Simulation Study of Adaptive Sampling Site Allocation for Typhoid Environmental Surveillance in Ward 58 & 59, Kolkata

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Overview

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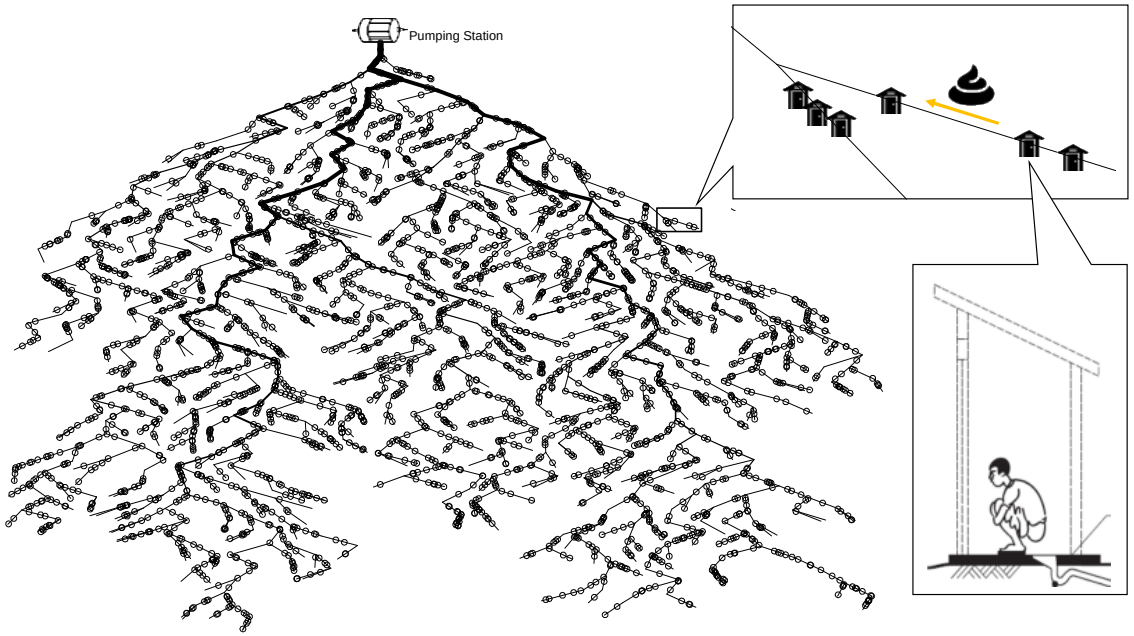
Background

- Environmental surveillance (ES) is an approach for monitoring specific fecal pathogen(s) circulation in a population by examining sewage samples[1].
- Multiple countries, including Egypt, Israel, Pakistan, India, and Nigeria, have deployed ES along with clinical surveillance for poliovirus and "silent outbreaks" were detected[2,3].

A "Silent outbreak" means detection of poliovirus circulation by environmental surveillance in the absence of clinical cases.

Sampling for ES?

Pumping station vs. toilets?
If sample toilets, where?
Fixed samples site?



- In 2003, WHO published the "Guidelines for ES of poliovirus circulation" that recommended sampling at inlets to sewage treatment plants or other major collector sewers[4].
- However, in cases where there is no sewage network, inconsistent sewage flow, rapid pathogen decay, loss of pathogen, or dilution of pathogens in the sewage system, combined with not very sensitive lab detection methods, sampling at sites distant from shedding sources may fail to detect pathogens.

