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Wastewater Surveillance for Disease Epidemiology:
Embracing the Chaos and the Uncertainties

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Abstract

Wastewater-based epidemiological surveillance (WBE) showed the potential to become a pivotal public health tool for measuring community disease burden during the COVID-19 pandemic. Many countries used WBE as part of their national disease surveillance to inform on the optimal deployment of public health measures. In India, civil society groups, research institutions, and private companies across various urban areas also demonstrated the utility of WBE in assessing community burden. While the European Union has recently begun to craft policies for the integration of WBE into a global surveillance network, many countries (including India) do not have a national policy to enable such integration. This paper argues for a national wastewater surveillance system for India, covering community-level assessment of various public health threats, along with integration of data from urban marginalised populations, to promote health equity and facilitate OneHealth-based thinking of disease emergence and spread. The paper outlines WBE efforts around the world, highlights its advantages as a cost-effective tool to supplement rather than supplant existing frameworks, and makes a case for its implementation in India, along with recommendations for next steps towards such implementation. The effective use of WBE should help India identify areas of emerging health threats, prepare for future infectious disease outbreaks, and allocate resources according to population requirements.

Keywords: Wastewater surveillance, public health, disease surveillance, IDSP

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1. Introduction

Nearly all existing disease surveillance methods focus on clinical case detection: they depend entirely on an actively symptomatic, infected individual presenting themselves to a healthcare facility, where their data is fed into the surveillance system, recorded, and analysed to inform public health action. Thus, public health action is invariably reactive to the incident of a (severe-enough) infection.

In the normal course of disease progression, most infected individuals begin to shed markers of infection (such as intact and viable viruses, which may themselves be infectious, or specific proteins or nucleic acids) in their stool or urine, often before symptoms arise. This release of markers enables an additional method of estimating the extent of infection in a community: testing of wastewater for presence of markers of infection.

For instance, for several decades globally, wastewater has been monitored for the presence of the polio virus, an indicator of an actively infected person somewhere in that community contributing to that wastewater sample (Link-Gelles et al., 2022, Bloom et al., 1958). Routine wastewater-based epidemiology and epidemiological surveillance (WBE) may be a cost-effective and proactive method for community-level detection, studying underlying transmission and/or seasonal onset of diseases, or even for the detection of novel emerging pathogens and genomic variants.

The idea of using wastewater to detect pathogens is old; the potential of wastewater to carry disease-causing bacteria was first discussed in the 1800s (Playter, 1886; Fergus, 1872; Hawksley, 1857). Soon after the discovery of Mycobacterium tuberculosis by Robert Koch, Musehold described detecting tuberculosis bacilli in sewers, wastewater drains, and cultivated fields (Musehold, 1900). This was followed by several other articles showing the presence of Mycobacterium species in various types of wastewater (Laird et al., 1913; Brown et al., 1916).

In 1933, James Wilson showed the presence of *Bacillus typhosus* (*Salmonella typhi*, as it is known today) in wastewater, and connected it with cases of typhoid fever in communities where the bacterium could be isolated from wastewater (Wilson, 1933). WBE was first used in the US in the 1960s to track poliovirus before, during, and after a vaccination campaign (Riordan, 1962). In 2001, the World Health Organisation (WHO) started environmental surveillance for polio in India by setting up a wastewater sampling site in Mumbai. In 2003, during the SARS-CoV1 pandemic, attempts were made to determine if there could be waterborne transmission of the virus. At the time, RNA of the coronavirus could be found in wastewater, although no live virus was isolated from these samples.

Since then, WBE has been used in research settings to track Norovirus (Huang et al., 2022), measles (Benschop et al., 2015), Hepatitis E (Takuissu et al., 2022), antimicrobial resistance (Hendrikson et al., 2019), and substances (Centazzo et al., 2019) such as cocaine, as well as the incidence of non-communicable diseases such as obesity in a community (Newton et al., 2015). Currently, a variety of pathogens including Influenza, Respiratory syncytial virus, Human meta pneumovirus, Para influenza, Norovirus, Rota virus, Adeno virus group, Entero virus D68 Mpox, Candida auris, and

Hepatitis A are being assessed in wastewater (Wastewaterscan, 2023), as part of active surveillance in the US by private players. However, wastewater surveillance was not integrated into national public health programmes of many countries before the onset of COVID-19.

The outbreak of COVID-19 brought global attention to the technique. Multiple studies have found SARS-CoV-2 in wastewater (reviewed in Tran et al., 2021). Groups worldwide began to track SARS CoV2 in wastewater to determine if it could predict the community burden of COVID-19, which can spread rapidly and asymptomatically.

Thus, in the past few years, several WBE programs across the world have worked on various pathogens to varying degrees of success. While some of these programs have a research focus, COVID-19 pushed for WBE use beyond research, into active surveillance to influence public health action. In this article, we focus on programs that inform public health decisions, and argue for an Indian National Wastewater Surveillance System (NWSS).

The objectives of this paper are:

a) Summarise the premise of WBE and the scope and range of global WBE programs
b) Assess the advantages of such surveillance, including aspects of relative anonymity, cost-effectiveness, and potential impact on public health action.
c) Highlight the need for a WBE policy in India to resolve issues of standards, regulations, ethical considerations, justice, and lack of integration into other surveillance metrics, which obstruct large-scale adoption or lead to unintended problems.
d) Recommend guidelines for integration of WBE into India's public health system.

2. Premise, scope, and range of WBE

WBE is based on three primary premises:

a) that the pathogen/s of interest are shed in the stool or urine of infected individuals;
b) that these pathogens or their genetic signatures/molecular markers can be detected in wastewater; and
c) that the presence and/or intensity of the measured levels of these pathogens or genetic signatures is indicative of the burden of that pathogen and disease in the community contributing to the tested wastewater sample.

Thus, the first premise is based on the life cycle of the pathogen within the human host, wherein something of the pathogen (whether the whole organism, or some nucleic acid or protein, or some other marker) finds its way into the gastrointestinal (GI) tract of the infected individual, and gets shed in the stool or urine. This automatically precludes many viruses and bacteria, for instance, those that infect only the central nervous system. However, it allows monitoring of many pathogens that appear symptomatically outside of the GI tract (for example, the respiratory system) and are eventually shed from the GI tract. For instance, Mycobacterium tuberculosis, which causes tuberculosis – a predominantly pulmonary infection – is shed through the GI tract.

