Particle characterization and transport processes in view of modelling the fate of SARS-CoV-2 in sewer systems

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Highlights

- Particles of all settling velocity classes contain viral signal.
- A viral tracer test was simulated to show the importance of tracking suspended solids.
- Solids settling and varying wastewater flow affect the interpretation of the viral signal.

Introduction

Wastewater-based epidemiology/wastewater surveillance has been a topic of significant interest over the last year thanks to its successful application in prediction of SARS-CoV-2 population outbreaks. However, the complexity of the processes occurring in sewers makes this task hard. In fact, the viral signal is difficult to interpret due to the many impacting phenomena occurring in a sewer, such as: dilution from snowmelt and rain events, time and temperature-dependent degradation of viral particles, complex interaction with wastewater particles (Hill et al., 2020). The latter is the focus of attention for this contribution. Characterizing particles based on the distribution of their settling velocities gives a better appreciation of the transport dynamics of particles in sewers compared to traditional sewer solids models (Ledergerber et al., 2019b) and this can be coupled to phenomenological sewer models, allowing to describe the various aforementioned phenomena occurring in a sewer network and to simulate their impact on the fate of adsorbing pollutants, including chemicals of emerging concern (Vezzaro et al., 2014).
The objective of this contribution is to investigate to what extent the observed variability in the SARS-CoV-2 signal can be related solely to sewer dynamics by employing and extending an existing phenomenological sewer quality modelling framework to estimate the fate of SARS-CoV-2 in sewersheds.

Methodology

Case study description

Our study focusses on Quebec City in Canada where a daily wastewater sampling campaign has been running since June 2020 with the specific purpose of tracking SARS-CoV-2. 24h refrigerated flow-composite samples are taken at both treatment plants of the city, each treating wastewater of about 350,000 citizens. Next to online flow data, the wastewater samples were also analysed for typical water quality parameters (TSS, NH_4, PO_4, conductivity, turbidity) according to Standard Methods (APHA, 2005). The viral signals of SARS-CoV-2 and Pepper Mild Mottle Virus (PMMoV) were obtained by using a protocol based on Ahmed et al. (2020). Hereby, 50ml of raw wastewater is filtered on a negatively charged membrane as preconcentration step, followed by extraction and amplification of viral RNA targeting the SARS N2 gene, with spiked Bovine Respiratory Syncytial Virus (BRSV) as external and PMMoV as internal control for viral analysis.
To fractionate the particles in settling velocity classes, targeted elutriation experiments (Figure 1, Krishnappan et al., 2004) were performed. Pumping a wastewater sample through a series of columns with increasing internal diameter, particles with certain cut-off settling velocities accumulate at the bottom of the columns and can subsequently be analysed for viral signal.

Both wastewater and primary sludge sampled in both Quebec City and Ottawa treatment plants were elutriated in this way.

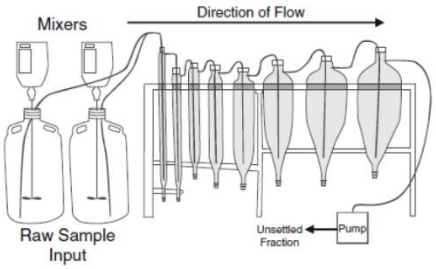

Figure 1. Elutriation setup (Krishnappan et al., 2004) used to fractionate wastewater particles into different settling velocity classes for subsequent analysis for viral signal.

Modelling framework

Part of the Quebec City sewershed (Figure 2) has been modelled for water quality before (Maruéjouls et al., 2015), using a simplified flow propagation model in WEST (MIKE powered by DHI). Settling and resuspension of particles and sediments in sewers is described by the Particle Settling Velocity Distribution (PSVD) model as described in Ledergerber et al. (2019b). The fate of the virus (decay, adsorption-desorption) is modelled in the same way as done for micropollutants by Vezzaro et al. (2014). The measured distribution of viral signal over the different particle classes served as input to the PSVD model.

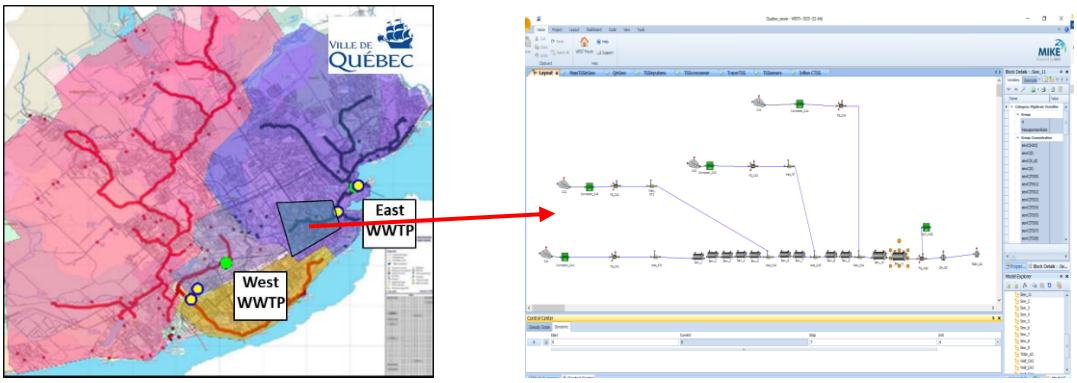

Figure 1. Quebec City's sewershed and its translation into a water quality model based on PSVD.