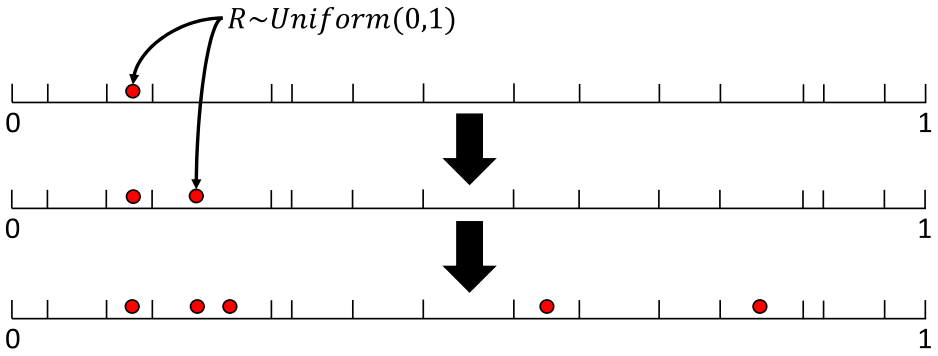
Objectives

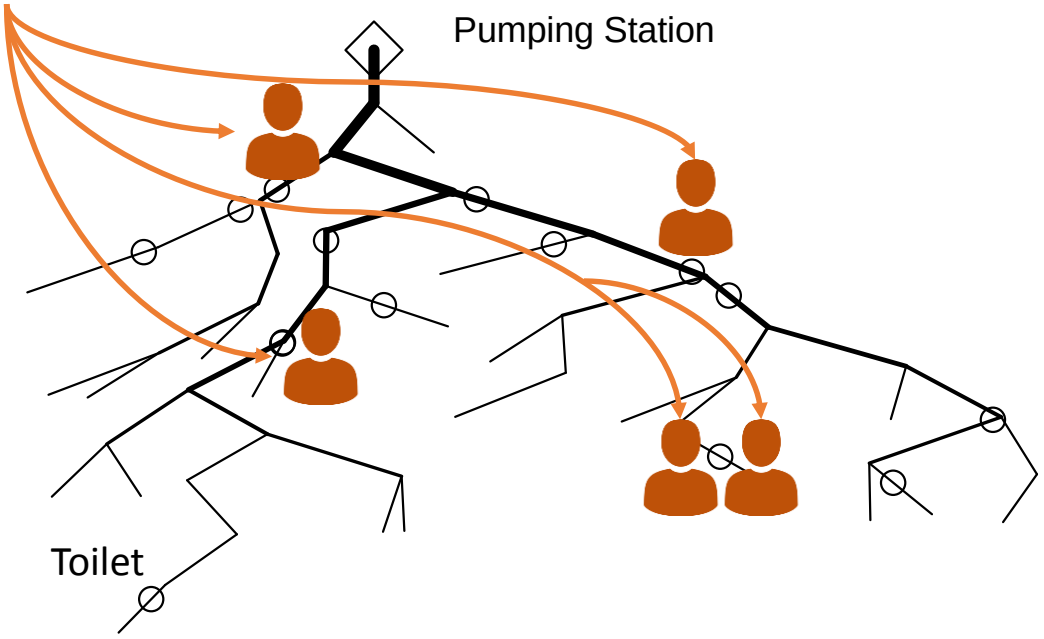
- Build a mathematical model to simulate fecal shedding dynamics and pathogen fate in the sewage network.
- Compare sensitivities of different sampling strategies in different scenarios.
- Develop an adaptive method for sampling site allocation to optimize the chance of detecting pathogen circulation.