The second premise reflects current technical limitations: assuming that the genetic material of the pathogen is present in the water, do current methods accurately measure it in a sensitive and specific manner? The holy grail of wastewater surveillance is not merely the detection of pathogens, but their *early* detection: can a pathogen of epidemic or pandemic potential be detected early enough, and with sufficient specificity, to alert the public health system and give it enough time to both build its capacity and resources and take swift and decisive control measures?

The assumption (now scientifically proven for certain pathogens) is that people start shedding the virus in their stool (or urine) earlier than they become symptomatic. Thus, a spike in viral load shed in the wastewater could indicate an upcoming spike in clinical cases. The technical evolution of the protocols and procedures of wastewater surveillance has been rapid, with newer technologies (digital droplet PCR, next-generation sequencing) coming into the mainstream, and promising greater accuracy and earlier detection.

The third premise, that of wastewater-based surveillance data being indicative of community burden – and therefore a supplement to community clinical data – is arguably the most important. It deals not just with the scientific aspects of methodology and correlation, but also with appropriate scientific communication of caveats and risks, integrating data from other surveillance methods, and joint sense-making with multiple stakeholders.

This premise and its underlying questions propel WBE from merely a scientific inquiry to the volatile, unpredictable, complex, and ambiguous realm of public health. Here lie ethical questions of data ownership, anonymity, and health equity; technical questions of the type of sewerage networks, flows of water, what to test and how often; finance and sustainability questions of piloting and scaling, and when to fund what and whom; and critically, implementation questions of "what do we do based on this information?"

The scope and range of the publications of global WBE programmes are summarised in Table 1. Please note that we have restricted our search to programs whose data were used in public health action and implementation, though they might not be specifically integrated with government surveillance plans.

Table 1: WBE programmes of countries around the world.

1A. Lower/Middle Income Countries (LMICs)

Sl. No	Country	What was WBE used to track?	Integrated within govt. public health program or not?	Source of wastewater sample
1	Bangladesh (International Centre for Diarrhoeal Disease Research, Bangladesh research platform, 2023)	SARS CoV2	Part of the International Centre for Diarrhoeal Disease Research, Bangladesh research platform	Both formal and informal wastewater networks
2	China (Zhang et al., 2022)	SARS CoV2	No, not integrated at a national level. Some programs have been used at the local level.	From well-functioning drainage system
3	Ghana (WHO, n.d.)	Polio, SARS CoV2	Existing infrastructure for polio was upgraded to include SARS CoV2 with a grant from the Bill and Melinda Gates Foundation	Only 10% of Ghana's WW is connected to a sewerage network. Hence the project also includes WW from community toilet facilities
4	India	SARS CoV2, AMR, Monkeypox, RSV, Influenza by multiple groups nation-wide	INSACOG under DBT has been collecting viral load data and genomic surveillance information. But not yet integrated into the National Center for Disease Control (NCDC)'s Integrated Disease Surveillance Program (IDSP) dashboards. State Technical Advisory Committees in Karnataka and Gujarat have used information for state actions.	Open drains, manholes, apartment complexes, airport surveillance, and WWTPs (by different groups, in different cities). No integration of data between groups or with the national surveillance dashboard.
5	Kenya	SARS CoV2	Internationally funded. Expected to be among the EU Global WBE Surveillance Network.	Wastewater treatment plant, river water
6	Nepal (Tandukar et al., 2022)	SARS CoV2	Not yet integrated; done by independent researchers	Wastewater, river water, hospital wastewater

7	Pakistan (LMIC) (Ansari et al., 2023)	SARS CoV2	Not yet integrated; done by independent researchers	Lyari river water
8	Senegal (Ndiaye et al., 2014)	Polio, SARS CoV2	Expected to be among the EU Global WBE Surveillance Network. National Reference Lab for polio, will be used to upgrade the pathogen range with international support.	WWTPs
9.	South Africa (South African Medical Research Council, 2020)	SARS CoV2	Yes, Environment and Health Research Unit, South African Medical Research Council	Selected WWTPs
10.	Thailand (Wannigama et al., 2023)	SARS CoV2	No, data collected by the Global Initiative on Sharing All Influenza Data	Shopping centres, condominium complexes, office complexes, food markets, wastewater treatment plants, and entertainment venues
11	Turkey Dept of Agriculture and Forestry (Tlhagale, 2022)	SARS CoV2	National reference network covering 22 WWTPs.	Sludge, influent, effluent of WWTPs

1B. High Income Countries

S. No	Country	What was WBE used to track?	Integrated within govt. public health program or not?	Source of wastewater sample
01	Australia (Department of Health and Aged Care, Govt of Australia., 2022)[4]	SARS CoV2	Yes, with the government's health ministry	Airports, community sites, ports of entry
02	Belgium (Gawlik et al., 2021)	SARS CoV2, multi-pathogen panels	Belgium Reference Project, with multiple diverse stakeholders, covers over 40% of the population through WBE, testing 42 WWTPs twice a week	WWTPs, airport and aircraft surveillance
03	Canada (The Department of Environment and Climate Change, Govt of Canada, 2021)	SARS CoV2, Respiratory Syncytial Virus (RSV)	Yes, integrated with the government's public health agency	Municipal wastewater system, typically from a wastewater treatment plant, airport surveillance
04	Chile (Ampuero et al., 2023)	Monkeypox	Yes, with Centre for Disease Control	WWTPs
05	Finland (WESTPAN project, National Corona Dashboard, WBE-specific dashboard) (Naughton et al., 2023)	SARS CoV2, polio, illicit drug use	Yes, integrated into the National Corona Dashboard	WWTPs, airport and aircraft surveillance
06	France (Obepine and Paris Sanitation Authority., 2020)	SARS CoV2	Pilot project done by Obepine consortium and Paris Sanitation Authority, scaled to over 150 WWTPs across the country, including overseas territories)	WWTPs

