REVIEW – Microbes & Disease

Wastewater monitoring, surveillance and epidemiology: a review of terminology for a common understanding

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One sentence summary: Number of articles per year referenced in PubMed by various terminologies related to wastewater-based epidemiology.

ABSTRACT

Response to the COVID-19 (coronavirus disease 2019) pandemic saw an unprecedented uptake in bottom-up efforts to incorporate community wastewater testing to inform public health. While not a new strategy, various specialized scientific advancements were achieved to establish links between wastewater concentrations of SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2) and public health outcomes. Maximizing public health benefit requires collaboration among a broad range of disciplinary experts, each bringing their own historical context to the central goal of protecting human health. One challenge has been a lack of shared terminology. Standardized terminology would provide common ground for this rapidly growing field. Based on the review herein, we recommend categorical usage of the term 'wastewater-based epidemiology' to describe the science of relating microbes, chemicals or other analytes in wastewater to public health. We further recommend the term 'wastewater surveillance' to describe continuous monitoring of health outcomes (either microbes or chemicals) via wastewater. We suggest that 'wastewater tracking' and 'wastewater tracing' be used in more narrow ways, specifically when trying to find the source of a health risk. Finally, we suggest that the phrase 'wastewater monitoring' be abandoned, except in rare circumstances when ensuring wastewater discharge is safe from a public health perspective.

Keywords: wastewater-based epidemiology; wastewater surveillance; wastewater monitoring; environmental surveillance; wastewater tracking; wastewater tracing

INTRODUCTION

A community's wastewater is a valuable tool for public health professionals because of the wealth of information it provides, including evidence of the circulation of infectious disease pathogens (Asghar *et al.* 2014), the levels and amounts of environmental exposures or toxicants (Gracia-Lor *et al.* 2018), the amount of different drugs used (Zuccato *et al.* 2008) and dietary patterns (Choi *et al.* 2019). The representative nature of wastewater for those connected to the sewer system, the anonymity
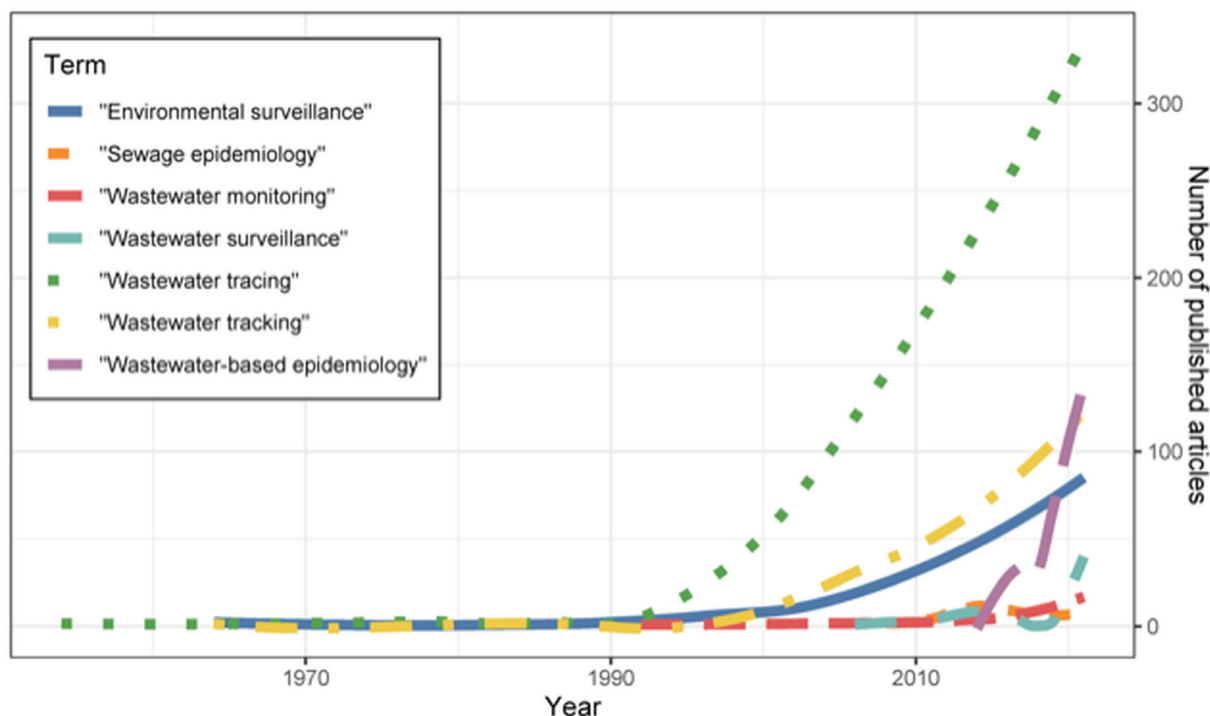
Figure 1. Trends in results from PubMed searches of various terminology related to wastewater-based epidemiology. Searches were conducted on 11 June 2021 with all filters cleared and terms in quotations, e.g. 'environmental surveillance'.

