The Annual Review of Interdisciplinary Justice Research
Volume 12, 2023

Edited by
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The University of Winnipeg
Centre for Interdisciplinary Justice Studies (CIJS)

ISSN 1925-2420 (Print)
ISSN 2816-4253 (Online)

IJR, 2023, Vol. 12, pp. 4-29

Watching Epidemiology Go Down the Drain: Wastewater Surveillance and Public Health

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Abstract

Wastewater-based epidemiology has been a powerful tool for community-level surveillance of SARS-CoV-2 virus during the COVID-19 pandemic. Individual diagnostic testing is inherently biased due to assumptions of access and voluntary participation. While wastewater surveillance offers a different set of biases, it has revolutionary potential to guide effective resource allocation through low-resolution monitoring at unprecedented scale and low cost. As governments build capacity for these tools, conversations are needed about the many biomarkers of human health, behaviour, and identity that can be detected through our sewage systems. While the potential for abuse of this information is low, wastewater epidemiology is inherently distasteful and invasive; it uses data collected from our most private moments to glean insights into other deeply personal information, like our health and consumption habits, and can be correlated with income and cultural identity. The potential exists for misuse of these data, particularly when combined with other personal information or in controlled settings like prisons. Researchers and institutions must be accountable not just for the data they produce, but also how law enforcement, government, and industry partners use those data.

Keywords: bioethics, epidemiology, privacy, surveillance, wastewater

SARS-CoV-2, the virus that causes COVID-19, was detected in wastewater early in 2020. While initial concerns focused on transmissibility, many researchers recognized the value of wastewater as an epidemiological tool to track virus concentrations, monitor emerging viral strains, and gain community-level data at times when individual testing had limited effectiveness. Humans put a wide range of substances down their drains, many of which can be detected, quantified, and correlated with a person's health. These data can range from virus particles shed from the gastrointestinal tract to undigested organic wastes that correlate with one's diet and metabolism, including pharmaceuticals they have consumed. Wastewater monitoring is a near-invisible tool for surveilling a population, examining what that population consumes and, through the public health lens, what is consuming the population. While the COVID-19 pandemic is not the first widespread use of wastewater monitoring for public health, a dramatic leap in public awareness of these tools and innovative applications raises questions of their use.

While the right to privacy is currently a nebulous legal concept, one could reasonably assume that if it exists anywhere, it must be within the sanctity of the bathroom. However, the capabilities of these deeply personal data are potentially more nuanced than current media commentary or scientific reports suggest. Handling wastewater is distasteful in ways that can deflect warranted scrutiny. Biomarkers can reveal current viral infection, as is the case with COVID-19, but also health and disease status, consumption of legal and illicit drugs, and even dietary metabolites that correlate with socioeconomic status and education level. The inevitable result of consumption is waste, and the access to, and use of, data that measure who we are and what and how we consume can be a powerful and dangerous tool.

Analysis of big data in Canada between 2016 and 2021 identified four persistent problems: the public is largely unaware of the data being collected; surveillance mechanisms and sharing of data are opaque and convoluted; surveillance technologies evolve faster than they can be regulated; and some groups are more vulnerable to surveillance and its impacts (Lyon, 2022). The social, economic, and bureaucratic upheaval of the pandemic often exacerbated these problems. While Lyon speaks of aggregate digital surveillance and data, these issues appear in wastewater surveillance, as the accumulation and consumption of data from supposedly anonymized and unaware populations lacks regulation, potentially exposing systemically disadvantaged populations. The tools to sequence viral pathogens in our sewers can collect human genome information, revealing ancestry and potential genetic risk factors. While currently impractical compared to other means of cataloguing or examining human genetic diversity, studies show that the capacity exists. Kapoor et al. (2017) sequenced human mitochondrial DNA from wastewater and identified matrilineal haplogroups such as West Eurasian, sub-Saharan African, and American Indian ancestry that correlated with population census data. Genetic information poses higher risks to privacy because it persists longer than more transient biomarkers such as acute infections or drug metabolites, and the information can go beyond an individual to their biological relatives.