07	Germany (Federal Ministry of Health, Govt of Germany, 2022)	SARS CoV2	Yes, integrated with the government's health ministry	WWTPs
08	Greece	SARS CoV2	Pilot study at two Greece municipalities. Then integrated into a national program	Untreated wastewater at WWTPs.
09	Israel (HIC) (Ministry of Health, Govt of Israel., 2022)[17]	Enterovirus D68	Co-ordinated sporadically by Health ministry	Manholes
10	Japan (Yoo et al., 2023)	SARS CoV2	Only a pilot study, yet to integrate fully	WWTPs
11	Netherlands (Ministry of Health, Welfare and Sport, Govt of Netherlands, 2023)[1]	SARS CoV2, Hepatitis A	Yes, Ministry of Health	Wastewater treatment plants (WWTPs)
12	Spain (Giron-Guzman et al., 2023)	SARS CoV2, Monkeypox	Yes, under National Epidemiological surveillance network, Ministry of Health.	WWTPs
13	UK (UK Health Security Agency, 2022)	SARS CoV2	Yes, with the government's health ministry	WWTPs (influent and sludge)
14	USA (Centers for Disease Control and Prevention, Department of Health and Human Services, Govt of USA, 2020)	SARS CoV2, RSV, Influenza	Yes, with the CDC and government's health departments	WWTPs, airport and aircraft surveillance. In parallel, conducted longitudinal nasal swab testing of volunteer travelers to compare

3. The advantages of using WBE

Surveillance methods for infectious diseases have traditionally been based on clinical case monitoring. In recent years, other lines, such as social media mining or community dipsticks based on physician group chats have become more common. Wastewater surveillance has features in common with these methods, but it also has advantages over other methods that make it attractive for community health surveillance. Below we outline the key advantages of using WBE as an integrated part of national disease surveillance.

3.1 Community-level snapshot from a single source

The chief advantage of WBE is that it allows the assessment of disease burden in a community from a single source (in the case of Wastewater Treatment Plant-based surveillance), or from a likely community (in the case of open drain surveillance). Clinical case monitoring requires coordination and flow of information across various sources, including clinics, hospitals, etc. While this provides more granular information, e.g. in terms of the severity of the disease, that might not be essential for deploying measures such as masking. On the other hand, WBE may more accurately reflect disease burden in cases of asymptomatic infections, where the pathogen would continue to be shed in the community, even though asymptomatic individuals might not present at the clinic.

3.2 Early Detection

WBE may be able to detect the onset of diseases early, providing public health authorities with crucial time to take necessary measures.

- SARS-CoV-2 virus RNA was detected in wastewater before the cases were clinically reported in the Netherlands (Medema et al., 2020).
- In India, groups in Bangalore and Ahmedabad reported SARS CoV2 spikes during the 3rd wave to government authorities before the rise in clinical cases (Prasad, 2021; Kumar et al., 2023).
- In 2013, wild poliovirus type-1 (WPV1) was detected in the wastewater from the West Bank and the Gaza Strip. WHO and regional authorities took countermeasures based on this information to contain the disease (Tiwari et al., 2021).
- In 2022, Canadian authorities were able to use information on spikes in RSV (respiratory syncytial virus) in wastewater and communicate warnings to the public in time to prevent hospitalisations and infections (Global Wastewater Conference, 2023).

3.3 Detection of Silent Waves

WBE may be of use in the detection of 'silent waves' - phases where the pathogen is circulating in the environment without causing major clinical manifestations in humans. For example, ongoing WBE efforts tracked a silent COVID-19 wave in Bengaluru in May 2023 (Prasad, 2023), and Hepatitis A in the Netherlands (Global Wastewater Conference, 2023a). Such silent phases might not be of clinical significance, but require public health scrutiny to monitor the emergence of more severe variants of the pathogen.

3.4 Relative anonymity/ Individual privacy

Unlike clinical surveillance, wastewater samples cannot be traced back to a single individual, thus preserving privacy and anonymity. However, if there are geographical zones that are hotspots for many diseases, there may be adverse effects on that zone, in terms of property prices dropping or residents of that zone being discriminated against.

3.5 Cost-effectiveness

Wastewater surveillance can test a city of a few million people at a fraction of the cost of individual testing. For instance, in the experience of the Precision Pandemic Health Initiative (of which the lead author is part) with Bengaluru city during the COVID-19 pandemic, the cost to appropriately test an area of 750 sq. km, covering 13 million individuals, was approximately INR 2 crores over 6 months (~INR 3 Lakhs/day) with WBE. The city of Bangalore tested 30,000 individuals a day at the peak of the second COVID-19 wave at INR. 400 per test, making the cost of clinical surveillance about INR 1.2 crores a day.

It is apparent from these calculations that the marginal cost to the government of using WBE to inform on community health decisions is non-significant. The rewards – in terms of cost-saving, effective targeting of clinical screening, and improved health outcomes – can be substantial.

The inclusion of newer technologies such as digital droplet PCR (ddPCR), which is a very sensitive technique to pick up single molecules of the nucleic acid of interest, or next generation sequencing (NGS), which allows for reading of the genetic sequence of the nucleic acid of interest may increase the costs. However, the greater sensitivity might also allow for novel insights and knowledge.

3.6 Reduction of bias

Health systems data is usually collected from tertiary care hospitals, often those with an academic or research department. However, this data fails to capture disease epidemiology in those who are either not severely sick or who have availed alternate resources, or who never manage to access a healthcare facility at all (for instance, migrant or daily wage workers, marginalised communities, etc.) WBE, especially from open drains (which often run through slums or temporary settlements), can help capture anonymous data from these otherwise-excluded communities.

4. WBE in India

India's tropical climate and its environmental conditions pose challenges to uniformity or standardisation in sampling, testing, and data collection through WBE. For instance, viral fragments may disintegrate quickly in hotter conditions of north India during the peak of summer, thus obscuring the actual scale of the outbreak. Yet, the COVID-19 outbreak saw several successful regional attempts using WBE to track community infection.

Asia's first city-wide wastewater surveillance system was established in Bengaluru in May 2021 by Precision Health Platform, a coalition consisting of public health, research, academic, private sector and civil society agencies, assisted by several local and government bodies. The platform sampled 45 open drain sites and 28 wastewater treatment plants (STPs) twice a week, covering almost 11 million people, representing nearly 92% population of the city (Ishtiaq, 2022).

A few other cities, such as Hyderabad (Hemlatha et al., 2021), Pune (Rajput et al., 2023), and Ahmedabad (Kumar et al., 2020) also used WBE to detect SARS-CoV-2 during the pandemic.

Although there were several efforts to track COVID-19 in wastewater in India, there was no centralised programme to coordinate these efforts. SRM Institute of Science and Technology created a set of standard operating procedures for WBE, which was passed on to the states and union territories for possible implementation (Shubhra, 2021). However, there was no mandate for implementation or standardisation of the operations. This lack of overarching governance meant that the data collected could not be always converted into public health action. Another reason for this inaction is the lack of awareness about WBE and its interpretation among public health officials, the government, and municipal corporations.

