Introduction on Wastewater Based Epidemiology and Applications in COVID-19

Pengfei Song, Postdoc, LIAM Lab

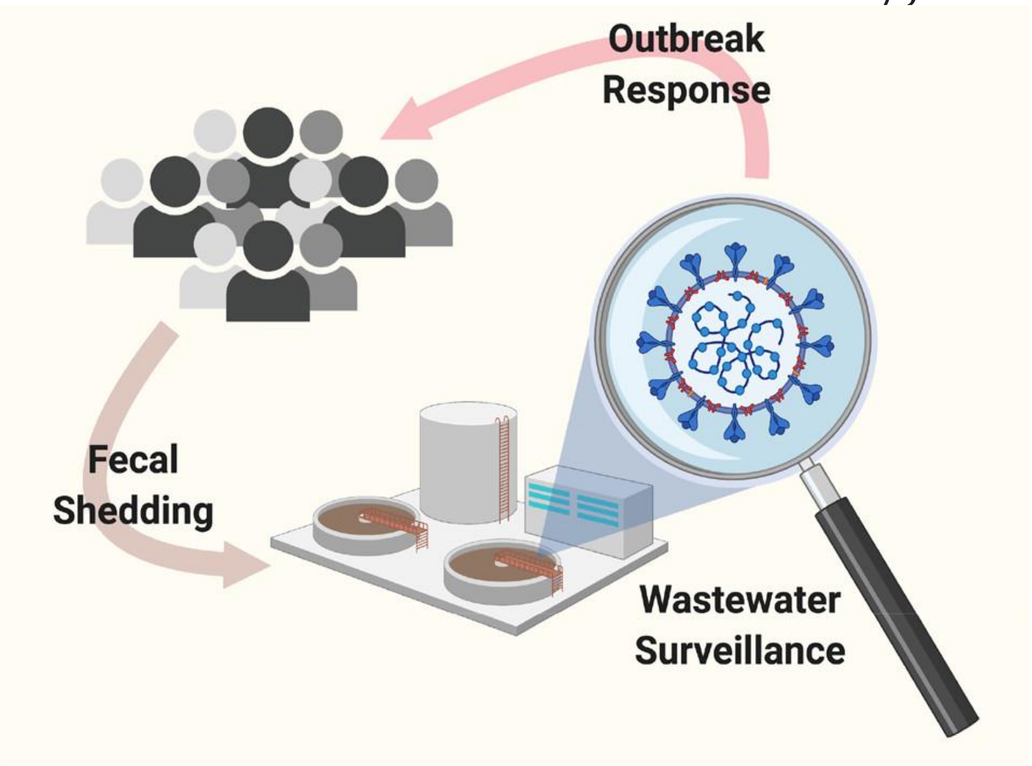
Content

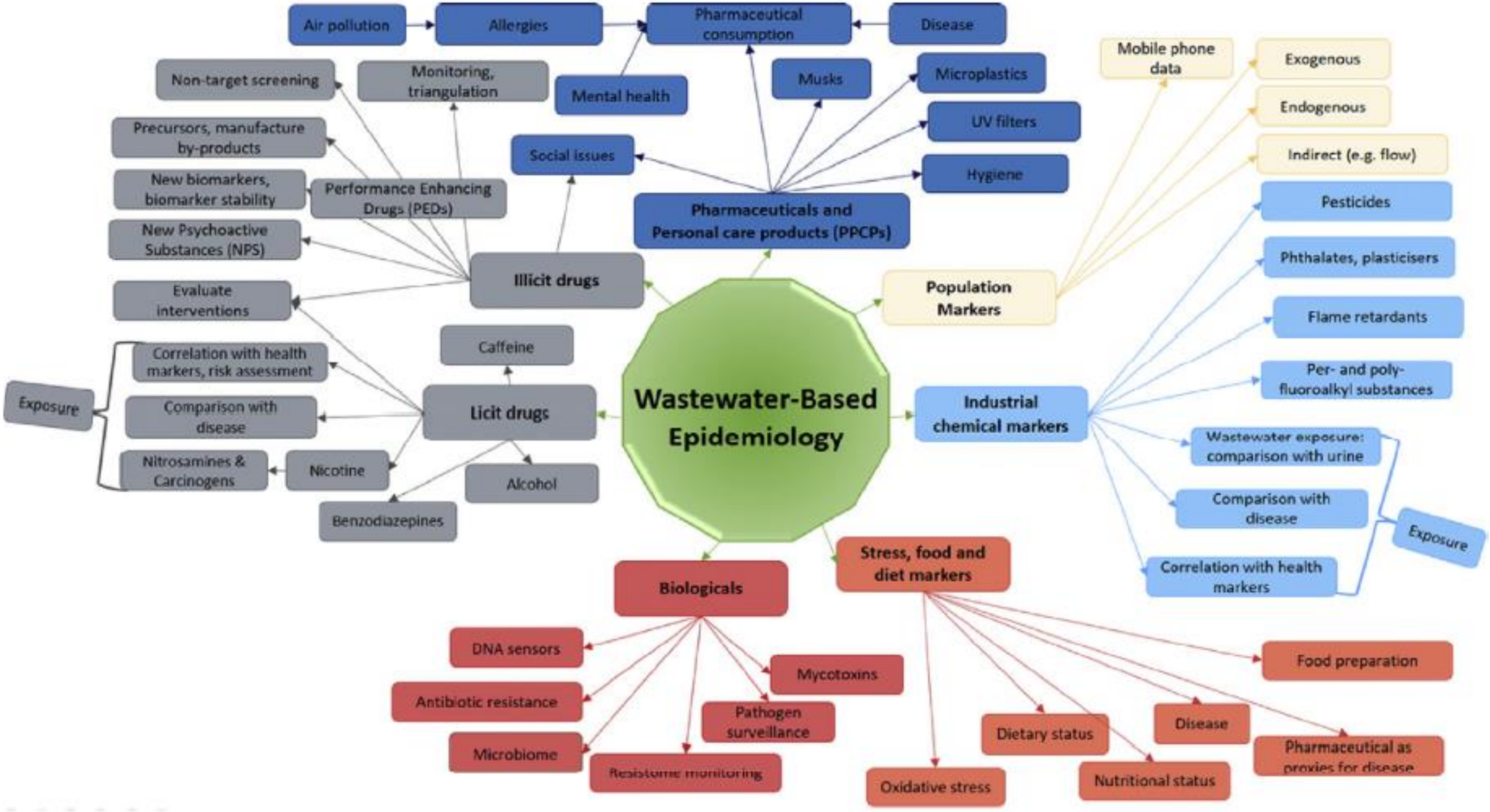
- Part I: Overview of wastewater based epidemiology (WBE)
- Part II: What can modelers do?
- Part III: Our work on WBE
- Part IV: Future Ideas

Part I: Overview of wastewater based epidemiology (WBE)

What is wastewater-based epidemiology (WBE)?