it provides and the low cost lend themselves well to gathering population-level health data from wastewater. Throughout 2020, the COVID-19 (coronavirus disease 2019) pandemic saw a broad and rapid adoption across the globe of testing wastewater for evidence of SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2) transmission in the community (Naughton *et al.* 2021), and a revived interest in wastewater as a source of public health information in general.

Testing wastewater to benefit public health is often a collaboration between engineers, microbiologists, chemists and epidemiologists. Each discipline has an essential role in maximizing the utility of testing wastewater, whether it be improving sampling, calibrating sample analysis or estimating trends. The various disciplines and entities involved in testing wastewater will more easily collaborate with a common understanding and standardization of terminology. However, that is not currently the case. Numerous terms have been used to describe testing wastewater for public health benefit, as evidenced by the number of articles in PubMed that reference various terminologies each year (Fig. 1). Herein, we review each of these terms in the literature and provide definitions and insight regarding their usage from a public health lens.

WASTEWATER TRACING OR TRACKING

Wastewater tracing and tracking are some of the first terms identified in the literature with regard to testing wastewater for public health benefit. In 1954, epidemiologists traced cases of rectal bilharziasis to wastewater contaminating a nearby reservoir (Bayer 1954). Similar to microbial source tracking, the terms 'tracing' and 'tracking' suggest efforts to identify a source of exposure for issues in public health, whether they be snails infected with *Schistosoma mansoni* as Bayer investigated, cases of an infectious disease via contact tracing (Eames and Keeling

2003) or investigation of a potential source of an environmental toxin. While these are the two most common terms of those investigated here, they seem a poor fit for most of the programs started for COVID-19 because the source of the pathogen is known, while its abundance is most often in question.

ENVIRONMENTAL OR WASTEWATER SURVEILLANCE

Public health surveillance is the ongoing systematic collection, analysis and interpretation of health-related data needed for the planning, implementation and evaluation of public health practice (WHO 2021). Public health surveillance dates back to the ancient Egyptians recording epidemics, but it was not functionally defined until 1963 by Alexander Langmuir (Choi 2012). The term environmental surveillance was first used in the peer-reviewed scientific literature in 1964; however, it was first used to describe radioactivity surveillance of nuclear reactors (Lieberman, Harward and Weaver 1970). The first report of environmental surveillance related to wastewater detailed the ability to surveil wastewater and other water bodies for cholera as part of an early warning platform (WHO Scientific Working Group 1980). Environmental surveillance was quickly adopted as a method to track poliovirus transmission (Asghar *et al.* 2014) and even prevent outbreaks of polio-caused paralysis (Brouwer *et al.* 2018). Usage of the term wastewater surveillance is much newer, and is obviously more specific in terms of what environment is being surveilled. Surveillance best encompasses efforts during the COVID-19 pandemic to systematically test wastewater for SARS-CoV-2 for public health benefit. The term wastewater surveillance ensures that environmental surveillance is not misconstrued as testing other environments such as the air for SARS-CoV-2 (Liu *et al.* 2020) or high-touch surfaces (Wan *et al.* 2021).