Wastewater monitoring's capacity to identify biomarkers is not a reason to abjure these technologies, but should lead to deep interrogation on the use of these data and a universal commitment to bioethics from researchers and institutions using these tools. Researchers must lead conversations about responsible data use for the benefit of all our communities and particularly those in the wastewater catchment. This paper will explore some biomedical applications of wastewater surveillance and examine ethical issues that can underpin private and public consumption of these data, which are often collected without knowledge or consent. I will unpack potential problems in our current system and propose key questions that any body undertaking or authorizing wastewater surveillance must ask for the good of the community being monitored.

Wastewater Surveillance as Disease Monitoring

The first large-scale wastewater monitoring as an outbreak early warning system was part of the poliovirus eradication efforts, referred to as environmental surveillance (Nelson et al., 1967). Poliovirus spreads through ingestion of contaminated water, so monitoring wastewater for virus particles can track current cases and detect subclinical concentrations of virus to enable a pre-emptive public health response. Poliovirus can cause the disease poliomyelitis, often called polio. Most cases of polio are asymptomatic, but approximately one in 200 develop potentially life-threatening muscle weakness or fatal respiratory system paralysis (reviewed in Pallansch et al., 2013). The virus can remain infectious in the environment — in contaminated water or soil — for weeks to months (Kline et al., 2022). Even when spreading in a community, most infections are asymptomatic or mild transitory illness; thus, the virus can circulate undetected for years between identified cases of paralytic poliomyelitis, particularly in rural settings without sufficient water treatment (Kalkowska et al., 2015; Khan et al., 2018). Travel can bring an asymptomatic case into an urban centre, creating the potential for an outbreak.

Routine wastewater surveillance detected asymptomatic cases of polio in Israel in 2013, allowing health officials to thwart outbreaks with targeted vaccinations (Anis et al., 2013; Brouwer et al., 2022; Kopel et al. 2014). While polio vaccines are part of the standard schedule for childhood immunizations in Canada and other countries, the COVID-19 pandemic has heightened barriers to routine childhood vaccinations through restrictions to accessing non-critical health services, as well as fomenting the politicization of vaccines (Ota et al., 2021). An increase in the population's vulnerability to vaccine-preventable diseases may have contributed to the 2022 polio outbreaks in New York, London, and Jerusalem.

The World Health Organization (WHO) International Health Regulations (IHR) function as a set of agreements that aim "to prevent, protect against, control and provide a public health response to the international spread of disease in ways that are commensurate with and restricted to public health risks, and which avoid unnecessary interference with international traffic and trade" (World Health Organization, 2005, p. 10). The IHR third edition in 2005 specifically aimed to create and maintain a system that can address any health risks by leveraging all available tools to investigate outbreaks, including gathering data from information and communication technologies and unofficial sources. While the WHO includes the tertiary goal of "introduc[ing] important safeguards to protect the rights of travellers and other persons in relation to the treatment of personal data, informed consent and non-discrimination in the application of health measures under the Regulations" (World Health Organization, n.d.), they also normalize data collection as a requisite practice to participating in global society. The stated focus on safeguards for privacy and travel speaks to the neoliberal centrality of the individual over the community (Blouin-Genest, 2015), while the listed value of the individual nation-states participating in the monitoring and reporting of disease outbreaks is "to limit the spread of health risks to neighbouring countries and to prevent unwarranted travel and trade restrictions" (World Health Organization, n.d.). The importance of maintaining borders and personal freedoms in the face of outbreaks often has an opposite effect, as French and Monahan (2020) note:

> The declaration of an emergency also provides moral license to depart from business as usual, and indeed we have since seen many countries take drastic measures to contain the spread of COVID-19, including implementing travel bans and quarantines, as well as intensified surveillance in places like airports. (p. 3)

Using surveillance with limited invasive and personalized data appears preferable, but as French and Monahan point out, the dangers of normalizing additional layers of monitoring means the "'solution' will likely invite even further data-harvesting and -sharing" (p. 6). This concern around the collection of the data must be weighed against the capacity for data-driven responses to the rising of non-COVID and vaccine-preventable diseases, particularly in large urban populations.