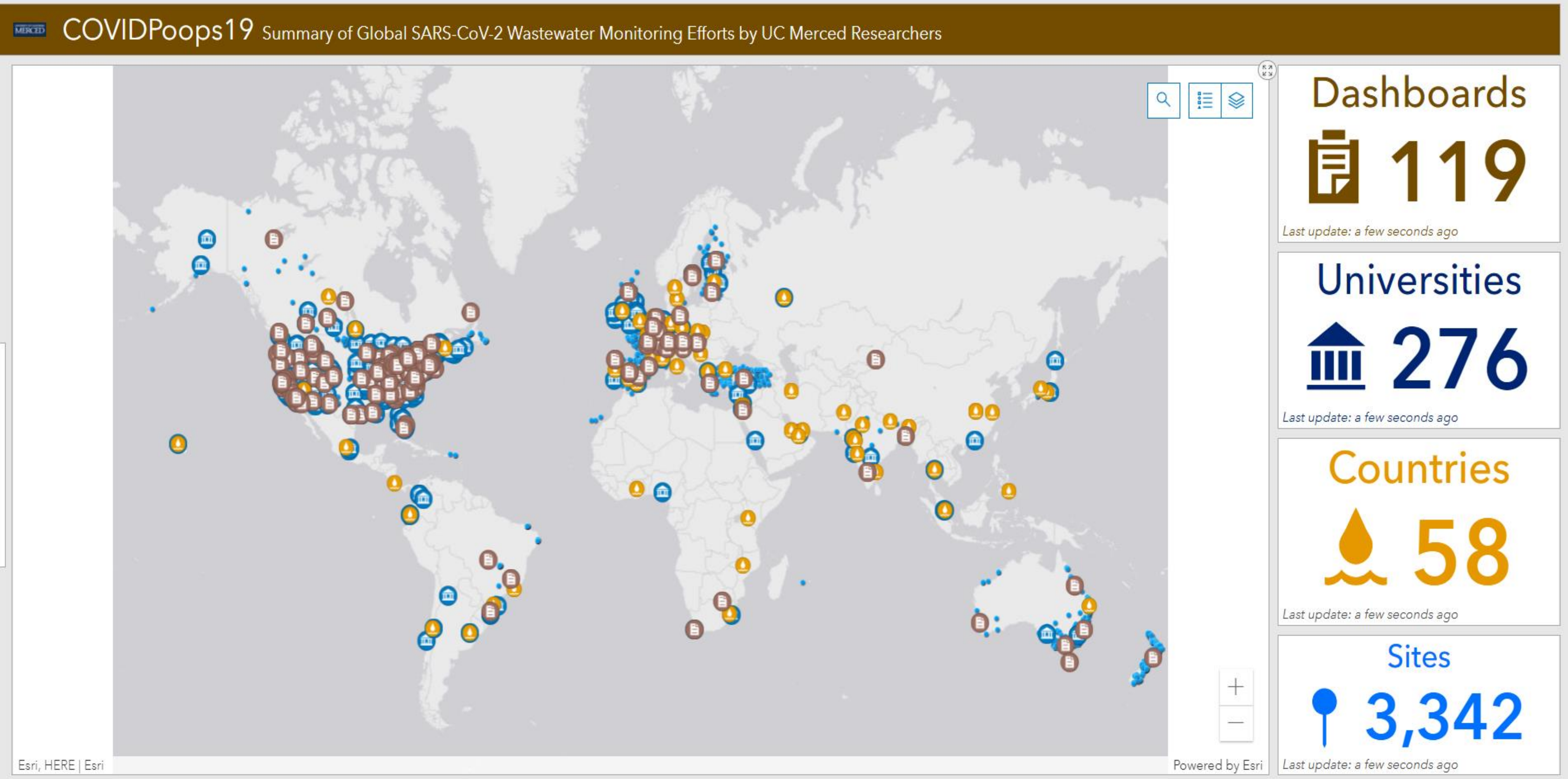
- WBE is a technique for determining the consumption of, or exposure to chemicals or pathogens in a population by measuring chemical or biomarkers in wastewater treatment plant.
- Commonly used to estimate illicit drug use and measure the load of pathogens such as SARS-COV-2 in a community, monitor antimicrobial resistance

