Effective Deployment Strategy Model of SARS-CoV-2 Sampling Tools for Wastewater-Based Epidemiology

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Highlights

- Passive sampling devices is found to be able to detect traces of SARS-CoV-2 in the wastewater network of up to 5000 people.
- Grab sampling method has the ability to adequately detect SARS-CoV-2 wastewater fragments for a catchment population of approximately 130,000 people or more.
- Dilution is found to significantly impact the performance of SARS-CoV-2 sampling tools in the wastewater system.

Introduction

There is a rising interest of utilising wastewater surveillance approach (i.e. wastewater-based epidemiology) within the research community to complement clinical surveillance (e.g. nasal swab test) of SARS-CoV-2 (Mao et al., 2020). Wastewater-based epidemiology (WBE) provides authorities with health information of the population based on the presence of the virus in the wastewater system (Mao et al., 2020). In terms of WBE sampling tools, there are two most commonly used sampling methods, namely grab-sampling and auto-sampling (Schang et al. 2021). Grab-sampling samples wastewater within one specific time and place, while auto-sampling samples wastewater within a certain time period. Recently, a novel method called the passive-sampling method is suggested to provide better cost efficiency than the auto-sampling method as well as higher temporal coverage than the grab-sampling method (Schang et al. 2021). As there is still lack of standardised approach and deployment strategy of passive samplers as well as traditional sampling method (Schang et al. 2021), this study aims to develop a hydrological model of a hypothetical wastewater catchment to better understand the performance of two sampling techniques, the grab sampling and the passive sampling method to develop a standardised approach for the deployment of both sampling tools.

Methodology

Model Description

A stochastic hydrological model of a hypothetical wastewater network has been developed in order to estimate the performance of the grab-sampling and passive sampling. The model catchment is based on the general characteristics of an Australian suburb, where it consists of 43,740 house units (3 people per household) of an approximate size of 32 x 12.5 m^2. The catchment is comprised of 8 scales (identified as R1 consisting of 20 people, R2 consisting of 180 people, R3 consisting of 540 people, R4 consisting of 1600 people, R5 consisting of 4860, R6 consisting of 14,600 people, R7 consisting of 43,700 people, and R8 consisting of 131,200 people) ranging from the smallest scale R1 to the largest scale R8 . The model runs from iteratively from R2 which consists of 3 R1 units and progress further up the scale until it reaches the highest scale (R8) (Figure 1). For each scale, the model utilises the Muskingum-Cunge model to simulate the hydrological routing of wastewater flowing from the start inlet (outflow of the previous scale) to the outlet (inflow of the subsequent scale).

To estimate the performance of the sampling methods, the model randomly allocates one infectious person in an upstream household for a period of 96 hours to allow for the virus concentration load to reach the outlet of the R8 scale catchment. The duration of shedding, number of virus copies per shedding, daily wastewater flow generation, and other parameters are normally distributed. The virus concentration load is routed using the Muskingum-Cunge model alongside the wastewater flow.

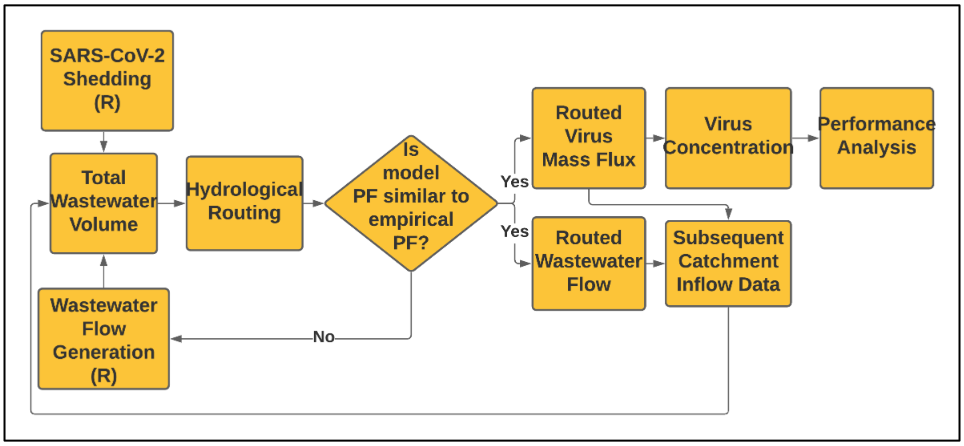


Figure 1. Flowchart of the model for a single catchment scale, where (R) denotes randomised input parameter.