Wastewater surveillance is based on testing a community's collective wastewater. A major challenge in deploying WBE in India is that the wastewater system is fragmented, with only about 33% of the wastewater system connected (Census, 2011). Of the rest, only 38% use septic tanks. A connected wastewater system or a central wastewater collection system is necessary for WBE to operate, as these are ideal sampling sites.

This problem is not unique to India. and reflects the lack of infrastructural development across LMICs. Wastewater sampling in LMICs occurs at several locations: wastewater treatment plants (30%), manholes (20%), surface waters (22%), open drains (15%), pit latrines (7%), and other locations (7%) (Keshaviah et al., 2023). These other sources of wastewater may not accurately depict disease burden, and therefore reduce the efficacy of WBE. For example, preanalytic issues such as the presence of unknown and unexpected materials in the wastewater can affect the detection of the analyte of interest. Environmental factors such as rainfall and bright sunshine magnify these impacts when sampling is done through open drains.

Thus, for India to effectively use WBE, there has to be infrastructure and regulatory capacity development, governed by an institutionalised Union government programme.

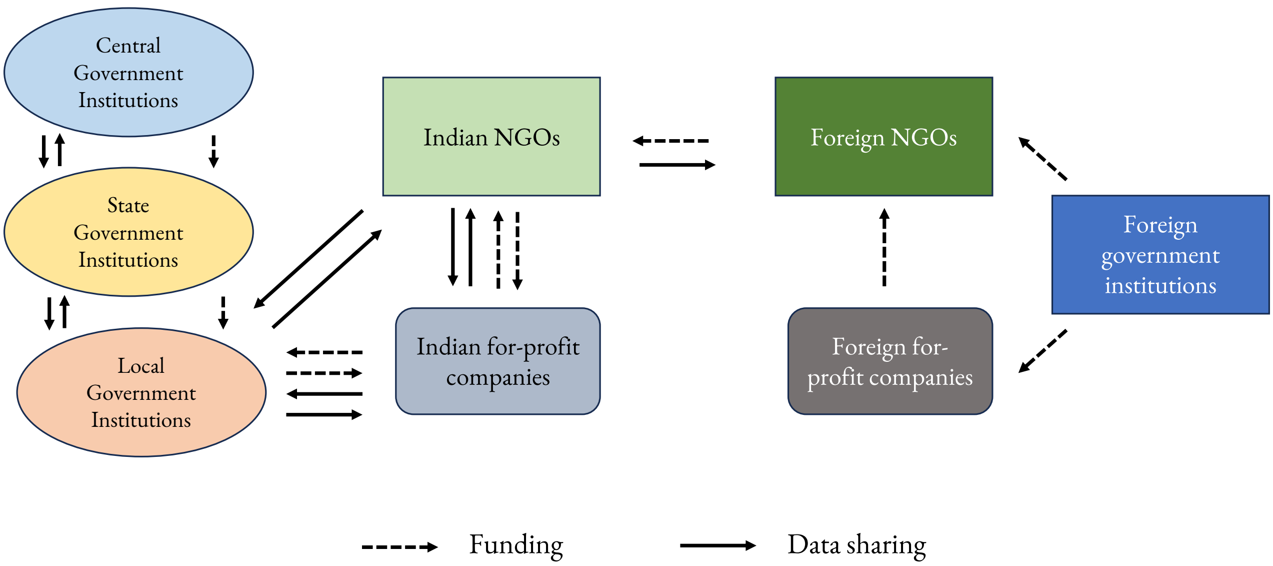
5. The case for an Indian National Wastewater Surveillance Programme

WBE can complement routine surveillance programmes to catch the early onset of new outbreaks and assess community disease burden during an ongoing outbreak. Both assessments can feed into public health action, when appropriately contextualised with clinical burden and supported by community action. However, this pathway from WBE data to policy action is not linear – an assumption that may be prevalent not only in research and technical proposals, but also in the minds of funding agencies.

The optimal use of WBE will depend on the co-production of knowledge and insights from the diverse (and often conflicting) perspectives and priorities of researchers, policymakers, community members, vendors, and funders. This is a time-consuming, long-term, trust/relationship-based process. For example, the ecosystem of players carrying out wastewater surveillance in Bengaluru during the COVID-19 pandemic has been depicted in Figure 1.

Figure 1: The categories of institutions that were involved in Bangalore wastewater surveillance during the Covid-19 pandemic years (2020-22)

The Nature of Coalitions in Environmental Surveillance



Scaling WBE into a national programme has to embrace this complexity, and set out common goals that need to be achieved. In "Scaling Excellence", Sutton and Rao describe 3 types of scaling:

- Scaling Out is when a geographically restricted organisation or one with a restricted scope expands in geography and/or scope (Sutton and Rao, 2014).
- Scaling Up is when there are attempts made to change policy or influence the field at a national or international level.
- Scaling Deep is when the organisation chooses to stay geographically restricted, but delves deep into multiple aspects of its interactions with the community that it serves. It chooses to build "tribes" influenced by its culture and philosophy.

WBE programs have globally done all 3 types of scaling at various levels, and to varying degrees of success. For instance, the Bangalore Precision Pandemic Health Initiative scaled out to 5 different cities over 2 years, catalysed the creation of the Indian Alliance for Public Health Preparedness (IAPHP) to scale up (by working on policy), out (by expanding to other cities), and simultaneously deep, by delving into wastewater, its fate, and other infections that could be detected through WW in and around Bangalore city. Another similar alliance, called APSI, has also been formed with similar goals and vision.

Any WBE program needs a consortium that strikes a balance between samaaj-sarkaar-bazaar (society-government-industry) and is carefully curated in its implementation partners to minimise overlaps or competition, yet with low entry barriers to allow innovation, nimbleness, and agility. While it is not necessary that every consortium has to merge into one, it would be useful to collect all the data into a single integrated dashboard that promotes knowledge-sharing and robustness.

WBE also depends on highly complex samples containing the analytes of interest (from the infected individuals), material from uninfected people, and other unrelated organic and inorganic materials. The sensitivity, specificity, and positive predictive value of community wastewater therefore depend on many variables, much of which may be entirely unknown. This brings a significant degree of complexity to the field, and therefore the need for institutionalisation of standards and protocols to bring consistency to results obtained across the country.