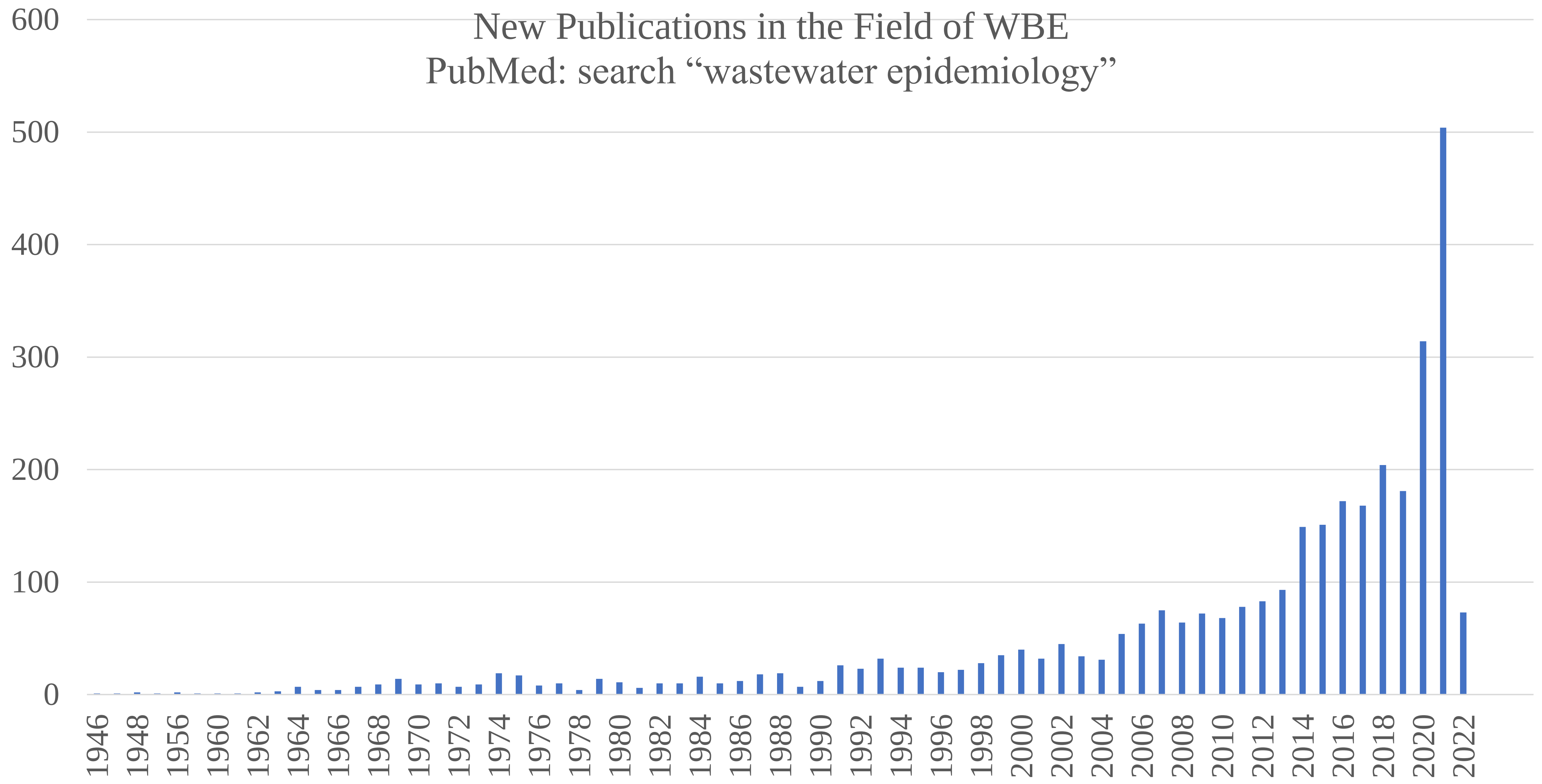




Choi P M, et al. 2018. TrAC Trends in Analytical Chemistry, 2018, 105: 453-469

3300+Testing Sites in 58 Countries

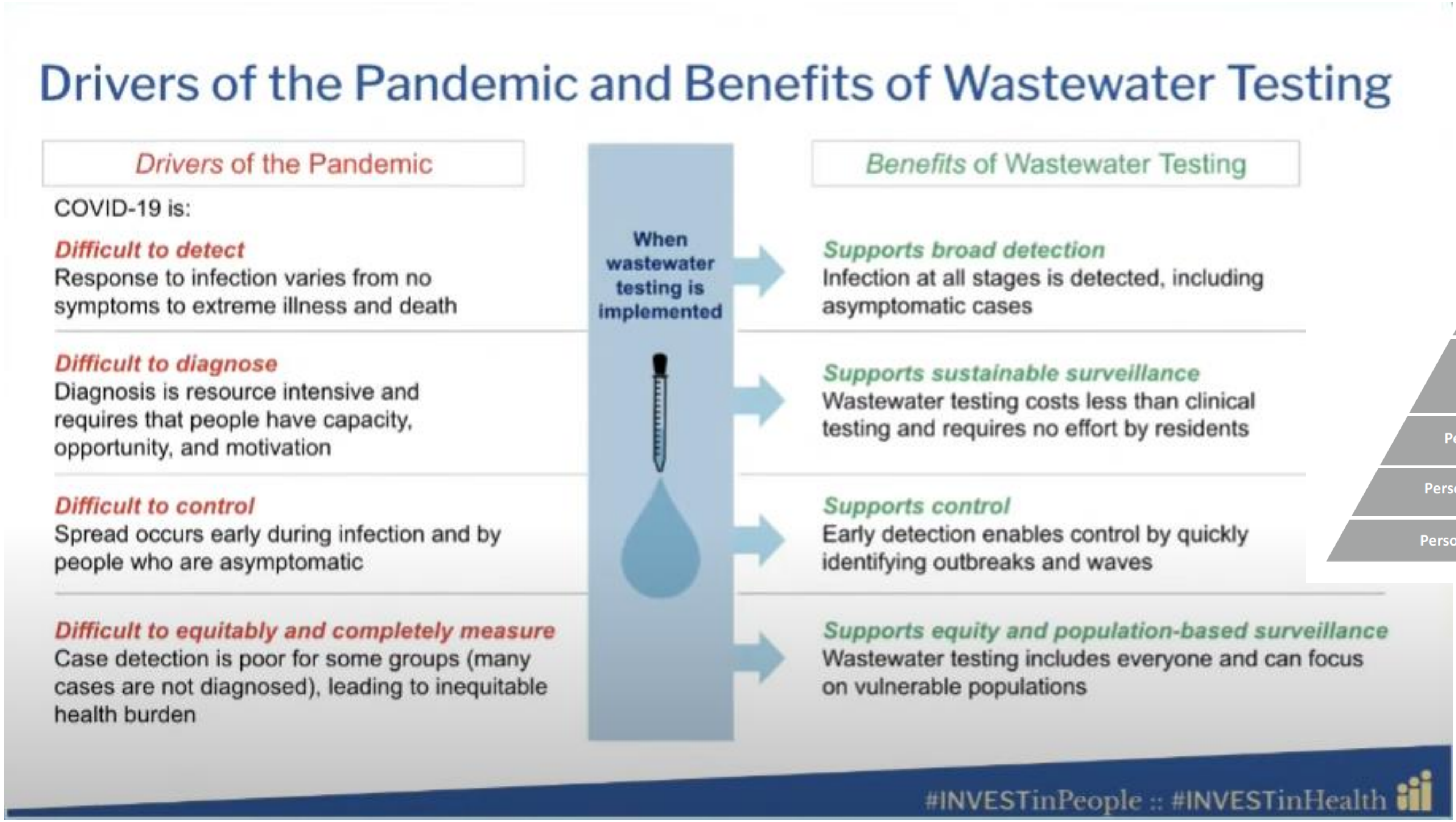


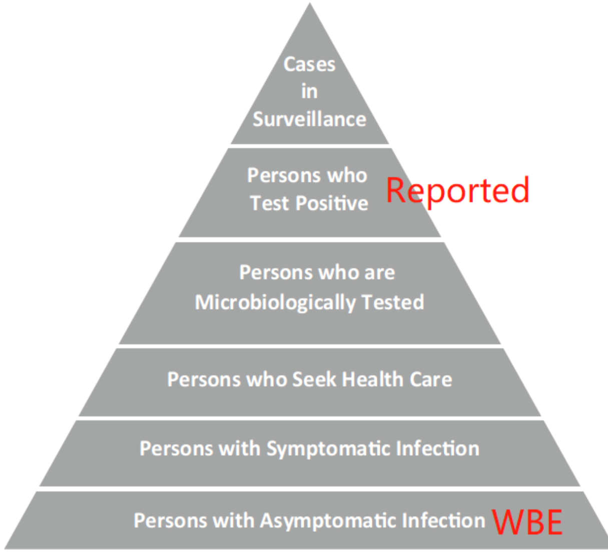

New Publications in the Field of WBE
PubMed: search "wastewater epidemiology"
600
500
400
300
200
100
0
1946
1948
1956
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022

Applications of WBE in SARS-COV-2

- Early warning for specific population in University, Community Hospital [1]
- Early warning for population-wide surveillance [1]
- Variant of concern, such as Omicron [4], novel influenza A viruses.
- Aircraft wastewater, overseas travelers control [2]
- Second act in vaccine distributions [3]
- Spatial and temporal distribution of SARS-CoV-2 diversity circulating in wastewater [5]
- Lockdown Effects: [6]

[1]Aguiar-Oliveira M L, et al. 2020. International journal of environmental research and public health
[2]Ahmed W, et al. 2022. Environment international, 2022
[3]Smith T et.al. 2021 JAMA Health Forum. American Medical Association.
[4]Kirby A E.2022 MMWR.
[5] Pérez-Cataluña A, et.al. 2021. Water research
[6]Wurtzer S, et al.2020. Eurosurveillance





Slide from world bank group [From waste to action: wastewater as a lens to control COVID-19 - YouTube]

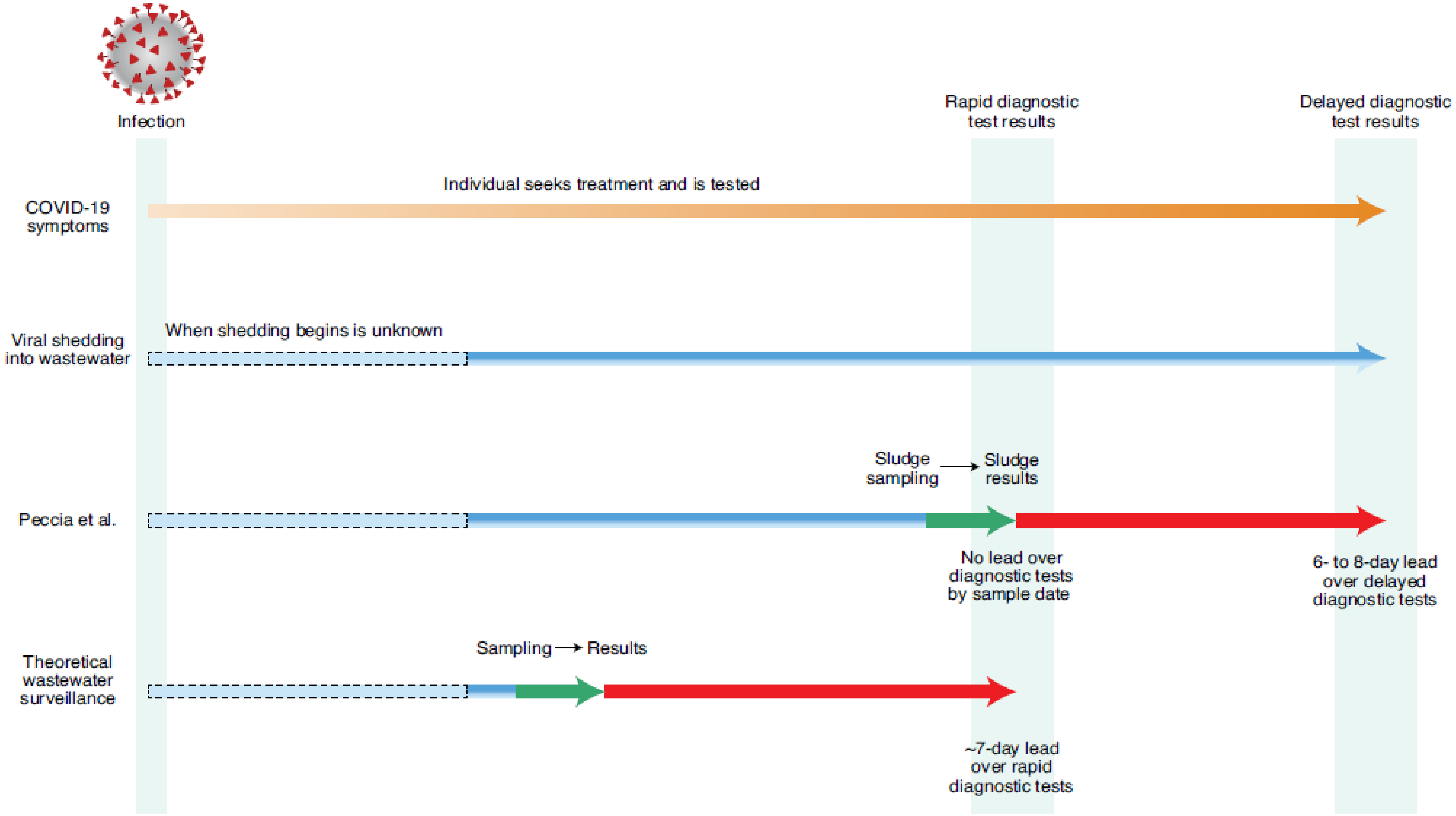
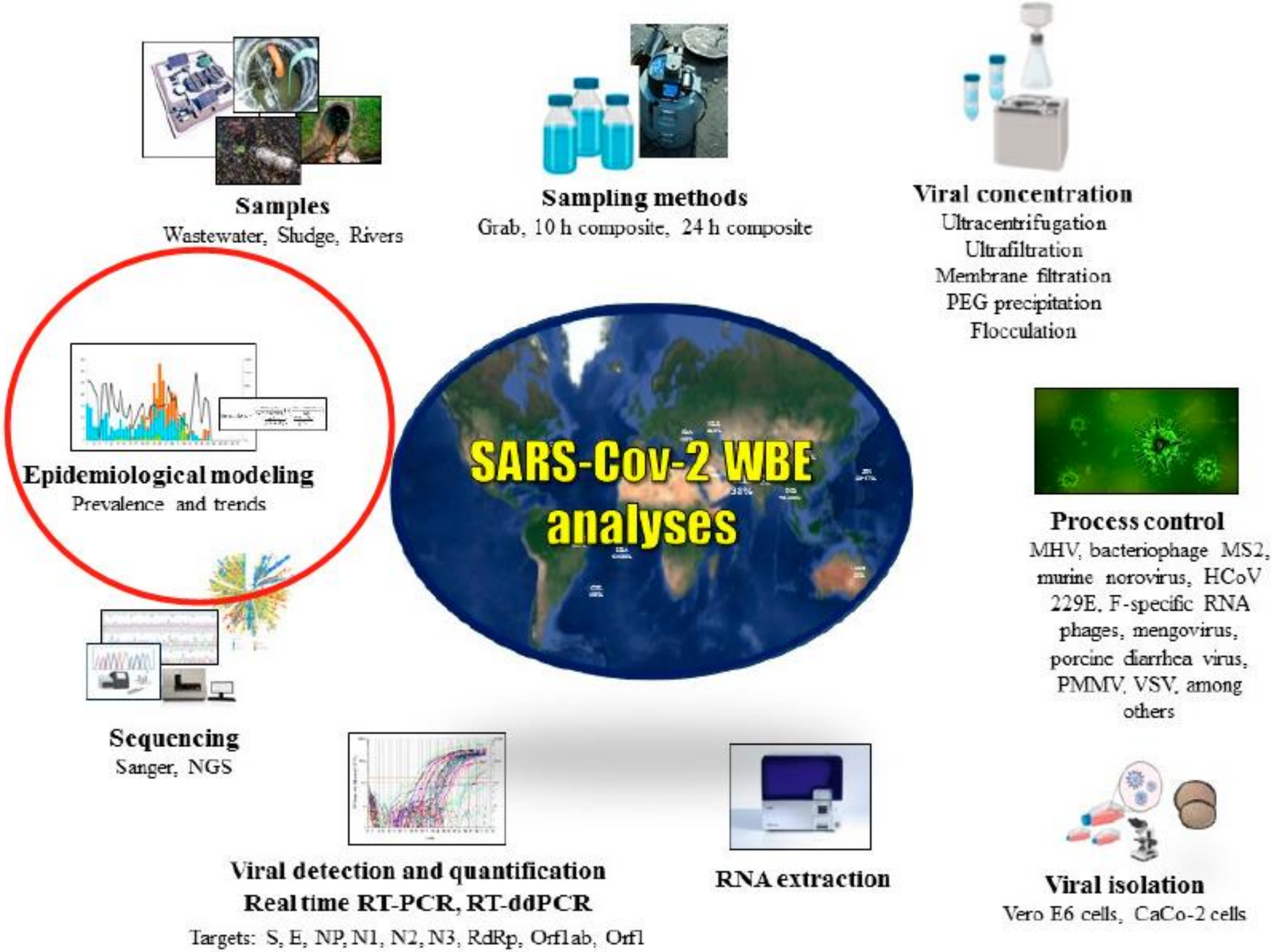