The COVID-19 pandemic lockdowns broadly impacted many non-critical health services, including childhood vaccinations (Lee et al., 2021). Following pandemic lockdowns, social gatherings resumed faster than these vaccine schedules, while vaccine-preventable diseases such as poliovirus and polio-related enterovirus D68, which appear to have caused hundreds of cases of acute flaccid myelitis in children in recent years, have re-emerged with the lifting of pandemic restrictions (Nguyen-Tran et al., 2022; Tedcastle et al., 2022). Pandemic restrictions impacted the case numbers of many common childhood infections (Yamamoto-Kataoka et al., 2022) and wastewater surveillance can be a resource-efficient way of monitoring pathogens within communities as restrictions are lifted. This monitoring is part of the national obligation under the IHR to detect acute health events and respond.

Epidemiologists and public health officials have an obligation to provide guidance on current and potential pathogens. To reduce harms, data collected from individual incidents can illuminate broader trends — an inherent conflict with patient privacy. Health officials may be obligated to share enough information with the public to enable people to assess personal risks and make informed decisions. Research standards consider privacy maintained if sharing or publishing of those data could not reasonably be harmful to those individuals; however, while individual privacy may be maintained, improving technologies of wastewater surveillance complicate the collection of these data.

Wastewater Surveillance as Diagnostics

In 2022, many governments described the novel coronavirus pandemic as over. As SARS-CoV-2 variants will likely continue circulate for the foreseeable future, declaring the pandemic over reduces emergency resources and public health measures. At-home test kits and the relative lack of reported diagnostics skew statistics like test positivity rate. If only those hospitalized with respiratory infections have reportable tests, the positivity rate describes the percentage of respiratory pathogen hospitalizations for which COVID-19 is responsible; this number will decrease as other diseases rise in prominence, not necessarily because of a decreased community burden of COVID-19. As often happens after a disaster appears to have ended, epidemiologists and public health officials will need to focus on efficiency to continue their work and few systems are as fiscally efficient as wastewater surveillance.

Wastewater testing can be based at a sewage treatment plant with a catchment area that covers hundreds of thousands of people, or can be conducted by collecting samples from a neighbourhood, city block, or single building. As molecular biology tools become cheaper and easier to use, high-throughput systems can process hundreds of samples and portable field kits can rapidly analyze samples. These advances mean that wastewater monitoring can overcome financial barriers with a low cost per sample in large centres and low-cost deployment in remote settings. Pathogens and biomarkers in wastewater are often relatively stable compared to other microbiological specimens, providing additional flexibility in collection and transportation. These technological advances bring wastewater monitoring to historically underserved areas, but also mean smaller catchment areas can be monitored: narrowing catchments reduces the anonymity that comes from sampling large populations.

Diagnostic testing is inherently biased because it relies on assumptions of access and voluntary participation (Gable et al., 2020). Accessing a site may be inhibited by barriers to physical travel, along with broader socioeconomic barriers such as inflexible work hours, lack of sick leave, or obligations like caring for family members, which are also suggested causes for the COVID-19 pandemic's disproportionate harm to minoritized communities (Tai et al., 2021). Wastewater surveillance offers different biases, but can be employed as a low-resolution complementary tool to allocate diagnostic and treatment resources. This form of diagnostics cannot replace individual testing but can offer a 30,000-foot view. As French and Monahan (2020) note,

> from a surveillance studies perspective, this definition of disease surveillance and the WHO's guidelines for surveillance of COVID-19 leave unnamed a wide swath of practices implicated in the surveillance of presumptive coronavirus cases. Between the categories of the suspected, the probable, and the confirmed lies a mess of complex social reality. (p. 4)

Wastewater tracking does not pinpoint specific cases, but can create social pandemic anxieties, or dis-ease, as French and Monahan call it. There is always lag between infections and reported confirmed cases, but more sensitive detection and modelling from wastewater viral RNA can help predict case trajectories, prepare hospitals, and distribute supplies.