Shedders

Number of new shedders on day t follows $Poisson(\lambda)$

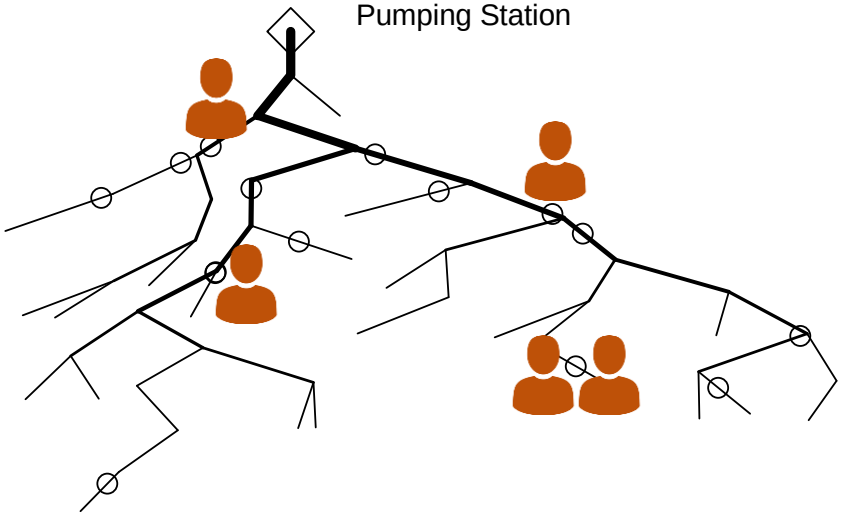
Assign new shedders to toilets

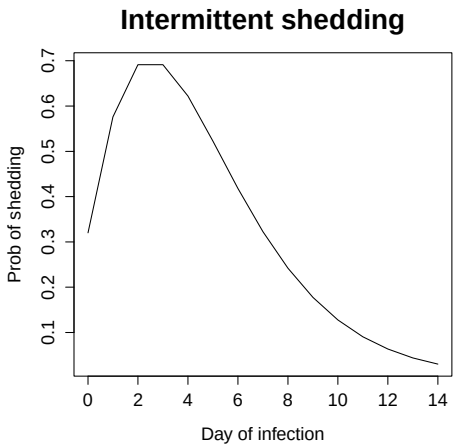


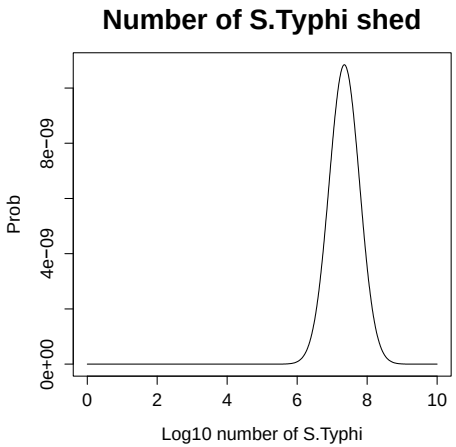


The sewage network and locations of toilets were simulated using the SSN package in R.

Shedding

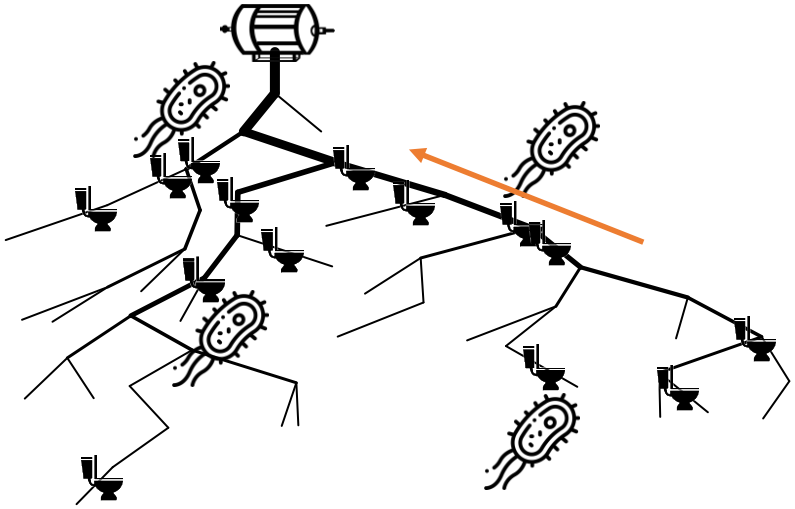


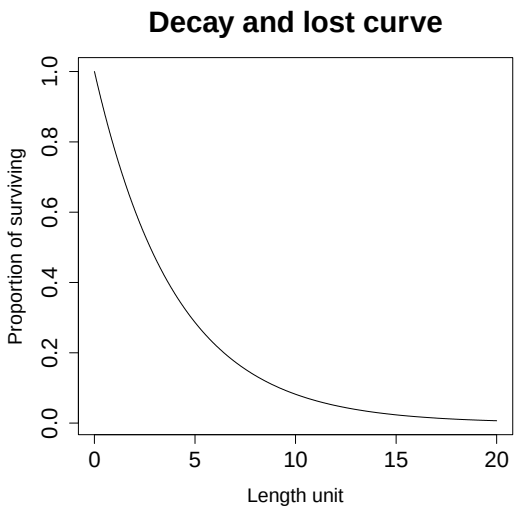




Day of infection	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Shedding (Y/N)	N	Y	Y	Y	Y	N	Y	Y	N	N	N	Y	N	N
Num of S. Typhi Shed	0	$10^{8.1}$	$10^{7.6}$	10^{7}	$10^{8.3}$	0	$10^{8.1}$	$10^{6.5}$	0	0	0	$10^{7.2}$	0	0

