) Page 6, '*The discontinuation of SARSCoV-2 WW data collection has encouraged researchers to think beyond COVID-19, for example by expanding towards a multi pathogen surveillance system including seasonal respiratory and gastroenteritis diseases, as well as interest in monitoring for antimicrobial resistance.*': it would be nice if additional discussion can be provided regarding what are the potential targets and what is the rationale for choosing them for wastewater surveillance.

8) Page 6, '*Only two participants preferred the use of a geographical map.*': did they mention why? It could be because their projects cover a larger number of WWTPs hence a map would make more sense.

9) Page 7, '*Two stakeholders mentioned having to separate the data into an internal dashboard and a public dashboard.*': did they mention what are the differences between the two and what are the reasons for doing so?

10) Page 9, *'In the United States, since 9/11 it was reported that systems have been identified as a potential target of a biothreat.'*: what systems? Sewers? Please specify.

11) Page 9, *'While dashboards were not initially intended for a general audience, it became apparent that the public were broadly interested in the information displayed'*: this was not talked about in interview results, is there any data or quote to support this?

12) Discussion section: some ideas were briefly touched upon but not discussed in more details. For instance, the paragraph of whether or not to include variant surveillance result can elaborate on how variant information helped influence public health policies and how wastewater surveillance can benefit from it.

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Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Not applicable

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Epidemiology

We confirm that we have read this submission and believe that we have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however we have

significant reservations, as outlined above.