Fig. 1 | Observed and theoretical time lags between infection and detection of increasing SARS-CoV-2 transmission in wastewater and the health system.

- Theoretically, WWS can be earlier 7 days. Larsen D A. 2020. Nature Biotechnology, 2020, 38(10): 1151-1153.

Part II: What can modelers do?

- WBE is a project needing cooperation. Building the connection between WWS and Case Data based on the background knowledge of WBE.



Preparedness of WBE project

- Global WWS datasets: Wastewater SPHERE | Global Water Pathogen Project (waterpathogens.org)
  US Covid Wastewater Dashboards by State (covid-wastewater.github.io)

- WBE Community:
  COVID-19 Wastewater Epidemiology SARS-CoV-2 | Covid19wbec.org

  Slack

- Filtered References

2021Wastewater_Transmission_Model | Zotero

Global Datasets of WBE

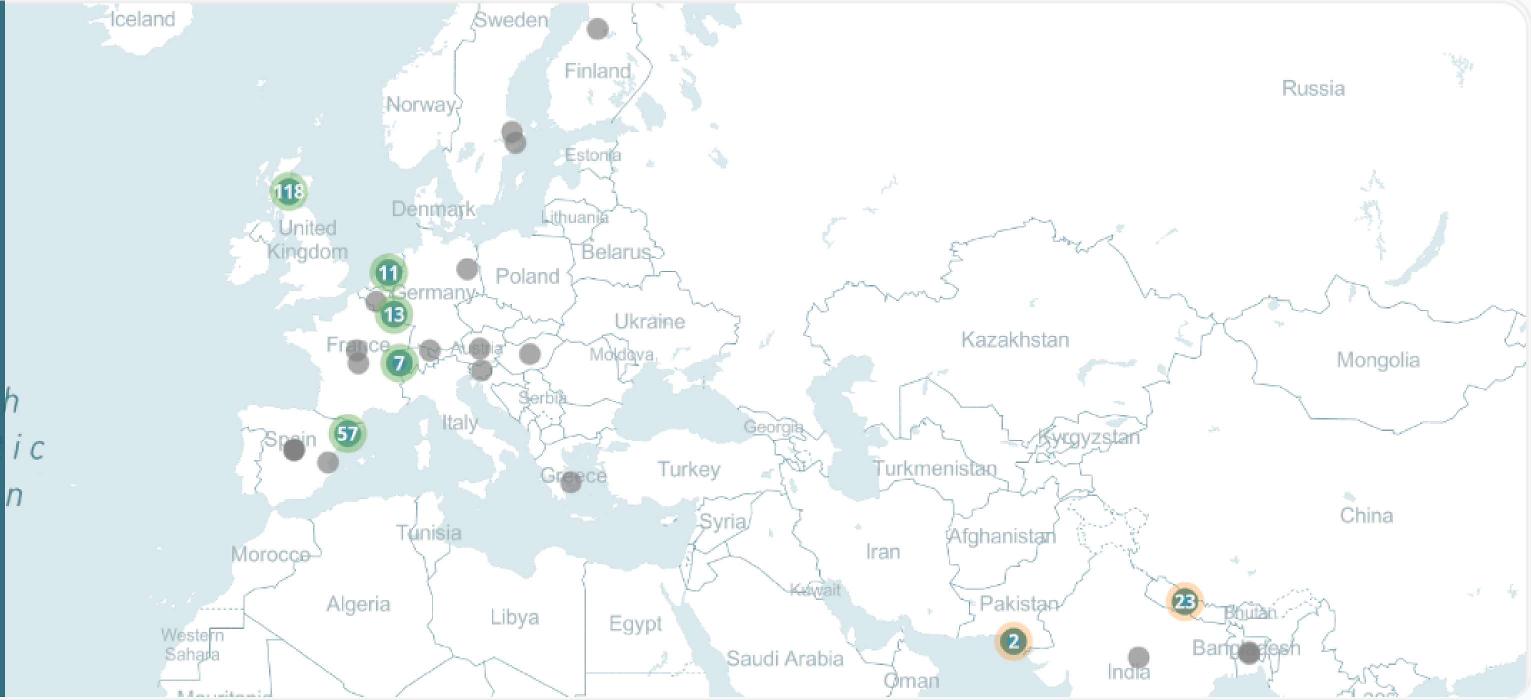
WASTEWATER **SPHERE**

GLOBAL MAP | DATA | USE CASES | ABOUT | CONTRIBUTE

A global data center by the Global Water Pathogens Project

Advancing environmental surveillance of sewage to inform local and global efforts for monitoring and supporting public health measures to combat disease.