Pathogen Fate and Sampling





$$Average\ Concentration = \frac{Number\ of\ S.Typhi\ passed\ through\ on\ the\ current\ day}{Volume\ of\ water\ passed\ through\ on\ the\ current\ day}$$

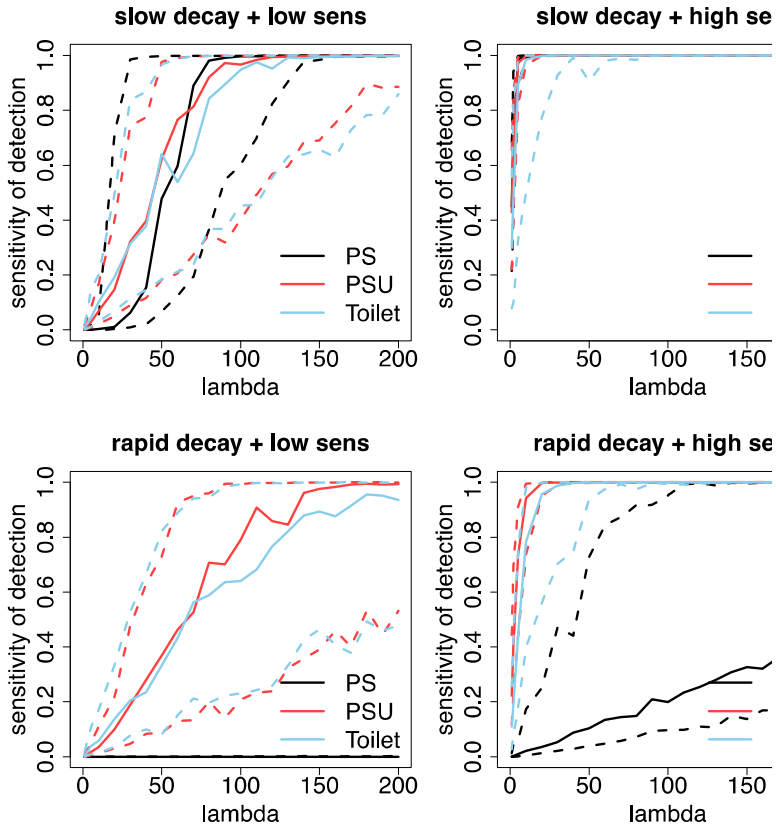
Sampling Sites $\boldsymbol{S}$:

1. Pumping Station (40 L)
2. Toilets (500 mL)
3. Primary Sampling Unit (PSU), pooled sample from 5 toilets (500 mL with 100 mL from each toilet)

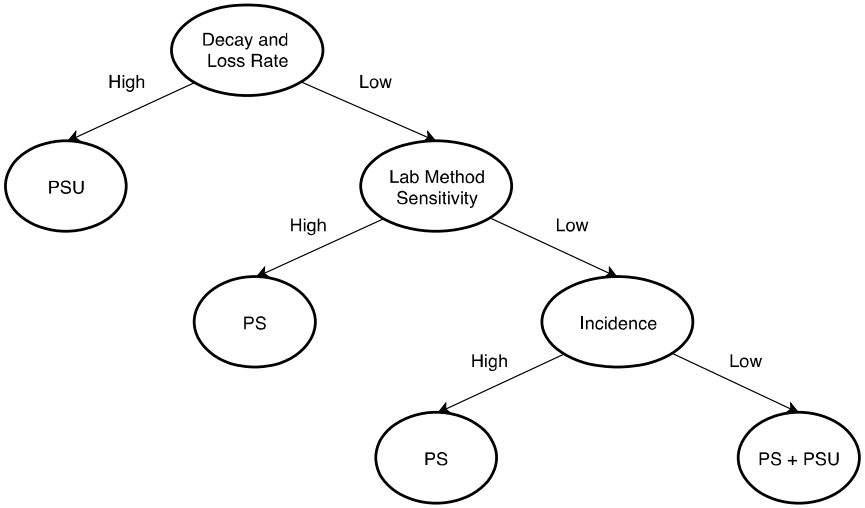
Site	Week 1	Week 2	Week 3	Week 4	…	Week 12
Pumping Station	0	1	0	0	…	1
PSU 1	0	1	0	0	…	1
PSU 2	1	1	0	1	…	0
…	…	…	…	…	…	…
PSU 9	0	0	0	0	…	0