Table 1. Definitions of various terms relevant for testing wastewater for public health benefit.

Term	Public health purpose
Wastewater tracing or tracking	Using wastewater to identify the source of a pathogen or toxin
Environmental surveillance	Systematically and continuously testing some aspect of the environment for public health benefit; for infectious disease, the environment is relative to the mode of transmission
Wastewater surveillance	Systematically and continuously testing wastewater for public health benefit
Wastewater monitoring	Ensuring that wastewater discharge is not a public health risk
Wastewater-based epidemiology	The scientific field of linking pathogens and chemicals found in wastewater to population-level health

WASTEWATER MONITORING

The term wastewater monitoring has gained some popularity recently, but has not been historically used very often. In public health, the terms monitoring and surveillance can both refer to analysis of measurements aimed at detecting changes in the health status of populations, but they differ in a few important ways (Porta 2008). First, monitoring is intermittent rather than ongoing and not considered a system. Second, monitoring can be specifically used when ensuring that an intervention is working. Lastly, monitoring does not necessarily imply public health action. For example, COVID-19 vaccine coverage and effectiveness could be monitored using wastewater surveillance. Wastewater surveillance provides the data for the vaccine monitoring efforts. Other aspects related to the social determinants of health such as clean drinking water could also be monitored using wastewater surveillance along these same lines. Alternatively, the term wastewater monitoring suggests that the wastewater itself is being monitored, as happens regularly to ensure that wastewater treatment plants are not discharging pollutants into the environment. Thus, the term wastewater monitoring should rarely, if ever, be used in public health.

WASTEWATER-BASED OR SEWAGE EPIDEMIOLOGY

Epidemiology is the study and analysis of the distribution and determinants of health and disease in populations and the application of this study to the prevention and control of health problems (Porta 2008). Epidemiology is linked to hypothesis-based research about the prevalence and incidence of disease (or health) and elucidating the risk (or protective) factors associated with disease. The term sewage epidemiology was first utilized in the scientific literature in 2008, when Zuccato *et al.* (2008) estimated illicit drug use in Milan, Italy, with the concept of estimating illicit drug use from wastewater growing in popularity (Bohannon 2007). Sewage epidemiology fell out of use compared with wastewater-based epidemiology, which was first utilized in the scientific literature in 2014 to describe the use of ammonium to normalize measures of illicit drug use to the population (Been *et al.* 2014). The majority of articles referencing wastewater-based or sewage epidemiology build the science around estimating the prevalence of drug use from wastewater samples (Feng, Zhang and Li 2018). Wastewater-based epidemiology should be used with wastewater testing designed to test hypotheses, when reporting advances in methods in linking what is found in the wastewater back to the population, or generally when it is not linked to ongoing efforts for public health action.

DISCUSSION

In Table 1, we present the definitions and purposes of the different terms reviewed herein. We propose the adaptation and normalization of the term wastewater-based epidemiology, which is already in widespread use, to be a general scientific field encompassing all activities linking population-level health with pathogens, exposures or other health indicators in wastewater, sewage or sludge. However, operationally, the term surveillance is more descriptive for the continuous monitoring of factors affecting health, with the goal of providing information for public health action. Historically, environmental surveillance has been more often used than wastewater surveillance, but environmental surveillance is more broad than wastewater surveillance. In this context, it encompasses the monitoring of non-wastewater media for physical, chemical and biological agents that can lead to adverse health outcomes, including vector populations (Braks *et al.* 2011), dust (Pandey *et al.* 2016) and drinking water (Spira *et al.* 1980). Furthermore, epidemiologists prior to the COVID-19 pandemic have typically limited wastewater surveillance to fecal–oral transmission of pathogens (Kilaru *et al.* 2021). Therefore, while those involved in wastewater-based epidemiology would benefit from understanding the history of environmental surveillance for fecal–oral pathogens such as polio and typhoid, we suggest the use of wastewater surveillance as a term for monitoring trends in wastewater over time for public health benefit.