Wastewater-monitoring capabilities have grown in recent years. Direct detection of SARS-CoV-2 virus builds on poliovirus surveillance, while DNA-sequencing technologies have become faster, more sensitive, and more portable. Seasonal influenza outbreaks can be monitored through wastewater, in one case predicting a city-wide outbreak by more than two weeks (Mercier et al., 2022). Wastewater testing was rapidly adapted to mpox surveillance (de Jonge et al., 2022), which disproportionately impacts men who have sex with men. For many sociocultural reasons, men who have sex with men can face additional barriers accessing healthcare; wastewater monitoring can reduce barriers to community-level diagnostics, helping deploy additional resources and prepare healthcare facilities. However, government surveillance monitoring the health and, indirectly, behaviours of individuals whose sexual identities have previously been both pathologized and criminalized is deeply concerning for privacy and autonomy. Lee et al. (2012), in their discussion of public health surveillance, note the process sits at the intersection of principles of clinical and public health ethics. The competing ethical priorities are the health care provider's responsibility to protect patient confidentiality (derived from the ethical principle to respect the patient's autonomy to have a say in the dissemination of her or his health information) and the public health authority's responsibility to use the information to improve population health. Specifically, the right to keep one's health data private is an exercise of one's autonomy, a sort of informational privacy, which is emphasized in clinical encounters (p. 39). Surveilling historically stigmatized and overpoliced communities, even for the purposes of public health, complicates issues of personal autonomy and community health.

Wastewater Surveillance as Community Surveillance

Antibiotic resistance in bacteria, particularly around our personal microbiota, can provide valuable insights for researchers and pharmacologists working in antimicrobial stewardship. Microbes' capacity for horizontal gene transfer — sharing genetic material across lineages — means the presence of antimicrobial resistance genes in nonpathogenic microbes increases the chances of finding them in pathogenic microbes in the same environment. Our current microbial surveillance system almost exclusively uses samples that hospitalize people and are sent for diagnostic testing, stripping the context from these microbes. It is akin to attempting to assess the prevalence of firearms based solely on guns entered into evidence in court. A broader view helps monitor trends with larger, more reliable sample sizes; looking beyond clinical specimens can identify other factors driving antimicrobial resistance, such as pharmaceuticals in agricultural runoff, residual antimicrobials in improperly treated wastewater, or toxic metals.

Statistics Canada and other groups use biological metabolites in wastewater to track trends in alcohol and drug use (Lopez-Garcia et al., 2019; O'Keeffe, 2021). These data are often more reliable than surveys, particularly around topics of drug use where there may be stigma or fear of repercussion (van Wel et al., 2016), as researchers can compare legal sales of controlled substances with biomarker metabolites to estimate the size of illegal sales or monitor for new metabolites indicating novel psychoactive substances. However, these techniques have limitations: wastewater analysis can have difficulty distinguishing biomarkers from stimulant medications prescribed for attention-deficit/hyperactivity disorder (ADHD), such as Dexedrine, from illicit amphetamines (Hall et al. 2012). Researchers can detect exposures to toxic metals through metabolites associated with chronic exposure, which can identify communities with high levels of toxic-metal risk or harm, regardless of the sources, including exposures that might otherwise be undetectable in workplace safety inspections (Markosian & Mirzoyan, 2019).

Curtailing wastewater monitoring would have significant consequences on our capacity to detect and discourage abuses of our community sewers. Strict limits exist on what toxic materials can be added to wastewater, but as bad actors sometimes dump materials rather than pay for decontamination or safe disposal, monitoring for toxins or runoff is a way to detect this pollution. Forensic data can trigger investigations or legal authorities to inspect facilities that may be dumping wastes. More specific monitoring, sampling from smaller sewer catchments, or using in-sewer sampling robots can help to identify sources of pollution by monitoring smaller catchments before they connect to a treatment facility. If sampling takes place within a public sewer, moving perpendicular to a building’s effluent pipe joining the public sewer, specific search warrants would typically not be required — as the barriers of private property are not being crossed — but the data could reliably triangulate a single source of biomarkers. Thus, the same tools that offer greater specificity in identifying bad actors could also carry out neighbourhood-level or street-level surveillance for other biomarkers of interest.

Wastewater monitoring is likely to expand, both for epidemiology and as a broader research tool. Because of the links to some of our most private and vulnerable moments, wastewater surveillance can appear more intrusive than it actually is (Hall et al., 2012). Publicized SARS-CoV-2 tracking has made more researchers aware of these systems, and a lack of public concern compared to other more direct public health tools, such as masks and vaccinations, put Canada in a position to expand wastewater surveillance. However, ethical issues should be addressed, particularly as these tools move outside the justifications of a public health emergency.