At the outlet of each scale, the performance of the passive sampling method is analysed using the Loebenstein's chemical adsorption rate equation to determine the number of virus copies accumulated for one-day deployment of the passive samplers (Loebenstein, 1962). The passive sampling field operation is modelled based on Schang et al. (2021) study where a single 3D-printed torpedo-style housing (containing qtips, gauzes, and electronegative membranes) is lowered into a sewerage manhole and left for a duration of 24 hours. At the end of the deployment, the passive sampler is retrieved to be tested using qPCR method, and a new passive sampler is deployed. Detection is established if the passive samplers accumulate 50 or more copies per day. For the grab-sampling method, the model randomly assigns the grab sampler a one-hour window within 9:00 AM to 5:00 PM to simulate the deployment of grab-samplers during work hours. If at the given one-hour window the concentration of the virus load at a specific outlet is 1 copy/mL or more, detection would be registered in the qPCR test (Schang et al., 2021).

The model is calibrated by comparing the peaking factor of the outflow wastewater flow for each catchment scale with Harmon's empirical peaking factor equation (Imam & Elnakar 2014). The wastewater flow pattern is adjusted to allow the model PF to be within 10% of the theoretical PF by Harmon.

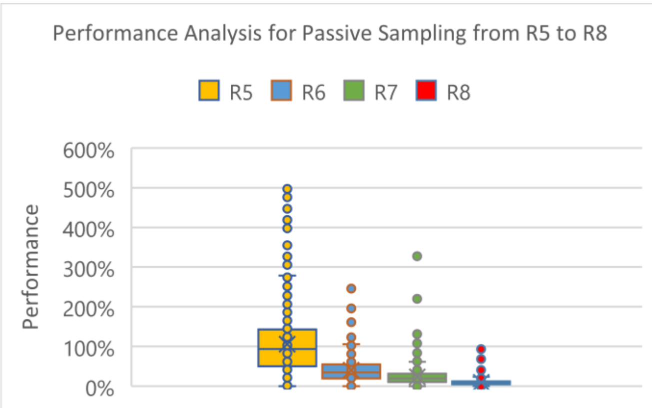
Model Assumptions and Limitations

Several assumptions of the model are as follows: (i) the wastewater flow pattern is assumed to be constant for the 4 day-period without changes affected by temperature or weekend patterns. (ii) it is assumed that the virus shedding events (i.e. number of times an infected person defecates) within a day is randomised but at least has one event each day. (iii). Additionally, it is assumed that hydrological routing to be modelled from R2 to R8 due to the short distance of the R1 scale model.

Several limitations of the model are as follows: (i) The Muskingum-Cunge model is primarily developed for open-channel water systems. In this model, the Muskingum-Cunge model is modified by assuming that the pipeline is half-full, which may not portray extreme flow events. (ii) Temperature, pH level, predation, competition, and inhibition are not accounted in this model. (iii) Additionally, the hydrological routing model has not been validated with actual data of actual suburbs.

Results and discussion

The performance of each passive samplers is quantified for each days and at different catchment scales. The performance refers to the number of SARS-CoV-2 copies detected by the end of the deployment day. Referring to Figure 2 (left), the model was run for 1000 times and the performance results were recorded



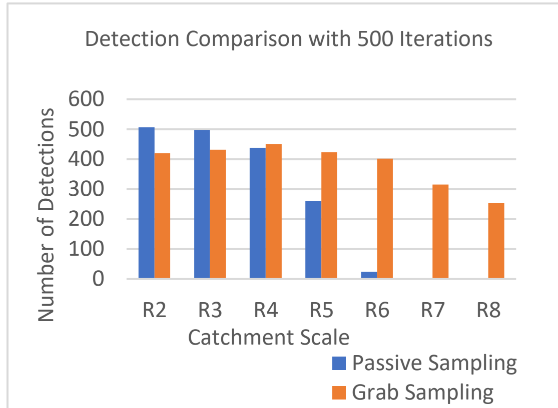


Figure 2. (left) Performance analysis box plot for passive sampling from R5 to R8 catchment scale. (right) Comparison of the grab and passive sampling methods for 500 iterations of the model.

to account for the randomised parameters. The performance of 100% suggests that the at the given iteration, SARS-CoV-2 fragments is successfully detected by the PCR test from the retrieved passive sampler. The result in Figure 2 (left) suggests that at catchment scale of R5 (approximately 5000 people), SARS-CoV-2 fragments of an infected person can still be positively detected. However, at catchment scale R6 to R8, the performance suggests below 100% average, which means that the passive sampling devices could not reliably detect SARS-CoV-2 at a catchment population of approximately 15,000 people and more. Referring to Figure 2 (right), the number of detections for the passive sampling is compared with the grab sampling method for 500 iterations. The result suggests similar trends for the passive sampling with a considerable drop in detections from R6 to R8. However, the grab-sampling method only experience steady but minor drop as the catchment scale progress further, with around half of the iterations registering detections at R8 (131,220 people).

Conclusions and future work

In summary, the model suggests that the grab sampling may have a higher chance of successfully detecting SARS-CoV-2 compared to the passive sampling method. However, due to the limitations of the model, more field data are required to validate the current model's assumptions. Future work should focus on data validation of the model as well as developing the model to allow quantification of the number of infected people based on the performance analysis of the passive and grab sampling method.

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