For any sampling site, if average concentration larger than the limit of detection, then the outcome is positive (1). Otherwise, the outcome is negative (0).

Where to Sample? Pumping Station vs. PSUs

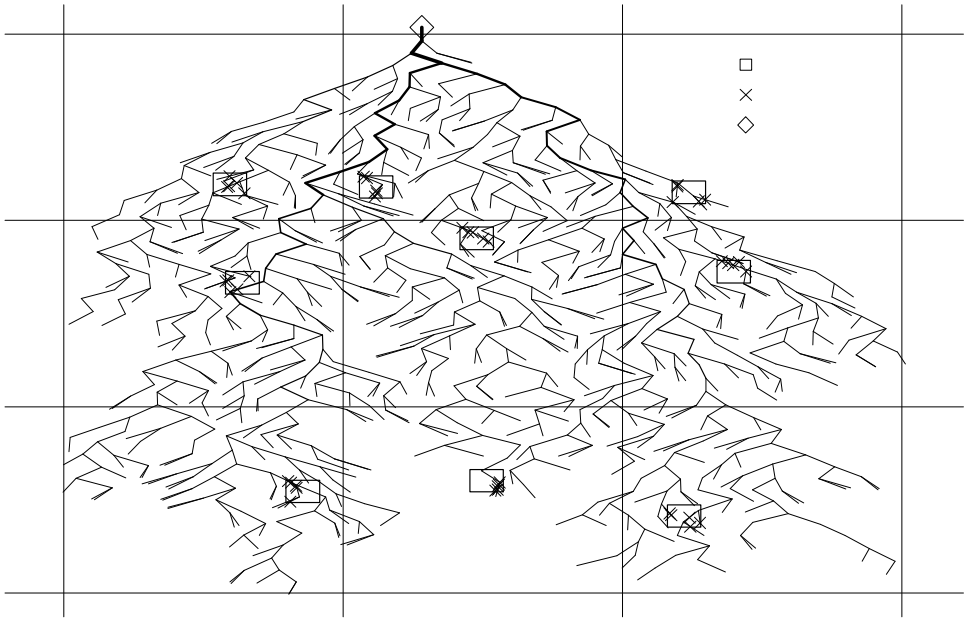


"lambda" is the infection pressure (average number of new shedders per day).



Using information on disease incidence, pathogen decay and loss rate in the environment, and sensitivity of lab method, we can determine whether we should sample at pumping station (major collector of sewage), toilets or PSUs.

Adaptive Sampling Site Allocation



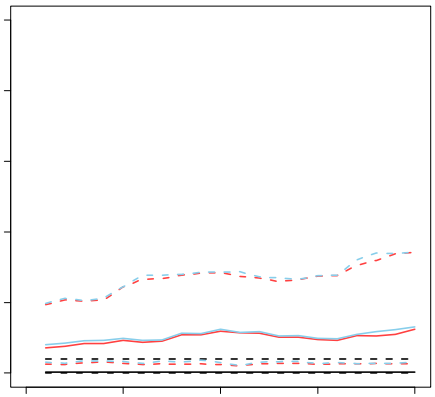
Initialization Divide the geographic area into certain number of cells and randomly select one PSU from each cell.