Read more | See global map



Contribute to the Wastewater SPHERE data center

Contributing data to SPHERE can help you get started with standardized data reporting and licensing, while creating your own space for visualizations and analysis.

CONTRIBUTE

Wastewater-Based Epidemiology: Global Collaborative to Maximize Contributions in the Fight Against COVID-19

Four import aspects while modeling WBE

- Epidemiological model (SEIR, mobility, NPIs, Vaccination, multi-strain, et.al.) Not our focus here.
- Virus shedding dynamics. (Challenging)
  shedding rate of the virus[3]
  water flow (sewage) network
- Virus decay dynamics. Review: [1-2]
  Water Source: river water, wastewater, sludge (treated or untreated)
  Temperature
  PH
- Delays in observation dynamics
  sewer transportation
  sampling and storage

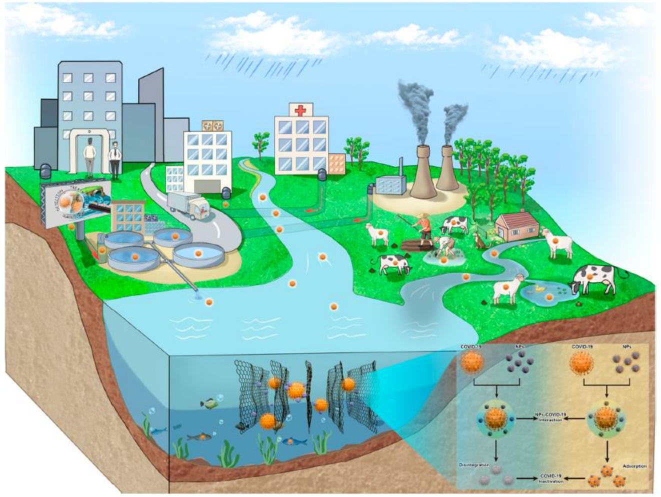


Figure 2. Schematic illustration of primary sources of SARS-CoV-2 in the water system and proposed removal mechanism.

[1] Mohapatra S, et al. 2021. Science of the Total Environment, 2021, 765: 142746.
[2] de Oliveira L C, et al. 2021. Water research, 2021, 195: 117002.
[3] Long Q X, Liu B Z, Deng H J, et al. 2020. Nature medicine, 2020, 26(6): 845-848.

Part III: Our work on WBE

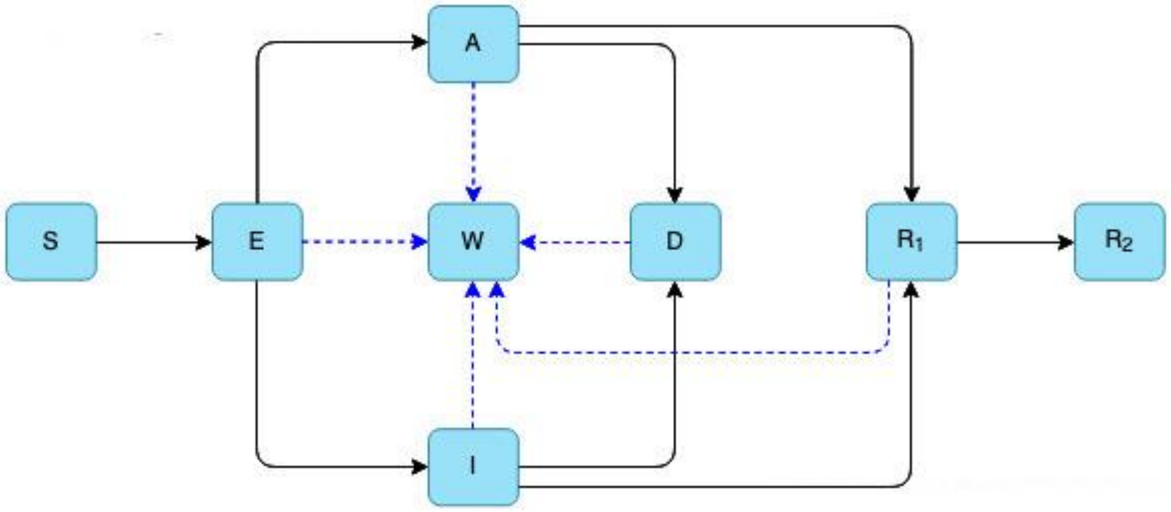
Part of Fields CQAM Thematic Program

Wastewater Testing as an Early Warning Tool for COVID-19 Outbreaks

Nicola Bragazzi, Srijana Ghimire, Zachary McCarthy, Marisa Signorile, Pengfei Song, Shuangshuang Yin

What we have done?

- Wastewater data and Covid19 data on 26 cities in Wyoming, USA.
- Cross-correlation analysis to explore time delays in estimated wastewater virus concentration and reported cases.
- A transmission dynamics model (SEAIRDW) was used to build the connection between wastewater data and case data, predict the prevalence by wastewater data.



$$
\begin{cases}
\frac{dS}{dt} = -\beta \mathrm{Ctrl}(t) S (k_E E + k_A A + I)/N, \\
\frac{dE}{dt} = \beta \mathrm{Ctrl}(t) S (k_E E + k_A A + I)/N - \sigma E, \\
\frac{dA}{dt} = \rho \sigma E - \gamma_A A - d_A A, \\
\frac{dI}{dt} = (1-\rho)\sigma E - \gamma_I I - d_I I, \\
\frac{dD}{dt} = d_A A + d_I I - \gamma_D D, \\
\frac{dR_1}{dt} = \gamma_D D + \gamma_A A + \gamma_I I - \gamma_R R_1, \\
\frac{dR_2}{dt} = \gamma_R R_1, \\
\frac{dW}{dt} = p_0 (I + p_A A + p_D D + p_E E + p_R R_1)/M - \delta W.
\end{cases}
\tag{2.2}
$$

Accumulated cases (H) are denoted as

$$\frac{dH}{dt} = d_A A + d_I I. \tag{2.3}$$

Virus shedding and decay dynamics

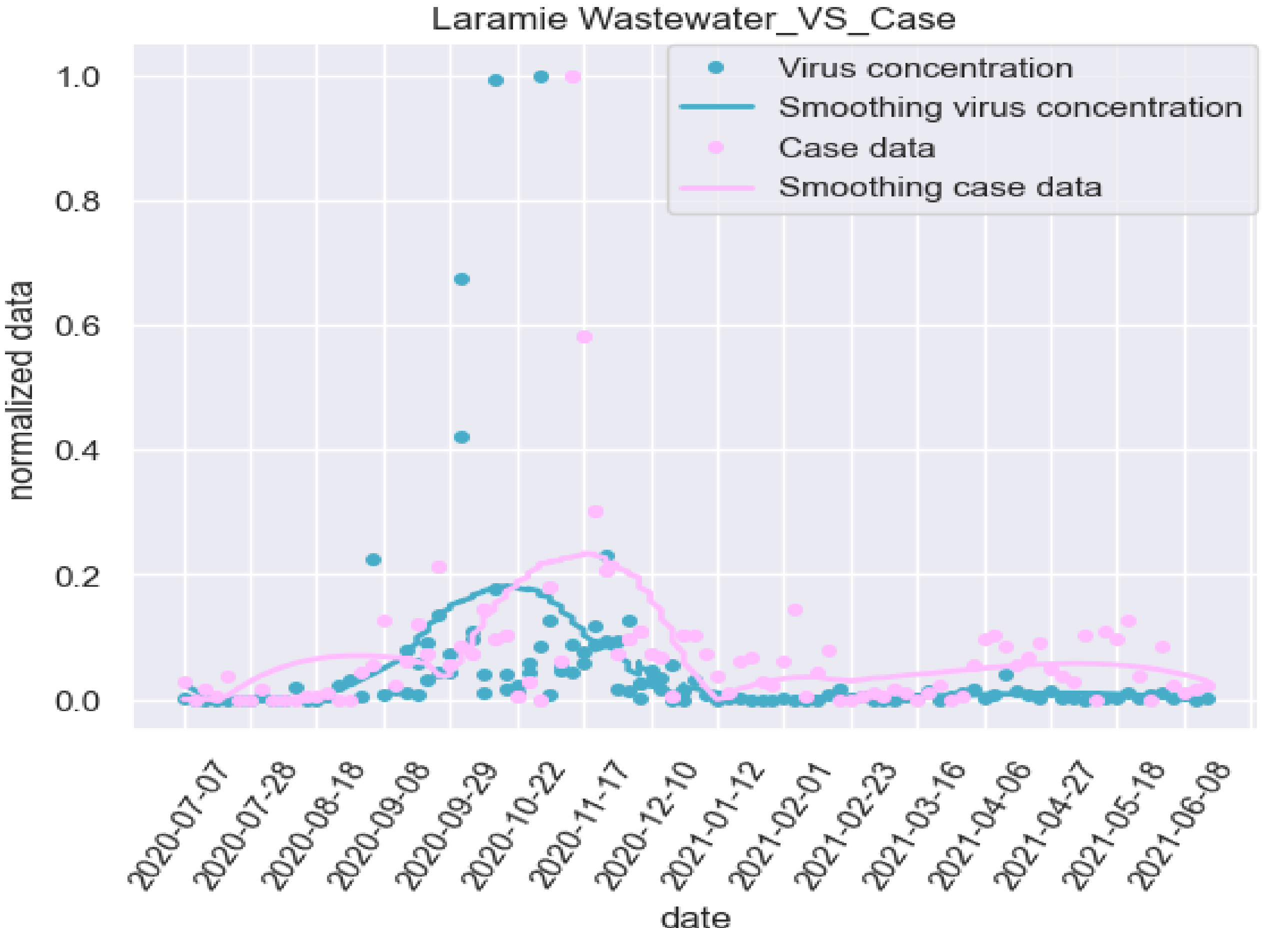
- Exposed, symptomatic, asymptomatic, and part of the recovered individuals can shed virus.
- Virus concentration in wastewater is characterized by dynamic systems. W: virus concentration. M: water volume in wastewater treatment plant.