Anonymity, Privacy, and Data

A principle of biosample collection, whether tissue, DNA, or wastewater, is that anonymization protects participants from potential harms by making individual tracking impossible. The parallel advantage for researchers is it masks any ethical obligation they may have toward any individual. Originally codified in the Nuremberg Medical Tribunal and subsequently reinforced in the Helsinki Protocol, biomedical research must obtain informed consent from participants. However, if the researchers cannot identify the participant to ask for that consent directly, the consent of an institutional research ethics board is sufficient, with the board acting to safeguard anonymized participants from foreseeable harms. Biobanks and genetic databases often practice intentional de-identification with samples so secondary consumers of data do not require consent from the original donor. As molecular biology investigations become increasingly powerful in breadth and depth, the limits of informed consent are already being stretched.

Stripping identifiable information is implicitly linked to the individual's loss of interest in the biological materials and the information they contain (Lowrance, 2002). Without any means of identifying an owner, tissues become *res nullius* — nobody's property — and thus can be claimed by researchers, institutions, or private companies (Tallaccini, 2005). Within the US, this process is called judicial transubstantiation, as the subject material becomes freely appropriable objective data without inherent value.

While basic research is greatly facilitated by mechanisms that circumvent conventional consent, surveillance is so integral to public health that the discipline could not exist without the legal and ethical authority to act without explicit patient consent (Lee et al., 2012). Wastewater requires no original informed consent, as samples are ostensibly collected anonymously. However, in contexts other than wastewater, researchers have demonstrated the ability to re-identify individuals from genotype data or even pooled DNA, given a reference sample (Homer et al., 2008). Current genomics research differentiates between whether a participant can be 'distinguished' or actually 'identified' in a way that compromises privacy and risks potential harms. However, distinguishing a single sample from a set of data without inferring the identity of the participant could still link them to other genetic or personal data in ways that increase the risk of potential privacy breaches. Depending on the size of the data set and other available information, something as seemingly inscrutable as wastewater cannot provide perfect anonymity. The question of a reasonable expectation of wastewater is also unsettled in Canada from a legal perspective. In 2009, the Supreme Court of Canada ruled in *R. v. Patrick* that the expectation of privacy is assessed by the totality of the circumstances; Patrick abandoned his original privacy interest in the contents of his garbage when he placed it in collection bags within reach of the edge of his property. However, a reasonable homeowner is aware that another person will collect their garbage; the courts have not yet taken up the question of what a reasonable homeowner would think will happen to the water going down their drain. In *R. v. Marakah* (2017), the Court simplified the assessment of privacy to whether one's expectation is objectively reasonable in a case involving cellphone text messages.

Administrative provincial database centres across Canada hold curated, de-identified records; linking information between databases can offer a more comprehensive understanding of individuals than any single data source. These records are not public and the standards to gain access to them are, justifiably, crucially high. However, glimpses of these and other personal data are often made public when researchers publish their findings and, when combined, can go beyond what participants, researchers, or ethics review boards may have intended. In 2018, Brumme et al. published work on how strains of HIV in Saskatchewan were adapted to immune system genes that are more common in Indigenous peoples. They reached this conclusion by combining genetic sequences of HIV and unrelated 2003 research on the genes related to diabetic kidney disease in Indigenous peoples in Saskatchewan (Chelico et al., 2020). The authors' note that "[i]t's almost as if the virus is nastier (in Saskatchewan)," where Indigenous peoples make up 16% of the population and up to 80% of HIV cases, is inexorably entangled with the social and structural effects of racism and colonialism that have shaped the HIV burden in Saskatchewan and across Canada. It also illustrates how a person does not need to be individually identified to risk being harmed by genomic research. The legal focus on individual privacy can mask the need to address legitimate family and group privacy concerns.

