Wastewater Surveillance—"Messy" Science With Public Health Potential

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See also Kotlarz et al., p. 79.

Wastewater testing for infectious diseases blossomed during the COVID-19 pandemic.[1] Public health agencies are using wastewater data to augment traditional case and syndromic disease surveillance systems.[2] In this issue of *AJPH*, Kotlarz et al. (p. 79) report on the correspondence between COVID-19 disease trends observed with wastewater analysis, clinical testing, and syndromic surveillance in Raleigh, North Carolina, in 2020. They found moderate to strong correlations in COVID-19 trends across these data sources with wastewater influent and clinical testing disease signals preceding disease signals from syndromic surveillance and wastewater solids.

Wastewater analysis is an emerging surveillance tool that has potential benefits but also presents challenges compared with existing disease surveillance approaches. We find it useful to think about wastewater surveillance in the paradigm of a SWOT (strengths, weaknesses, opportunities, and threats) analysis (Figure 1). Kotlarz et al. identified some of these issues as pros and cons in the first figure in their article.

Wastewater analysis as a disease surveillance tool has several potential advantages over traditional surveillance methods. Wastewater analysis theoretically provides information about all of the individuals contributing to the wastewater—in essence, pooled testing of a community. Kotlarz et al. measured disease biomarkers in wastewater samples that may have contained contributions from more than 500 000 individuals living in Raleigh. Compared with individual clinical testing, wastewater analysis is efficient and likely cost saving—one study estimated that it was 1.7% of the total cost of clinical testing.[3]

Unlike syndromic and case-based disease surveillance, wastewater analysis does not rely on an individual having access to or seeking health care. As the title to the popular children's book by Taro Gomi proclaims, *Everyone Poops*. For this reason, wastewater surveillance can increase health equity if deployed in populations with less access to clinical testing or health care. Marginalized, rural, and resource-poor communities and their associated public health institutions stand to benefit from timely wastewater disease data that can inform local decision-making and the community members. As more individuals turn to home-based rapid tests and as the frequency of mild or asymptomatic COVID-19 cases increases, syndromic and case-based disease surveillance may further underestimate disease prevalence. In these situations, wastewater analysis will still identify trends in community disease burden, such as during the recent Omicron variant–fueled waves of COVID-19 infections.[4]

Although wastewater surveillance is an excellent complement to traditional disease surveillance, it has limitations. Wastewater samples positive for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) viral RNA cannot tell us who in the community is infected. However, there are many reports of wastewater surveillance triggering enhanced clinical testing to identify infected individuals, such as happened in Yellowknife, Canada.[5] Kotlarz et al. also recognize that wastewater analysis cannot distinguish between individuals with new and those with convalescing infections. Nor do we know with confidence who is contributing to a community's wastewater. Populations are dynamic, and individuals have varied toileting behaviors. Some individuals residing in a community will leave for work or recreation, and visitors from outside the community will make "deposits" into the wastewater system. There is also substantial variation in the amount of virus an infected individual deposits into the system—not all infected individuals shed virus in their feces, viral shedding may last from days to weeks, and shedding intensity varies over many magnitudes[6]—likely because of a combination of host (e.g., age, illness severity, prior immunity) and virus (e.g., variant, infective dose) characteristics.

The tidal wave of enthusiasm for wastewater surveillance in the research and public health communities presents

FIGURE 1— **Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis of Wastewater Testing as a Public Health Disease Surveillance Tool**

an opportunity to build on the successes of this approach. As exemplified by the Raleigh wastewater study authors' affiliations, implementing wastewater surveillance fosters multidisciplinary and multiorganizational collaborations. Scientists, public utilities operators, engineers, epidemiologists, and others worked together to conduct the wastewater study. Partnerships like these are critical for addressing complex public health problems.

Wastewater analysis can and should look beyond estimates of COVID-19 disease trends. Wastewater surveillance detected a subclinical outbreak of polio in Israel in 2013 and informed targeted vaccine campaigns.[7] Less than a decade later, wastewater surveillance in New York State helped define the spread of a vaccine-derived poliovirus outbreak following its detection in a hospitalized patient.[8] The wastewater partnerships and infrastructure developed during the COVID-19 pandemic likely made the rapid pivot to wastewater testing for polio possible and can enable other critical disease (e.g., monkeypox) surveillance activities.

Community circulation of SARS-CoV-2 and poliovirus are only the beginning of what we can learn from wastewater analysis. With advances in molecular biology and genetic sequencing, laboratories are sequencing wastewater to track SARS-CoV-2 variants,[9] measuring levels of antimicrobial resistance genes,[10] and looking for novel viruses that could cause the next pandemic. The utility of wastewater analysis goes beyond infectious disease surveillance: scientists are testing wastewater for many biomarkers of public health importance, such as pharmaceutical metabolites[11] and markers of exposure to air pollution.[12]

Wastewater surveillance is a particularly attractive public health tool for communities with limited access to clinical testing or health care. However, these same communities may also lack laboratory infrastructure, human resources, and external partnerships as well as centralized sanitation systems. Hence, there is an opportunity for community-engaged research to design wastewater analysis approaches that meet the needs of these communities. Strategies that build local capacity, emphasize simplified analytic tests, and cultivate partnerships between local stakeholders can maximize the potential of wastewater disease surveillance across a diversity of settings.

Wastewater analysis as a disease surveillance modality faces potential threats. As with other public health programs, the availability of resources (i.e., funding) will influence the sustainability of wastewater surveillance initiatives. The Centers for Disease Control and Prevention has provided laboratory capacity grants to many states to enhance their wastewater surveillance programs. Wise investment of these funds in public–academic and public–private partnerships can build wastewater analytic capacity and sustain implementation activities.

Although measuring levels of SARS-CoV-2 RNA in wastewater is relatively easy by some standards (in four hours we taught a wastewater treatment plant operator to do this with high fidelity), interpreting wastewater disease data is complex. The public health significance of a wastewater SARS-CoV-2 signal requires contextualization, an understanding of the limits of the approach, and further analysis of its correspondence with traditional disease surveillance metrics, such as hospitalization rates. Although Kotlarz et al. reported significant correlations between the wastewater and clinical signals during their study, there were also instances when these surveillance methods disagreed. As public health officials gain experience using wastewater data, it will be important to continue to evaluate wastewater's performance compared with traditional surveillance data sources, develop visualization and analytic tools to support its use, and provide opportunities for sharing best practices.

In summary, Kotlarz et al. and others have demonstrated the public health potential of wastewater testing, particularly in the context of the COVID-19 pandemic. The groundswell of enthusiasm in the research and public health sectors suggests that wastewater testing will continue to integrate with more established public health disease surveillance approaches. Although wastewater testing has challenges that inspire creative problem solving, we believe that its advantages make it a compelling tool for public health surveillance. AJPH

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CONFLICTS OF INTEREST

S. M. Berry reports ownership interest in Salus Discovery LLC. J. W. Keck has no conflicts of interest to declare.

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