$$\frac{\mathrm{d}W}{\mathrm{d}t} = p_0(I + p_A A + p_E E + p_R R_1)/M - \delta W \quad ($$

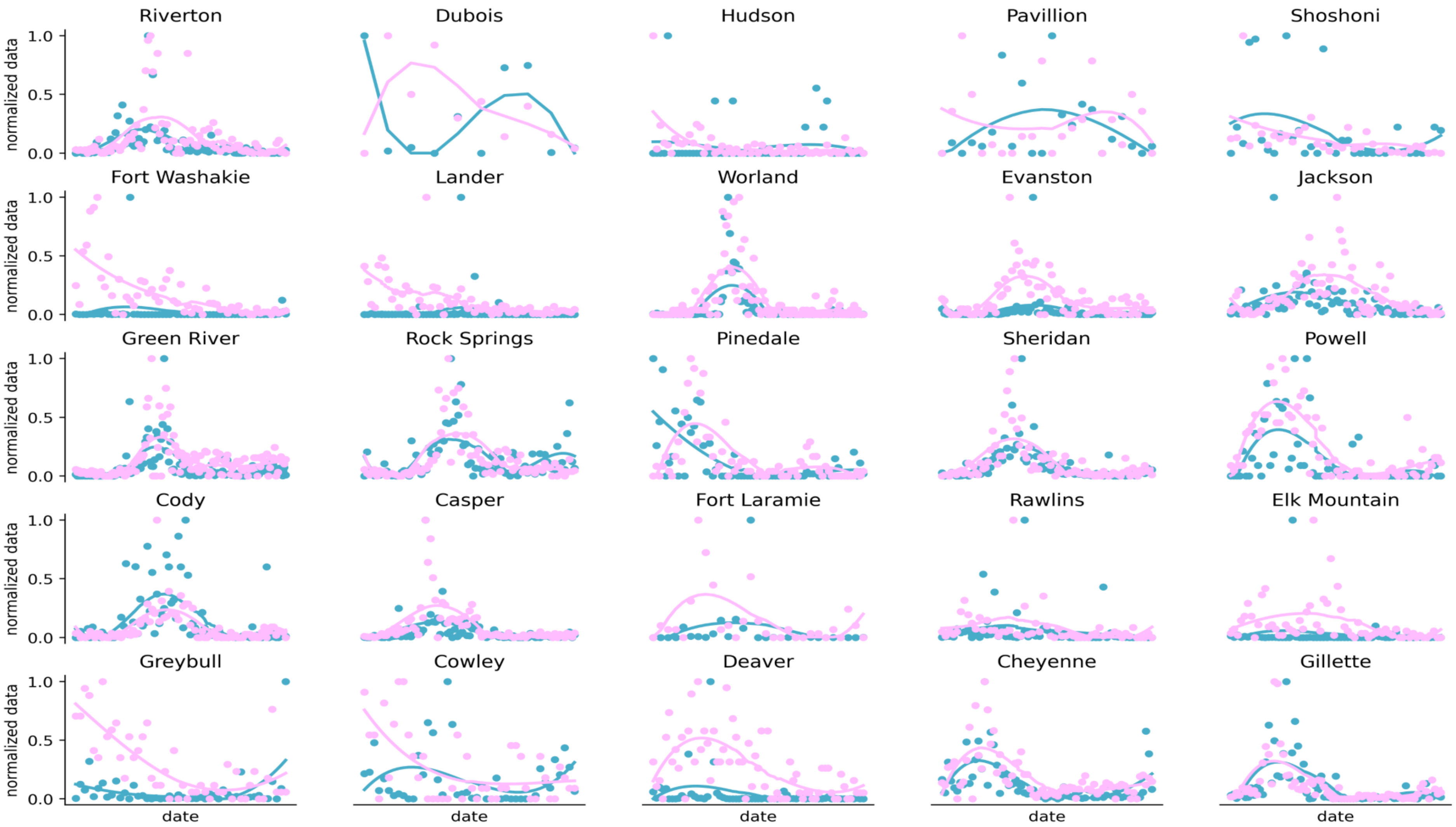
- Water volume in wastewater reservoir is time-dependent and virus waning rate is affected by temperature.

Cross-correlation analysis

- Result one: Strongly correlation between wastewater data and case data.
- Virus concentration in wastewater vs confirmed cases in Laramie city (Wyoming University)