The nature of wastewater monitoring assures some amount of anonymization; we cannot know whose drains a virus particle or biomarker may come from, nor who was in any given building at the time. However, the relative anonymity of the sample depends on the size of the catchment. For COVID-19 monitoring, sampling regions ranged from over 100,000 people in a city to single university dormitories. In the case of the University of Arizona, wastewater monitoring of a dormitory in 2020 detected two asymptomatic or presymptomatic cases that were not detected using antigen testing (Washington Post, 2020). Ongoing monitoring allowed the University to quantify the effectiveness of their pandemic interventions, facilitating evidence-based policy decisions within the microcosm of a campus. The narrow focus of the catchment helped in facilitating quarantines and limiting spread, but pointed to the variable granularity of supposedly anonymous data.

Not all biomarkers are equally common, and some are more persistently associated with an individual than virus particles from a transient infection; as such, a catchment area that appears to anonymize participants for COVID-19 may not be equally anonymous for lifestyle-related or chronic biomarkers. For example, researchers have estimated prevalence and trends of type 2 diabetes by measuring metformin, a commonly used treatment for the disease (Xiao et al., 2019; Yan et al., 2019). The study of biomarkers of stable, chronic diseases becomes the study of people with those diseases and their locations over time. Researchers have successfully linked wastewater biomarkers to socioeconomic factors such as household income, education level, and cultural background based on distinctive signatures typically arising from food choices. Interestingly and a moral statement in itself, low income has stronger correlates than high income because low income is more associated with restrictions in lifestyle and consumption patterns, driving convergence (Choi et al., 2020). Larger quantities of supplemental data make correlations and deanonymization easier, meaning the relative privacy risk of a wastewater study can change over time due to factors beyond the researchers' control, such as time, public records, cross-database referencing, or social media data. As Lyon (2002) notes, "the rise of routinized, systematic surveillance has rather mundane origins that should not in the first place be construed as socially sinister... The outcomes of this process, however, are not inconsequential as far as social order and social control are concerned" (p. 243).

The inability to trace individual samples or biomarkers back protects privacy but invites a different set of problems, often known as the ecological fallacy: a set of analytical errors in which a statistical association can be true at the population level but may be false or even reversed at the sub-group or individual level. For example, countries that consume higher fat diets tend to have higher rates of cancer but, within those countries, people who consume higher fat diets may not be any more likely to develop cancer than people who consume lower fat diets. This consideration is important in wastewater monitoring because correlations between biomarkers and socioeconomic or health outcomes at the population level are not reliable predictors for any individual (Coffman et al., 2021).

Related to the ecological fallacy is the justified concern from minority populations of cultural erasure, as averaged data may ignore the lived experiences of many individuals. While a large population increases potential anonymity, it also increases the risk that subgroups get lost in statistical noise. As Coffman et al. (2021) describe, researchers need training in techno-social sensitivities before they lend their expertise and credibility to these efforts. Data aggregation inherently diminishes any minority within the data set by concealing it within the greater bulk of the majority. While a mathematical fact of averages, this process can also hew painfully close to the lived experiences of minoritized individuals. Biomarkers that correlate with ancestries, cultures, behaviours, and identifiers — such as income and education level — can be carelessly phrased as deterministic or preferential for the population. Biomarkers of socioeconomic "lack of stability" correlate with certain pharmaceutical and personal care products that are often not an individual's choice and are not a direct treatment for the stresses that define a lack of stability (Coffman et al., 2021). A biomarker intended as a neutral correlative can become an imposed label or victim-blaming for individuals who feel examined but not seen.

Uses, Abuses, and Limitations of Wastewater Data

Wastewater monitoring cannot currently be a global approach to public health, as resource discrepancies limit universal wastewater surveillance. As of 2017, an estimated two billion people worldwide live without basic sanitation (Street et al., 2020). Open defecation is not evenly distributed globally or between rural and urban settings, with the 10 countries with the highest rates of open defecation all in sub-Saharan Africa (Kohlitz et al., 2019). Improving these conditions are part of the WHO Sustainable Development Goals and will offer local and global health benefits (Griggs et al., 2013). Public health benefits from charting trends across time and region at a global level. This long view requires sharing expertise and resources globally, between regions and levels of infrastructure. This approach, the goal of the WHO IHR, also inevitably leads to increased surveillance, as infectious disease monitoring solidifies risks to public health and those risks legitimize the surveillance (Blouin-Genest, 2015).