SUPPLEMENTARY DATA

Supplementary data are available at *FEMSMC* online.

Conflict of interest. None declared.

REFERENCES

Asghar H, Diop OM, Weldegebriel G *et al.* Environmental surveillance for polioviruses in the Global Polio Eradication Initiative. *J Infect Dis* 2014;**210**:S294–303.

Bayer FA. Schistosome infection of snails in a dam traced to pollution with sewage. *Trans R Soc Trop Med Hyg* 1954;**48**:347–50.

Been F, Rossi L, Ort C *et al.* Population normalization with ammonium in wastewater-based epidemiology: application to illicit drug monitoring. *Environ Sci Technol* 2014;**48**:8162–9.

Bohannon J. Hard data on hard drugs, grabbed from the environment. *Science* 2007;**316**:42–4.

Braks M, van der Giessen J, Kretzschmar M *et al.* Towards an integrated approach in surveillance of vector-borne diseases in Europe. *Parasit Vectors* 2011;**4**:192.

Brouwer AF, Eisenberg JNS, Pomeroy CD *et al*. Epidemiology of the silent polio outbreak in Rahat, Israel, based on modeling of environmental surveillance data. *Proc Natl Acad Sci USA* 2018;**115**:E10625–33.

Choi BCK. The past, present, and future of public health surveillance. *Scientifica* 2012;**2012**:875253.

Choi PM, Tscharke B, Samanipour S *et al*. Social, demographic, and economic correlates of food and chemical consumption measured by wastewater-based epidemiology. *Proc Natl Acad Sci USA* 2019;**116**:21864–73.

Eames KTD, Keeling MJ. Contact tracing and disease control. *Proc Biol Sci* 2003;**270**:2565–71.

Feng L, Zhang W, Li X. Monitoring of regional drug abuse through wastewater-based epidemiology: a critical review. *Sci China Earth Sci* 2018;**61**:239–55.

Gracia-Lor E, Rousis NI, Hernández F *et al*. Wastewater-based epidemiology as a novel biomonitoring tool to evaluate human exposure to pollutants. *Environ Sci Technol* 2018;**52**: 10224–6.

Kilaru P, Hill D, Anderson K et al. Wastewater surveillance for infectious disease: a systematic review. *medRxiv* 2021.

Lieberman JA, Harward ED, Weaver CL. Environmental surveillance around nuclear power reactors. *Radiol Health Data Rep* 1970;**11**:325–32.

Liu Y, Ning Z, Chen Y *et al*. Aerodynamic analysis of SARS-CoV-2 in two Wuhan hospitals. *Nature* 2020;**582**:557–60.

Naughton CC, Roman FA, Alvarado AGF *et al*. Show us the data: global COVID-19 wastewater monitoring efforts, equity, and gaps. *medRxiv* 2021. DOI: 10.1101/2021.03.14.21253564.

Pandey U, Bell AS, Renner DW *et al*. DNA from dust: comparative genomics of large DNA viruses in field surveillance samples. *mSphere* 2016;**1**:e00132–16.

Porta M. *A Dictionary of Epidemiology*. 5th edn. New York, NY: Oxford University Press, 2008.

Spira WM, Khan MU, Saeed YA *et al*. Microbiological surveillance of intra-neighbourhood El Tor cholera transmission in rural Bangladesh. *Bull World Health Organ* 1980;**58**: 731–40.

Wan B, Zhang X, Luo D *et al*. On-site analysis of COVID-19 on the surfaces in wards. *Sci Total Environ* 2021;**753**:141758.

WHO Scientific Working Group. Cholera and other vibrio-associated diarrhoeas. *Bull World Health Organ* 1980;**58**: 353–74.

WHO. *Public Health Surveillance*. 2021. file:///Users /dalarsen/Zotero/storage/9CG778YE/en.html (24 August 2021, date last accessed).

Zuccato E, Chiabrando C, Castiglioni S *et al*. Estimating community drug abuse by wastewater analysis. *Environ Health Perspect* 2008;**116**:1027–32.