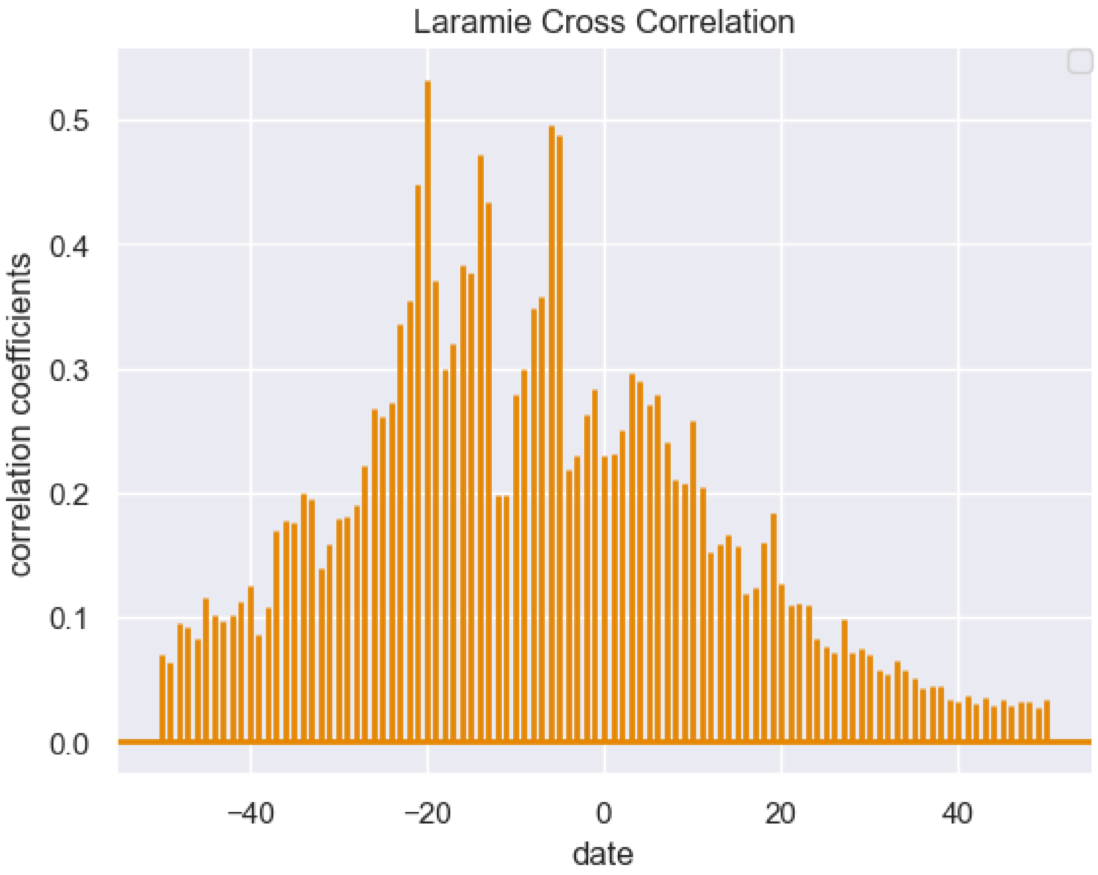
26 Cities



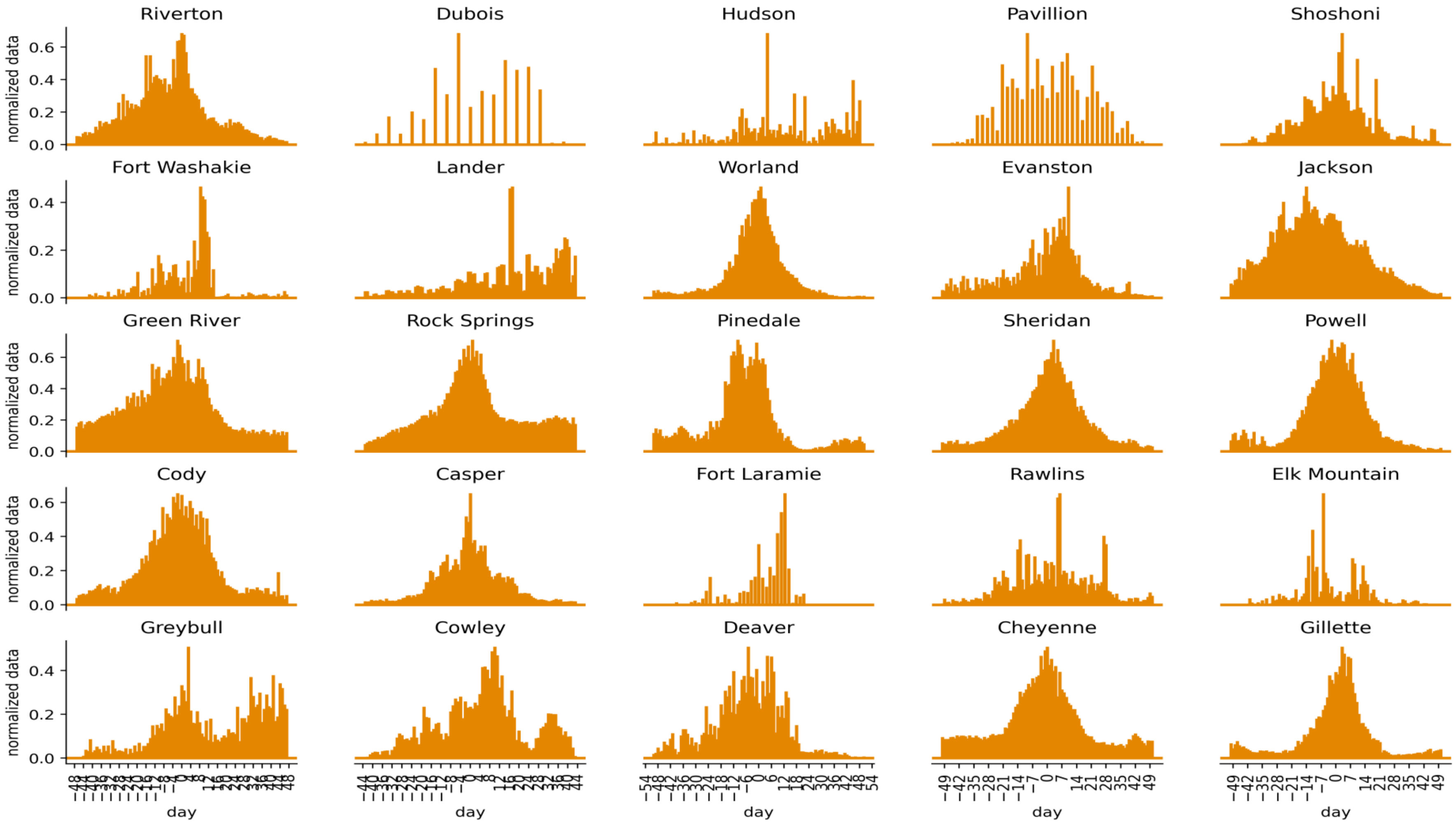
Riverton
Dubois
Hudson
Pavillion
Shoshoni
Fort Washakie
Lander
Worland
Evanston
Jackson
Green River
Rock Springs
Pinedale
Sheridan
Powell
Cody
Casper
Fort Laramie
Rawlins
Elk Mountain
Greybull
Cowley
Deaver
Cheyenne
Gillette
normalized data
date
1.0
0.5
0.0

Cross-correlation analysis

- Result two: wastewater signals can be leading over reported cases
- Wyoming: cross-correlation of viral concentration in wastewater and confirmed cases time series. About 7 days leading

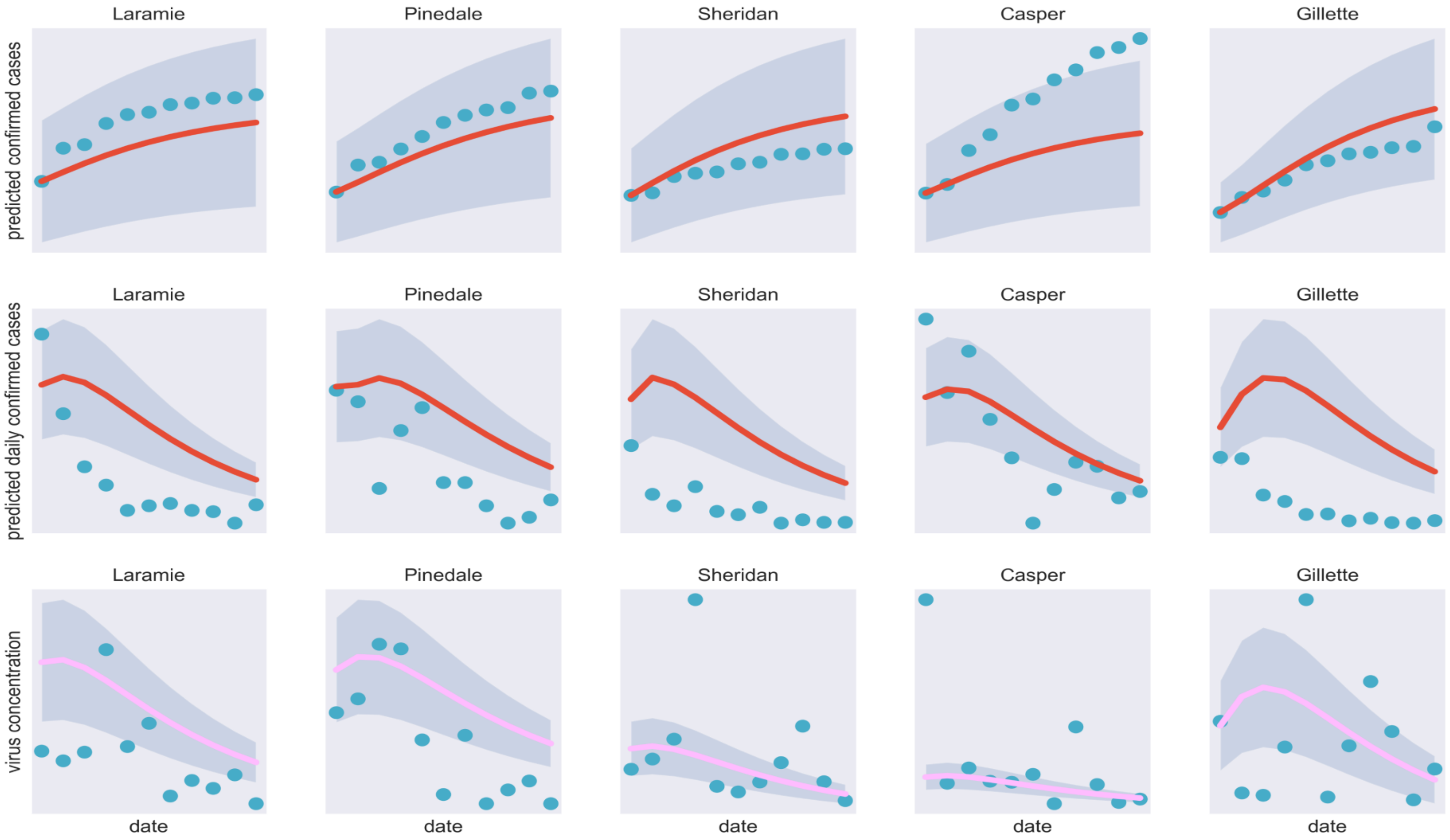


- wastewater signals can be used as warning tools, but not always earlier than case data. In big or developed cities, wastewater signals is more likely to be earlier.