A common vision and understanding of operational outcomes for WBE are necessary to bring all the stakeholders together under one umbrella. COVID-19 achieved this in a crisis, but the routine use of WBE will require overarching guidance on agents to be tracked and standards to be maintained. A national governmental policy will create the platform for plug-and-play by various public and private stakeholders, who can contribute with sampling, sequencing, analyses, and interpretation services.

Further, the objectives of WBE have to be clearly defined in terms of routine surveillance (which could be funded perhaps by a government health department or citizen action groups) and discovery/research (funded by research grants) to fully harness the potential of WBE. Funding structures should be such that WBE is not playing catchup (testing for something after the clinical cases start to rise), but is continuous, longitudinal, and ever-expanding in scope.

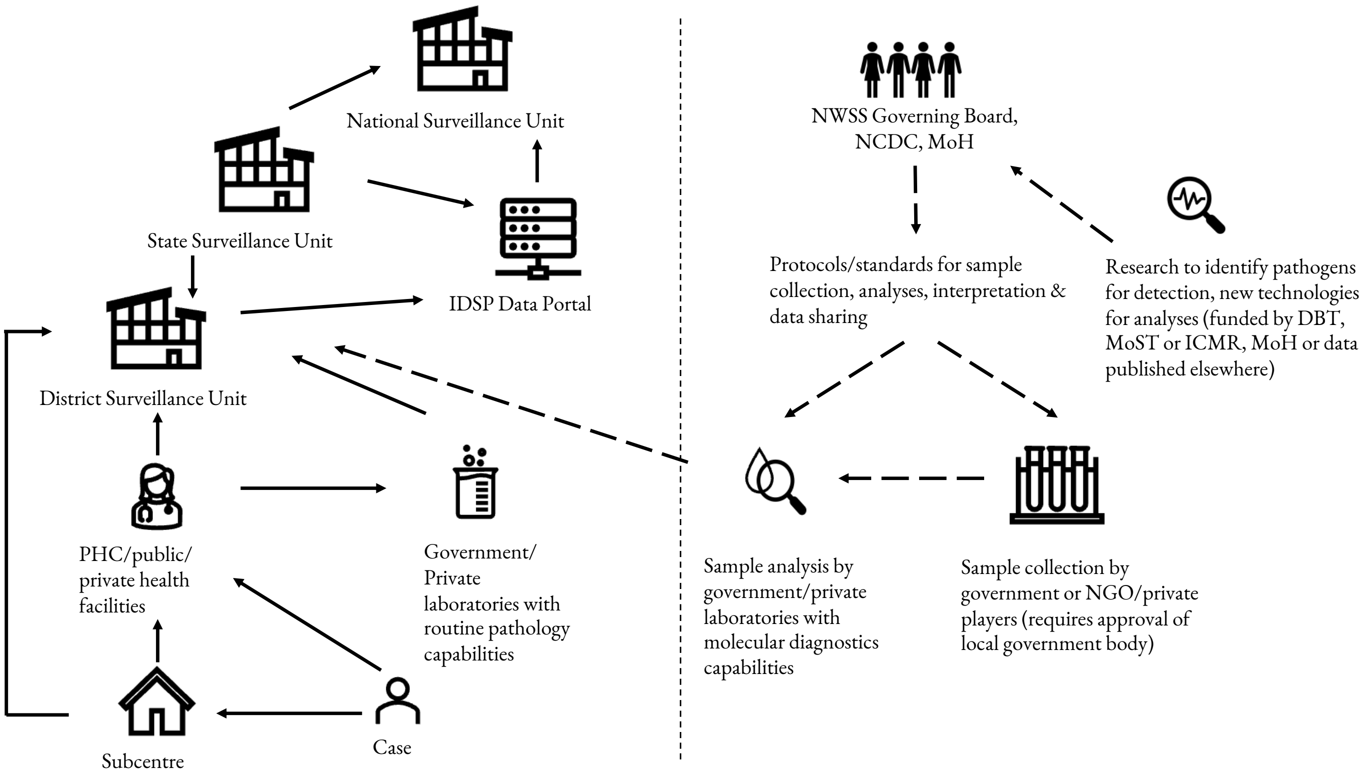
Finally, an important argument for a national-level policy is the need for data protection of WBE data. While individual privacy may be preserved, community-level stigma might be an inadvertent result of WBE findings. Consistently poor results from certain areas could lead to reductions in property value, the withholding of certain benefits from certain communities, and sub-population-level discrimination. Thus, the national programme has to outline standards for data-sharing and data safety. Additionally, the programme should develop a robust risk communication and community engagement strategy, to prevent the misuse and/or abuse of community-level data.

6. Recommendations:

1. **Institute a National Wastewater Surveillance Programme**

   The Ministry of Health, Government of India should institute a national wastewater surveillance programme under the aegis of the Integrated Disease Surveillance Programme of the NCDC (Figure 2). The programme should involve state authorities and local governments, since both health and sanitation are state subjects. The programme should set out standards and rules for wastewater surveillance, and identify diseases that are to be tracked. The programme's policymaking unit would be a governing council housed within the National Centre for Disease Control (NCDC), Ministry of Health, Government of India. This council would consist of experts with medical, public health, epidemiology, and research experience, and would set protocols/standards for WWS.

Figure 2: A proposed NWSS for India and its integration with existing disease surveillance.



The left side of the schematic with solid arrows shows existing disease surveillance (adapted from Phalkey et al., 2013). The right part of the schematic with dashed arrows shows the proposed NWSS structure and its integration with the existing structure.

2. **Better coordination between state and union agencies**, as well as between intersectoral agencies, especially those working on climate, animal health, environment, and human health

The national programme should equip local governments with infrastructure, skills, and human resources to monitor wastewater biweekly, in an institutionalised manner, through earmarked matching grants. States might be able to run the programmes in their capacity, but a national programme would provide most value by cross-pollinating data across states. In addition, most epidemic outbreaks in the past few decades have been zoonotic, and therefore, involve a complex ecology of animals, environment, and their interactions with humans. This ecology is rapidly changing with climate change and global warming, warranting better coordination and communication between intersectoral agencies.