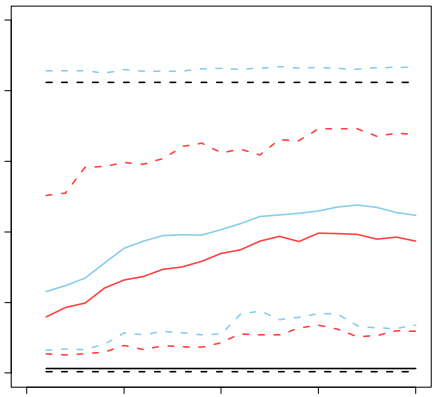
Collection 12 weekly samples are collected at each sampling site.

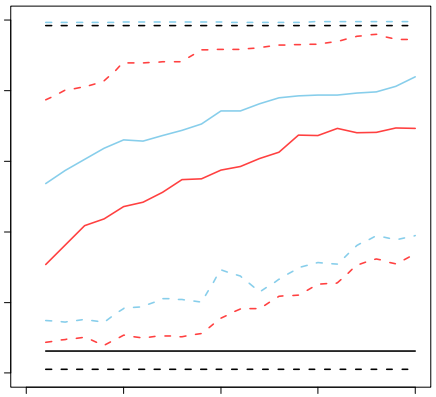
Analysis Apply a jackknife approach to the results collected by removing one sampling site at a time and accessing the corresponding information loss. The **loss function** can be defined as: $L(S_0, x_i) = I(S_0) - I(S_0^{x_i})$.

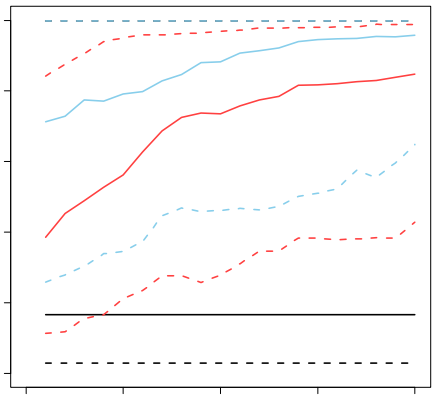
Update The PSU with the smallest information loss is relocated to another site (using expert opinion or randomization).

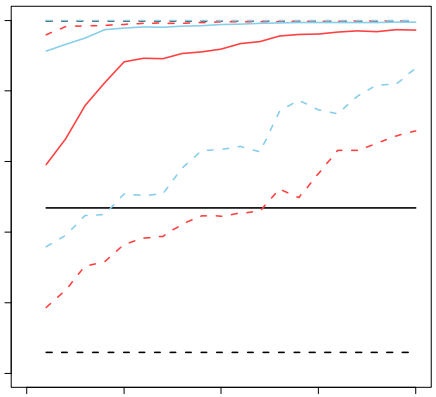
Results for Different Infection Pressures (slow decay + low sensitivity)