Results and discussion

First results of SARS-CoV-2 RNA detection in fractionated raw wastewater and primary sludge samples show a similar distribution of viral signal of SARS-CoV-2 and PMMoV in the different particle classes. In addition, viral signal was detected in all particle classes.

The developed PSVD model was used to perform a virtual tracer test (adding a 5 min pulse of SARS-CoV-2-carrying particles) on a small 3 km long sewer section under constant average daily dry weather flow (Figure 1). The viral tracer was distributed over the different PSVD classes, in line with the elutriation test results (Figure 2). The results for slowly settling SARS-CoV-2 particles, i.e. particles that remain suspended in the bulk wastewater, show little dispersion of the viral signal as it travels through the sewer. This will not influence the interpretation of the epidemiological situation. However, for particles that do settle in the sewer, the picture is different. The attenuated peak values and long tail for those faster settling particles indicate significant dispersion of the viral signal arriving at the end of the studied sewer stretch (Figure 2). The retention time of the SARS-CoV-2 viral fragments attached to these particles will therefore be longer.

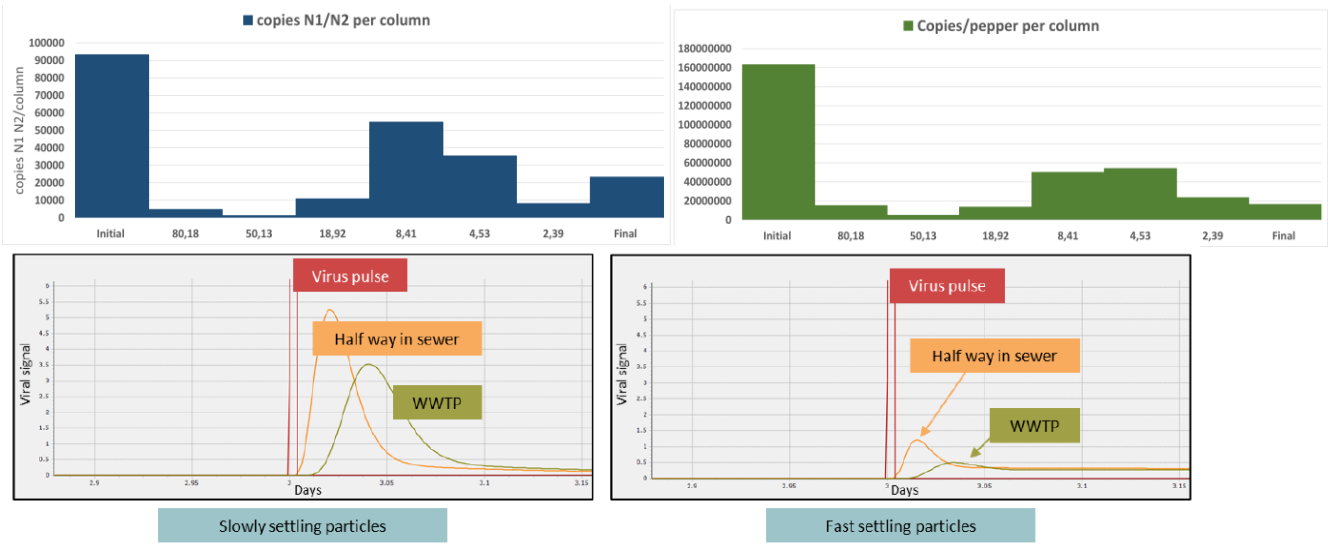

Figure 2. Top: Distribution of viral signal of SARS-CoV and PMMoV; Bottom: Virtual SARS-CoV-2 tracer test results showing the different sewer dispersion characteristics for slow (left) or fast (right) settling suspended solids to which the virus is attached.

Conclusions and future work

A phenomenological modelling framework has been put in place to quantify the impact of various sewer processes on SARS-CoV-2 wastewater signals. A proof-of-concept tracer study was performed showing the impact of sewer particle settling on the viral signal. Future work will include further elutriation tests on Quebec City and Ottawa wastewater and primary sludge samples to validate the first findings and have a better idea of the distribution of the viral signal over the particle fractions. A detailed PSVD-based modelling exercise of the pandemic situation that occurred over the last year will be conducted using detailed geo-referenced COVID case data from public health as input to the model as well as wastewater quality and viral measurements taken throughout Quebec City.

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