Wastewater researchers must be aware of the disingenuous tactics that misrepresent averaged data about incomes, education, or crime. For example, wastewater monitoring for toxic metal exposure in a neighbourhood could expand the sampling region until the average falls below safety guidelines. These manipulations must be challenged by researchers, who must understand how their data and credibility can be abused. The highest potential for abuse of wastewater monitoring comes from large facilities where there is existing authority over the people on site, such as prisons or schools (Hall et al., 2012). Many institutions already have policies around drug use or disease that justify restricting freedoms for community safety. While Alberta Health Services, one of the least restrictive Canadian provincial health authorities (Ferguson, 2019), does not mandate vaccinations for children to attend public school, “if a highly contagious vaccine-preventable disease, such as measles, occurs at school, children with missing immunization information or declined immunization may be excluded from school to protect their health. In some cases, children may need to stay home for several weeks” (Alberta Health Services, 2018). Legal and administrative authorities enshrine the power to significantly disrupt peoples’ lives in the face of an immediate health threat, and these restrictions have been repeatedly tested through legal challenges during the COVID-19 pandemic. The threshold of immediacy and severity of threat is open to interpretation, but diagnostics and epidemiology are the cornerstone of any evidence-based decision to implement these powers. The release of raw data may instead offer anxieties of infection and the "unnamed are countless instances of interpersonal surveillance of the kind embodied in side-long looks at — and evasion of — others who dare to sneeze, cough, or even walk too closely to others in shared spaces such as airports, mass transit, or cafes" (French & Monahan, 2020, p. 4). The awareness, and presumption, of illness in a community can amplify structural inequalities, even with aggregate and anonymized data.

Individual examination or screening typically requires consent, but this can also be suspended under exceptional circumstances, as described in the *Quarantine Act*. In 1985, the Penitentiary Service Regulations of Corrections Services Canada were amended to allow drug testing through urinalysis and the practice was upheld in the face of *Canadian Charter of Rights and Freedoms* challenges, specifically on the grounds of section 7[1], section 8[2], and section 15(1)[3] (Holmes, 1999). While the legal framework for urinalysis in Canada has not been entirely settled, current practices require only reasonable grounds to compel a urine sample (Correctional Services Canada, 2015, 2017). A reasonable belief that drug use may be occurring somewhere in the carceral facility could be sufficient justification for wastewater testing, as it has limited immediate harms; however, potential harms remain from the misuse of these data.

Before casually dismissing these risks, researchers who collect data and administrators who use data must understand and commit to minimizing these harms. While these data can be used to allocate resources and provide support, potential abuses remain, such as collec-

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[1] Everyone has the right to life, liberty and security of the person and the right not to be deprived thereof except in accordance with the principles of fundamental justice.

[2] Everyone has the right to be secure against unreasonable search or seizure.

[3] Every individual is equal before and under the law and has the right to the equal protection and equal benefit of the law without discrimination and, in particular, without discrimination based on race, national or ethnic origin, colour, religion, sex, age or mental or physical disability.

tive punishments when wastewater shows evidence of drug use in the population and administrators want information at the individual level. At the same time, wastewater monitoring in prisons can corroborate survey data on drug use, reducing uncertainty for harm-reduction programs (Postigo et al., 2011). Wastewater analysis can potentially detect frequencies and trends that random urinalysis drug screenings would not (Brewer et al., 2014). Researchers conducting wastewater monitoring must acknowledge that ethical dangers arise not just from the collection and analysis of the data but also from how the data are used.

Conclusions: The Ethics and Responsibility of Wastewater Data

The power of wastewater monitoring to examine who we are and what we shed means that surveilling what is discarded is as powerful as controlling what we consume. The dangers of monitoring populations with differential granularity and silent surveillance means that researchers, police, and government may have access to data that exposes people's most private moments. Disease occurs at the intersection of a pathogen and a host. While public health originally focused on surveillance of the disease and, through that, surveillance of the pathogen, surveillance of patients has always been part of that. Outbreaks, epidemics, and pandemics are fundamentally social events and the data on the social determinants of health have never been more available to address injustices or to target the vulnerable. "[S]urveillance studies might address not only the specter of emerging infectious disease, but also the entangled web of social relations that this specter feeds off of and helps to catalyze" (French & Monahan, 2020, p. 1). While often valuable for community well-being, policies and practices built off anonymous yet invasive data raise ethical and legal complications.