3. **Public-private partnerships in surveillance:**

   The COVID-19 pandemic has demonstrated the strength of India's private and non-government sectors in carrying out WBE. India's national surveillance can be made effective by promoting and strengthening coordination between public health agencies and private laboratories. This was seen to be the case in practically every aspect of the public health response to COVID-19: from the establishment of telehealth cells, COVID helplines, COVID care centres, diagnostic kit development, kit manufacturing, vaccine manufacturing, and more. Thus, for any rapid response, a multi-stakeholder team with diverse perspectives, priorities, mandates, and funding structures will enable faster achievements. The government can perform the steering function of setting up protocols, data quality standards, and mechanisms for effective data exchange.

   The programme should allow for non-governmental participation to harness the benefits of non-hierarchical, trans-disciplinary insights and experiences. While it will admittedly add new layers of complexity, it will be a role model for integrated surveillance worldwide. The existing Indian Alliance for Public Health Preparedness is a consortium of Indian academia, research industry, businesses, and civil society bodies (IA,PHP) which has been working on providing a platform for multiple stakeholders for advocacy, research, and knowledge sharing in wastewater and environmental surveillance. Government initiatives could consider actively co-opting such fora, and being open to a shared vision or aim, rather than strict vertical or top-down approaches.

4. **Integration into the Integrated Disease Surveillance Programme (IDSP)**

   The data from the programme should feed into the district surveillance units and flow to national units, as well as to other neighbouring districts. The IDSP should be able to contextualise these data along with data from other sources such as clinical investigations, social media mining, etc., to be able to inform on public health measures required to be taken. Integration of existing clinical testing at labs across the nation with wastewater surveillance systems may also require technological upgradation. Further, funding for WBE needs to be longitudinal and long-term. Funding for disease epidemiology so far has been reactive - after the first few clinical cases arise and are reported, traditional epidemiological systems come into play.

5. **Ramp up infrastructure**

   To overcome the challenges of the fragmented wastewater systems in India, unconnected networks can be temporarily included in regular surveying. For e.g., open drains, nullahs, informal settlements in rural and urban areas, and river water catchments could help bridge the data gap, while new infrastructure for a connected wastewater system is built up.

6. **Set up multiple research programmes as part of the national WWS programme**

   Apart from pathogens, it is imperative to measure the concentration of pharmaceutical and personal care products to track the level of antimicrobial resistance, an emerging silent pandemic. Further, the programme has to optimally use new technologies to reduce surveillance costs. These aims require constant research to be conducted to best use WWS in the Indian context. Thus, the NWWS should set up a dedicated research programme to identify diseases or other substances for surveillance, improve methods for sampling from unconnected water bodies and better testing protocols, again in collaboration with non-governmental players, for nimble and flexible thinking and implementation.

7. **Strengthen routine surveillance through robust data systems**

   The National Centre for Disease Control has to strengthen the ongoing IDSP, because WBE data's effectiveness will depend on the receipt of regional-level infection data. Accurate data sharing will also help researchers corroborate their WBE data and improve methodologies for WBE. Investments of resources into developing better systems for data capture and integration are required. Local data systems can be used by local agencies for quality tracking and improvement (for instance, bar codes to capture time of collection, sample drop off and processing, and GPS location of collected samples) while the final local epidemiological data can be auto-integrated into national dashboards. This enables scale, quality, and speed of information sharing, while minimising dependence on manual entry (and hence chance of errors).

7. Conclusion:

The inclusion of WBE as a tool to assess community disease burden and early onset of disease will likely become part of global disease surveillance programmes. India should also invest in developing a national wastewater surveillance (NWWS) programme, integrated with current disease surveillance.

This programme must build both infrastructural and regulatory capacity to sample, analyse, and interpret wastewater data, in congruence with other clinical data. The programme should co-opt existing non-governmental partners to leverage their expertise and reduce capital costs. Finally, the success of this programme will depend on effective inter-governmental communication and data-sharing, from local to national governments. If implemented well, WBE can act as an effective early warning system and a tool to track silent and epidemic outbreaks.

References

Ampuero Manuel, Martínez-Valdebenito Costanza, Ferrés Marcela, Soto-Rifo Ricardo, Gaggero Aldo. “Monkeypox Virus in Wastewater Samples from Santiago Metropolitan Region, Chile” Emerging Infectious Diseases. 2023;29(11):2358-2361. doi:10.3201/eid2911.230096.

Ansari, Nadia, Furqan Kabir, Waqasuddin Khan, Farah Khalid, Amyn A. Malik, Joshua L. Warren, Usma Mehmood, et al. “Environmental Surveillance for COVID-19 Using SARS-CoV-2 RNA Concentration in Wastewater – a Study in District East, Karachi, Pakistan.” The Lancet Regional Health - Europe, October 1, 2023, 100299. https://doi.org/10.1016/j.lansea.2023.100299.

Benschop Kimberley SM, van der Avoort Harrie G, Jusic Edin, Vennema Harry, van Binnendijk Rob, and Duizer Erwin. “Polio and Measles Down the Drain: Environmental Enterovirus Surveillance in the Netherlands, 2005 to 2015” Appl Environ Microbiol. 2017 Jun 16;83(13):e00558-17. doi: 10.1128/AEM.00558-17. PMID: 28432101; PMCID: PMC5478994.

Bloom, Henry H, Mack WN, Krueger Brian J, and Mallmann, WL “Identification of Enteroviruses in Sewage” The Journal of Infectious Diseases 105, no. 1 (July 1, 1959): 61–68. https://doi.org/10.1093/infdis/105.1.61.

Census of India, 2011.

Centazzo, Nicole, Bonnie-Marie Frederick, Alethea Jacox, Shu-Yuan Cheng, and Marta Concheiro. “Wastewater Analysis for Nicotine, Cocaine, Amphetamines, Opioids and Cannabis in New York City.” Forensic Sciences Research 4, no. 2 (April 3, 2019): 152–67. https://doi.org/10.1080/20961790.2019.1609388.

Centers for Disease Control and Prevention. “National Wastewater Surveillance System,” March 14, 2023. https://www.cdc.gov/nwss/wastewater-surveillance.html#:~:text=In%20response%20to%20the%20COVID,samples%20collected%20across%20the%20country.

Environment and Climate Change. “Wastewater Surveillance for COVID-19 Virus - Environment and Climate Change.” Environment and Climate Change -, October 17, 2023. https://www.gov.nl.ca/ecc/waterres/wastewater-surveillance-for-covid-19-virus/.