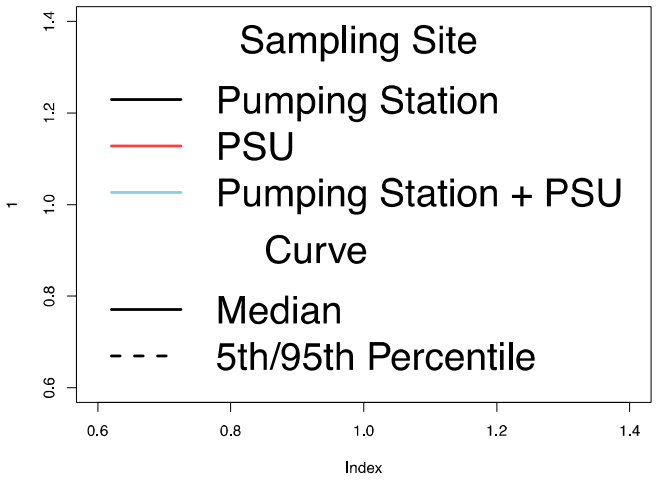




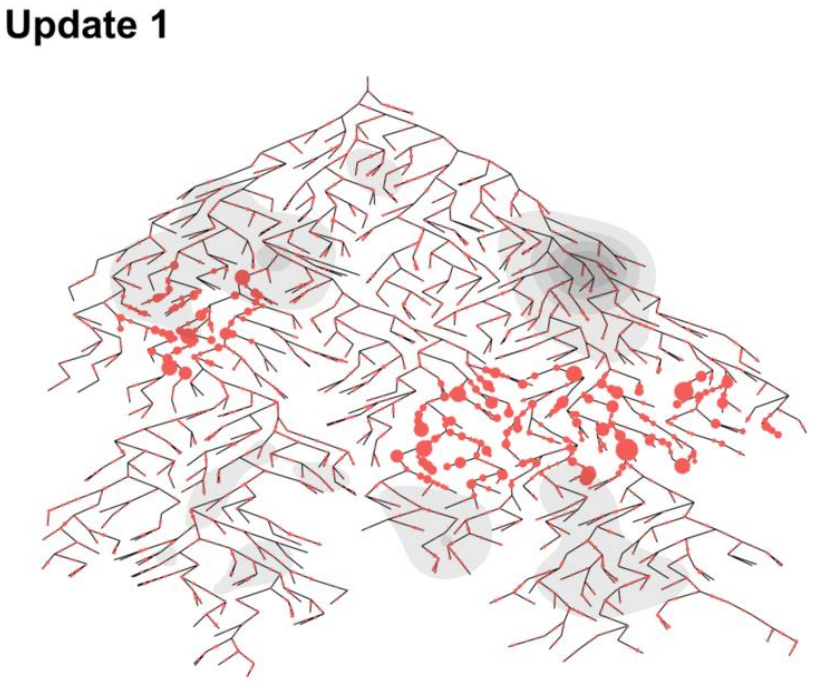




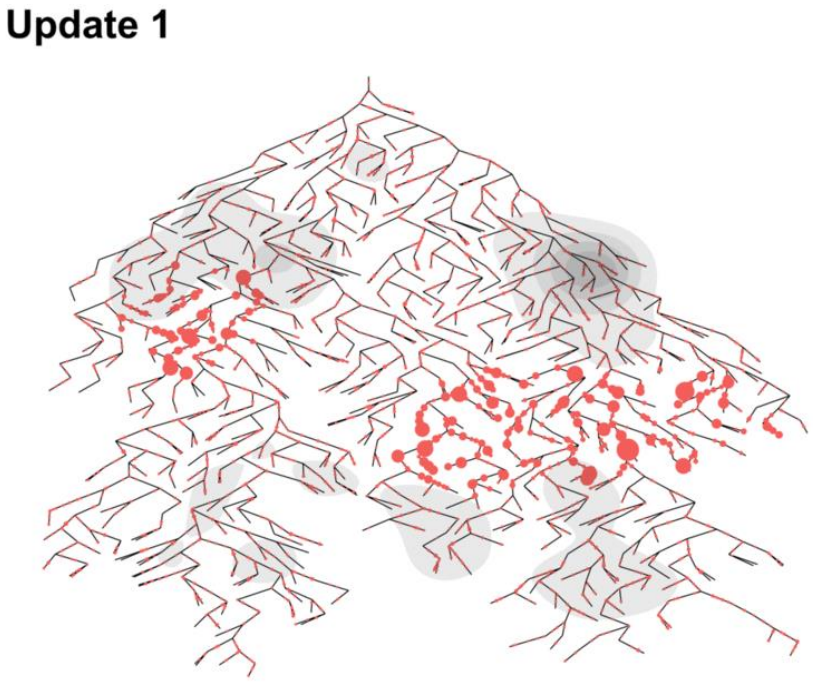




Sites Heat Map + Risk Map



$Lambda = 30$



$Lambda = 50$

Conclusions

- The simulation study is useful for exploring different scenarios for ES and test any proposed sampling strategy.
- The sampling locations for fecal pathogen ES can be determined systematically using information such as disease incidence, pathogen decay and loss, and sensitivity of detection.
- The adaptive sampling site allocation method can optimize sampling site locations and boost the sensitivity of ES in the presence of constraints on sampling numbers and frequencies.

References

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4. World Health Organization. (2003). *Guidelines for environmental surveillance of poliovirus circulation*. Geneva, Switzerland: Dept. of Vaccines and Biologicals, Health Technology and Pharmaceuticals, World Health Organization.

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