Prediction of case data by wastewater data

- Result three: can capture the trend but hard to predict real values with simple SEAIRDW model.



Methods

- Software: python 3.9.5. All the codes are put here [Song921012/2021Waste_Water_Project: Fields CQAM Thematic Program (github.com)]
- Data smoothing method
  The Savitzky-Golay filter was used for smoothing reported COVID-19 cases and the wastewater virus concentration.
- Cross-correlation method
  We performed cross-correlation analysis to explore time delays in estimated

Model calibration

- We utilized case data from Albany county, Wyoming and wastewater signal data from Laramie, a city in Albany county, for model calibration and simulation.
- Initial values of the SEAIRDW model are determined as follows:

$$S(0) = 38800, E(0) = 0, I(0) = 1, A(0) = 0, R_1(0) = 0$$

,

$$R_2(0) = 0, D = 43, W(0) = 0,$$

where 38800 is the total population in Albany county([6]). The start date of the simulation begins on July 7th, 2020 with 43 confirmed cases.

- Most of the parameters in model 2 are determined from references and seven parameters $(\beta_0, \beta_{end}, r, d_I, d_A, p_0)$ are unknown and estimated by stochastic simulation method and the nonlinear least-square method on the basis of newly confirmed, cumulative confirmed cases.

Model Prediction

- The transmission rate of symptomatic infectious without controlling measures and the connection between wastewater signal data and case data are obtained from the model calibration stage.
- p_0 and β_0 are fixed, however, the controlling measures and detecting rate of symptomatic and asymptomatic individuals will change as the time goes on. Thus, $(\beta_{end}, r, d_I, d_A)$ still need to be updated based on the wastewater virus signal data.
- The initial value of the model in prediction stage is the end value of the calibration stage. Moreover, the estimation method is the same as model calibration stage.

Part IV: Future Ideas

Opportunities and challenges of WBE

- Wastewater Surveillance as New Data Source:
  Not attracted enough attention, Not comfortable interpreting

- Lack of Institutional Knowledge and Resources:
  New institutional knowledge, organizational leadership, and investment.

- Ethics Considerations:
  The ethics of wastewater surveillance data collection, sharing, and use are not yet established.

Uncertainties

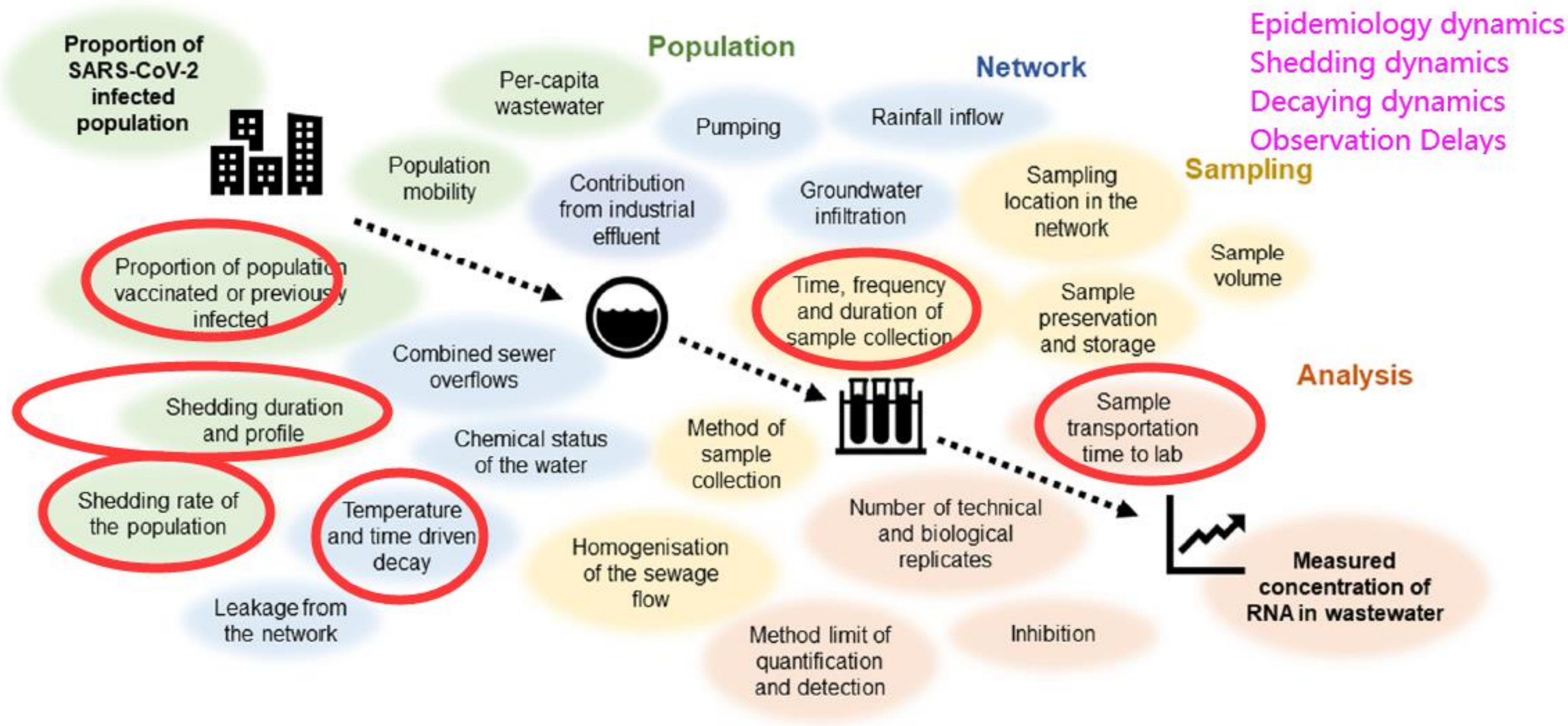


Fig. 1. Summary of known and suspected sources of uncertainty for WBE; a perspective specific to UK wastewater surveillance of SARS-CoV-2.

Wade M J, Jacomo A L, Armenise E, et al. 2022. Journal of hazardous materials, 2022, 424: 127456.

Handling Uncertainties and Improving Performance

- Epidemiology dynamics:
  Incorporating more layers: mobility, vaccination, multi-strain

- Virus shedding dynamics:
  Infection age, Vaccination age
  Neural networks

- Virus decaying dynamics: Incorporating temperature

Other Interesting Problems

- The leading time of WBE
- Estimating the minimum number of cases needed to detect virus in wastewater
- Optimal selection of monitoring sites for surveillance in sewage networks
- Developing a Flexible National Wastewater Surveillance System

Review Papers

- McMahan C S, Self S, Rennert L, et al. COVID-19 wastewater epidemiology: a model to estimate infected populations[J]. The Lancet Planetary Health, 2021, 5(12): e874-e881.
- Lorenzo M, Picó Y. Wastewater-based epidemiology: current status and future prospects[J]. Current Opinion in Environmental Science & Health, 2019, 9: 77-84.
- Medema G, Been F, Heijnen L, et al. Implementation of environmental surveillance for SARS-CoV-2 virus to support public health decisions: Opportunities and challenges[J]. Current Opinion in Environmental Science & Health, 2020.
- Li X, Zhang S, Shi J, et al. Uncertainties in estimating SARS-CoV-2 prevalence by wastewater-based epidemiology[J]. Chemical Engineering Journal, 2021: 129039.

Thank You