Several research groups, utilities, and public health bodies, such as the Canadian Water Network, propose ethical frameworks for wastewater monitoring that are fundamental to addressing issues of justice. The capacity for good means that banning these tools, either directly or through imposing onerous regulations, is a failure of public health. O'Keeffe (2021) proposes a framework for evaluating wastewater-based monitoring programs that includes: selection of the correct indicator or biomarker; consideration of the detection limit;

comparison to existing monitoring systems; establishing the purpose of the monitoring; and identifying all necessary stakeholders for reporting, actions, and assessments of impact or effectiveness. Clearly defining the roles, responsibilities, and relationships, including interpretation of the results, is essential to maximizing the benefits of wastewater monitoring and minimizing potential harms. We need to not only establish limitations to protect participants and other people affected by decisions made using these data, but to ensure that community good is at the core of any actions the researchers undertake.

The issue of how to protect the best interests of de-identified participants without stymying biomedical research is at the heart of current conversations about biobank regulations and consent for anonymized research materials such as genome sequences. The statistical power necessary to find correlations is based on the strength of the effect and the sample size; when many genes contribute toward the odds of someone developing a disease, a sample size of millions may be necessary to confidently identify a potential correlate worth investigating. Requiring each researcher to gain informed consent from millions of potential DNA database participants is unduly burdensome for the risks to participants whose data is analyzed; this balance of risk and benefit has led to our permissive data-handling system in bioinformatics. Based on Canada’s current lack of legal regulations on human genome data (Caulfield et al., 2020), which are similarly vague in terms of relationships or obligations between researchers and de-identified participants, prospective laws are unlikely to provide sufficient nuance for expanding uses of wastewater surveillance.

Beauchamp and Childress’ 1979 text on bioethics sets out central principles to approaching biological research ethically. They unpack autonomy (affirming that patients have the right to make their own decisions), non-maleficence (doing no harm), beneficence (acting for the benefit of others), and justice — all of which are necessary to wastewater research (Beauchamp and Childress, 2019). To assess a proposal’s ethical merits and individual risks, one must consider the whole project, including the data’s end use, not just its collection and analysis (Hrudey et al., 2021). The obligation rests with researchers conducting surveillance to identify, evaluate, minimize, and disclose risks for harm before conducting their study. Public health is a government-funded societal good but, as noted by Fisher (2021), “socio-political forces are intertwined with disease surveillance and, as such, can impact biological incidences and prevalences or estimates or perceptions thereof, especially amid disease epidemics” (p. 6). The principle of beneficence states that researchers should generate studies that not only avoid doing harm, but that include, from the proposal onward, mechanisms for the population under study to benefit from the work. For populations subject to wastewater monitoring studies who are already subject to additional oversight, such as carceral populations, these benefits must be genuine — not paternalistic or patronizing — and in line with the values of the communities themselves. Community collaboration has been tremendously successful in health fields such as HIV research; these relationships help build the trust that is essential to long-term dialogue between researchers and participants. Communities must be able to voice their research priorities and hold scientists accountable for equitably sharing the benefits of studies conducted with their participation.

Researchers need to take responsibility not just for the studies they conduct but for the users of those data they generate. While researchers do not have authority over their collaborators, forethought and ethics statements can forward these conversations. All parties involved in wastewater surveillance need to understand the meanings and limitations of these data. Biomarkers, socioeconomic markers, and substance markers available along with disease-tracking mean that monitoring waste can reveal who we are, where we go, and what we consume. The COVID-19 pandemic has brought increased recognition in public health that releasing raw data without interpretation is potentially harmful. Institutional research ethics committees and funding bodies must require researchers to consider the applications of their findings and appropriate safeguards. Institutions that want to use wastewater monitoring, particularly in carceral facilities, must develop policies so these tools can benefit vulnerable populations without subjecting them to further risk. These are tools we morally must use, but also must use morally; to do less is simply wasteful.

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