Fergus, A. "On the Sanitary Aspect of the Sewage Question; with Remarks on a Little-Noticed Cause of Typhoid Fever, and Other Zymotics" Edinb Med J. 1872 Feb;17(8):717-733. PMID: 29639974

Gawlik Bernd M, Tavazzi Simona, Mariani Giulio, Skejo Helle, Sponar Michel, Higgins Trudy, Medema Gertjan, Wintgens Thomas. "SARS-CoV-2 Surveillance employing Sewers Towards a Sentinel System, Feasibility assessment of an EU approach" EUR 30684 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-36888-5, doi:10.2760/300580, JRC125065.

Girón-Guzmán, Inés, Azahara Díaz-Reolid, Pilar Truchado, Albert Carcereny, David García-Pedemonte, Bruno Hernáez, Albert Bosch, et al. "Spanish Wastewater Reveals the Current Spread of Monkeypox Virus." Water Research 231 (March 1, 2023): 119621. https://doi.org/10.1016/j.watres.2023.119621.

Global Wastewater Conference, Maarten de Jong, GGD, Using passive samplers in sewage to monitor a Hepatitis A outbreak at an Amsterdam school, poster presentation at the Global Wastewater Conference, 2023

Hawksley, T. "Proposal for the Drainage of London" Sanit Rev J Public Health. 1857 Apr;3(9):28-36. PMID: 30378959; PMCID: PMC5981566.

Hemalatha, M., Kiran Uday, Kuncha Santosh Kumar, Kopperi Harishankar Gokulan, CG, S. Venkata Mohan, and Mishra Rakesh. "Surveillance of SARS-CoV-2 Spread Using Wastewater-Based Epidemiology: Comprehensive Study." Science of the Total Environment 768 (May 1, 2021): 144704. https://doi.org/10.1016/j.scitotenv.2020.144704.

Hendriksen, René S., Patrick Munk, Patrick Murigu Kamau Njage, Bram a. D. Van Bunnik, Luke McNally, Oksana Lukjancenko, Timo Röder, et al. "Global Monitoring of Antimicrobial Resistance Based on Metagenomics Analyses of Urban Sewage." Nature Communications 10, no. 1 (March 8, 2019). https://doi.org/10.1038/s41467-019-08853-3.

Huang, Yue, Nan Zhou, Shihan Zhang, Youqin Yi, Ying Han, Minqi Liu, Han Yue-Hong, et al. "Norovirus Detection in Wastewater and Its Correlation with Human Gastroenteritis: A Systematic Review and Meta-Analysis." Environmental Science and Pollution Research 29, no. 16 (January 19, 2022): 22829–42. https://doi.org/10.1007/s11356-021-18202-x.

IA.PHP Indian Alliance for Public Health Preparedness, n.d. http://www.esallianceforpublichealth.org/ last accessed 02, Dec, 2023.

Ishtiaq, Farah. "India Must Scale up Wastewater Analysis for Health Surveillance." Nature, December 15, 2022. https://doi.org/10.1038/d44151-022-00130-5.

Keshaviah, Aparna, Megan B. Diamond, Matthew J. Wade, Samuel V. Scarpino, Warish Ahmed, Fabian Amman, Olusola Aruna, et al. "Wastewater Monitoring Can Anchor Global Disease Surveillance Systems." The Lancet Global Health 11, no. 6 (June 1, 2023): e976–81. https://doi.org/10.1016/s2214-109x(23)00170-5.

Kumar, Manish, Arbind Kumar Patel, Ankit Shah, Janvi Raval, Neha Rajpara, Madhvi Joshi, and Chaitanya Joshi. “First Proof of the Capability of Wastewater Surveillance for COVID-19 in India through Detection of Genetic Material of SARS-CoV-2.” Science of the Total Environment 746 (December 1, 2020): 141326. https://doi.org/10.1016/j.scitotenv.2020.141326.

Link-Gelles, Ruth, Emily Lutterloh, Patricia Schnabel Ruppert, P. Bryon Backenson, Kirsten St George, Eli S. Rosenberg, Bridget J. Anderson, et al. “Public Health Response to a Case of Paralytic Poliomyelitis in an Unvaccinated Person and Detection of Poliovirus in Wastewater — New York, June–August 2022.” Morbidity and Mortality Weekly Report 71, no. 33 (August 19, 2022): 1065–68. https://doi.org/10.15585/mmwr.mm7133e2.

Medema, Gertjan, Leo Heijnen, Goffe Elsinga, Ronald Italiaander, and Anke Brouwer. “Presence of SARS-Coronavirus-2 RNA in Sewage and Correlation with Reported COVID-19 Prevalence in the Early Stage of the Epidemic in The Netherlands.” Environmental Science and Technology Letters 7, no. 7 (May 20, 2020): 511–16. https://doi.org/10.1021/acs.estlett.0c00357.

Musehold, P. "Uber die Widerstand flahigkeit der mit dem Lungenauswurf - herausbeforderten Tuberkelbazillen im Abwassern, im Flusswasser und im Kultiverten Boden." Arb. Kaiserl. Gesundh., 1900, 17, 56

Naughton, Colleen C, Holm, Rochelle H, Lin, Nancy J, James, Brooklyn P, and Smith, Ted, "Online dashboards for SARS-CoV-2 wastewater data need standard best practices: An environmental health communication agenda" J Water Health. 2023 May;21(5):615-624. doi: 10.2166/wh.2023.312. PMID: 37254909.

Ndiaye, AK, Diop PAM, Diop OM, “Environmental surveillance of poliovirus and non-polio enterovirus in urban sewage in Dakar, Senegal (2007-2013)” Pan Afr. Med. J., 19 (2014), p. 243, 10.11604/pamj.2014.19.243.3538

Newton, Ryan J., Sandra L. McLellan, Deborah K. Dila, Joseph H. Vineis, Hilary G. Morrison, A. Murat Eren, and Mitchell L. Sogin. “Sewage Reflects the Microbiomes of Human Populations.” MBio 6, no. 2 (May 1, 2015). https://doi.org/10.1128/mbio.02574-14.

Phalkey, R.K., Shukla, S., Shardul, S. et al. Assessment of the core and support functions of the Integrated Disease Surveillance system in Maharashtra, India. BMC Public Health 13, 575 (2013). https://doi.org/10.1186/1471-2458-13-575

Playter, E. “Our Inland Lakes and Rivers, the Disposal of Sewage, and the Spread of Infectious Diseases.” Public Health Pap Rep. 1886;12:123-32. PMID: 19600265; PMCID: PMC2266144

Prasad, R. “Wastewater Study Detects a Large, Silent Wave in Bengaluru.” The Hindu, May 6, 2023. https://www.thehindu.com/sci-tech/wastewater-study-detects-a-large-silent-wave-in-bengaluru/article66816590.ece.

Priyadarshini, Subhra. “India’s Sewage Surveillance for SARS-CoV-2 Going down the Drain.” Nature India, May 21, 2021. https://doi.org/10.1038/nindia.2021.75.

Rajput, Vinay, Rinka Pramanik, Vinita Malik, Rakeshkumar Yadav, Rachel Samson, Pradnya Kadam, Unnati Bhalerao, et al. “Genomic Surveillance Reveals Early Detection and Transition of Delta to Omicron Lineages of SARS-CoV-2 Variants in Wastewater Treatment Plants of Pune, India.” Environmental Science and Pollution Research, November 3, 2023. https://doi.org/10.1007/s11356-023-30709-z.

Riordan, J T. “The 1961 Middletown Oral Poliovirus Vaccine Program. IX. Isolation of enteroviruses from sewage before and after vaccine administration.” The Yale journal of biology and medicine vol. 34,5 (1962): 512-21

SAMRC. “SARS-COV-2 Wastewater Surveillance Dashboard,” n.d. https://www.samrc.ac.za/wbe/.
Takuissu, Guy Roussel, Sébastien Kenmoe, Lucy Ndip, Jean Thierry Ebogo-Belobo, C Kengne-Ndé, Donatien Serge Mbaga, Arnol Bowo-Ngandji, et al. “Hepatitis E Virus in Water Environments: A Systematic Review and Meta-Analysis.” Food and Environmental Virology 14, no. 3 (August 29, 2022): 223–35. https://doi.org/10.1007/s12560-022-09530-

Sutton, Robert I., and Huggy Rao. Scaling Up Excellence: Getting to More Without Settling for Less. National Geographic Books, 2014.

Tandukar, Sarmila, Niva Sthapit, Ocean Thakali, Bikash Malla, Samendra P. Sherchan, Bijay Man Shakya, Laxman Shrestha, et al. “Detection of SARS-CoV-2 RNA in Wastewater, River Water, and Hospital Wastewater of Nepal.” Science of the Total Environment 824 (June 1, 2022): 153816. https://doi.org/10.1016/j.scitotenv.2022.153816.

Tlhagale, Mamohloding, Stanley Liphadzi, Jay Bhagwan, V. Naidoo, Jonas Korlach, Lani Van Vuuren, Gertjan Medema, et al. “Establishment of Local Wastewater-Based Surveillance Programmes in Response to the Spread and Infection of COVID-19 – Case Studies from South Africa, the Netherlands, Turkey and England.” Journal of Water and Health 20, no. 2 (February 1, 2022): 287–99. https://doi.org/10.2166/wh.2022.185.

Tiwari, Satya Brat, Pallavi Gahlot, Vinay Kumar Tyagi, Liang Zhang, Yan Zhou, A.A. Kazmi, and Manish Kumar. “Surveillance of Wastewater for Early Epidemic Prediction (SWEEP): Environmental and Health Security Perspectives in the Post COVID-19 Anthropocene.” Environmental Research 195 (April 1, 2021): 110831. https://doi.org/10.1016/j.envres.2021.110831.

Tran HN, Le GT, Nguyen DT, Juang RS, Rinklebe J, Bhatnagar A, Lima EC, Iqbal HMN, Sarmah AK, Chao HP. SARS-CoV-2 coronavirus in water and wastewater: A critical review about presence and concern. Environ Res. 2021 Feb;193:110265. doi: 10.1016/j.envres.2020.110265. Epub 2020 Oct 1. PMID: 33011225; PMCID: PMC7528884.

UK Government. “EMHP Wastewater Monitoring of SARS-CoV-2 in England: 1 June 2021 to 7 March 2022,” March 31, 2022. https://www.gov.uk/government/publications/monitoring-of-sars-cov-2-rna-in-england-wastewater-monthly-statistics-1-june-2021-to-7-march-2022/emhp-wastewater-monitoring-of-sars-cov-2-in-england-1-june-2021-to-7-march-2022#:~:text=The%20EMHP%20team%20coordinates%20with,see%20figures%201%20to%209.

“Virus Particles in Wastewater | Coronavirus Dashboard | Government.Nl,” December 8, 2022. https://coronadashboard.government.nl/landelijk/rioolwater.

Wannigama, Dhammika Leshan, Mohan Amarasiri, Phatthranit Phattharapornjaroen, Cameron Hurst, Charin Modchang, Sudarat Chadsuthi, Suparinthon Anupong, et al. “Tracing the New SARS-CoV-2 Variant BA.2.86 in the Community through Wastewater Surveillance in Bangkok, Thailand.” Lancet Infectious Diseases, October 1, 2023. https://doi.org/10.1016/s1473-3099(23)00620-5.

WastewaterSCAN. “Home - Wastewater Talks. We Listen.,” October 24, 2023. https://www.wastewaterscan.org/en?gclid=Cj0KCQiAjMKqBhCgARIsAPDgWlwC3H1BeQr9vYGBFE021s6ltPpEzzp0aPWUMjhz6c4xMzGfY5jdMsEaAsbUEALw_wcB&utm_medium=search&utm_content=adgroup2&utm_source=google&utm_campaign=wastewaterscan.3.

WHO, n.d. https://www.afro.who.int/news/how-wastewater-surveillance-helping-covid-19-fight

Wilson, W J. “Isolation of Enteric Bacilli from sewage and water and its bearing on epidemiology” British medical journal vol. 2,3794 (1933): 560-2. doi:10.1136/bmj.2.3794.560

Yoo, Byung-Kwang, Ryo Iwamoto, Ung-il Chung, Tomoko Sasaki, and Masaaki Kitajima. “Economic Evaluation of Wastewater Surveillance Combined with Clinical COVID-19 Screening Tests, Japan.” Emerging Infectious Diseases 29, no. 8 (August 1, 2023). https://doi.org/10.3201/eid2908.221775.

Zhang, Ying, Kongquan Zhu, Weixin Huang, Ziyue Guo, Senhua Jiang, Cao Zheng, and Yang Yu. “Can Wastewater Surveillance Assist China to Cost-Effectively Prevent the Nationwide Outbreak of COVID-19?” Science of the Total Environment 829 (July 1, 2022): 154719. https://doi.org/10.1016/j.scitotenv.2022.154719.