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Fit-for-purpose wastewater treatment: Testing to implementation of decision support tool (II)

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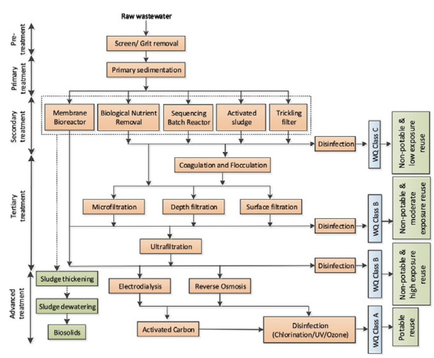
HIGHLIGHTS

- Proposed FitWater is validated and implemented, which has been effective.
- Helps to identify a cost-effective, risk-acceptable, and energy efficient treatment
- Developed relations between microbial removal energy intensity and plant capacities
- Established relations between unit microbial removal cost and plant capacities
- Useful to assess potential economic impacts of microbiologically stringent standards

GRAPHICAL ABSTRACT



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ABSTRACT

This paper is the second in a series of two papers. In Paper I, a decision support tool (DST), FitWater, was developed for evaluating the potential of wastewater treatment (WWT) trains for various water reuse applications. In the present paper, the proposed DST has been tested and implemented. FitWater has been tested with several existing WWT plants in Canada and the USA, demonstrating FitWater's effectiveness in estimating life cycle cost (LCC), health risk, and energy use. FitWater has also been implemented in a newly planned neighbourhood in the Okanagan Valley (BC, Canada) by developing 12 alternative WWT trains for water reuse in lawn and public parks irrigation. The results show that FitWater can effectively rank WWT train alternatives based on LCC, health risk, amount of reclaimed water, energy use, and carbon emissions. Moreover, functions have been developed for the variation of unit annualized LCC and energy intensity per unit log removal of microorganisms in different treatment technologies with varying plant capacities. The functions have power relations, showing the economies of scale. FitWater can be applied to identify a cost-effective, risk-acceptable, and energy efficient wastewater treatment train with a plant capacity of 500 m^3/day or more. Furthermore, FitWater can be used to assess potential economic impacts of developing microbiologically stringent effluent standards. The capability of FitWater can be enhanced by including physio-chemical quality of wastewater, additional treatment technologies, and carbon emissions from wastewater decomposition processes.

1. FitWater

Reclaimed water use is an option to augment water supply in communities. The wastewater that is available near initial water consumption is a steady source of water which can enhance the sustainability of water use.

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The use of reclaimed water has been increasing worldwide and water reuse is expected to be approximately 1.66% (26,000 Mm^3/year) of total global water use by 2030 (EU, 2016). Although water reuse has been increasing across the globe, it has yet to be universally applied, indicating the existence of certain challenges. Major factors affecting the implementation of reclaimed water use are cost, health risk of water reuse, and energy consumption (Chang et al., 2008; Guo et al., 2014; Health Canada, 2010; Liu and Logan, 2004; NASEM, 2016). Reclaimed water production can be optimized by treating wastewater specific to a particular reuse application, this approach is referred to as fit-for-purpose wastewater treatment. Fit-for-purpose wastewater treatment is based on the end use of reclaimed water to achieve economic efficiency and environmental sustainability (US EPA, 2012).

A decision support tool (DST), called FitWater, was developed for evaluating fit-for-purpose wastewater treatment potential for a specific reuse in a community. FitWater assesses the potential of wastewater treatment and reuse based on the following evaluation criteria: amount of reclaimed water production, life cycle cost (LCC) of wastewater treatment and conveyance, health risk, energy use, and carbon emissions. Conversely, FitWater can be used to identify an appropriate water reuse application based on the community specific ratings of the criteria. Altogether, 13 major categories of urban reuses have been included in FitWater. The conceptual framework of FitWater development is given in Fig. 1.

The reclaimed water produced from wastewater is estimated based on the water recycling efficiency of wastewater treatment plants. The LCC includes the capital and operation and maintenance cost of treatment units as well as wastewater collection and reclaimed water distribution systems. LCC is estimated as Net Present Value (NPV) (Davis et al., 2005). In addition, the energy use is estimated as the sum of energy consumption in wastewater collection, wastewater treatment, and reclaimed water distribution. Also, the total resulting carbon emissions from energy use is estimated using the carbon emission factor of electricity of the region (Canadian Geoexchange Coalition, 2010). Furthermore, the health risk of reclaimed water use due to microorganisms is estimated using Quantitative Microbial Risk Assessment (QMRA) (Chhipi-Shrestha et al., 2017a; Haas, 2002; Petterson et al., 2016). The rating, i.e., data of the evaluation criteria, is in fuzzy numbers, expressed as Triangular Fuzzy Numbers (TFNs) (Chhipi-Shrestha et al., 2016).

The ratings of five evaluation criteria are aggregated using a multi-criteria decision analysis (MCDA) technique. The weight, i.e., importance of each evaluation criteria, has been used for aggregation. The criteria ratings and weights are aggregated using a fuzzy weighted average technique to generate a final aggregated score (Guu, 2002). Each wastewater treatment train and reuse plan can be assessed based on the aggregated score. Higher scores result in better alternatives. FitWater ranks several alternative wastewater treatment train and reuse plans using the provided input information. Users are required to input water reuse application type, population, microbial concentration of raw wastewater, province, energy source, water recycling efficiency, annual interest rate, municipal water price, sewer charge, reclaimed water demand, price of electricity, weights of criteria, number of alternatives, wastewater source for reuse (wastewater or greywater), treatment units, and length and cost of wastewater collection and reclaimed water distribution. A screenshot of the FitWater interface is shown in Fig. 2. The detailed concept and development of FitWater is explained in the first article of this series paper (Chhipi-Shrestha et al., 2017b).

This research aims to apply the proposed DST to existing wastewater treatment plants (WWTP) and a water reuse plan in a community for testing and implementation, respectively. FitWater evaluates health risks of reclaimed water use in various urban applications, estimates the cost of wastewater treatment, and estimates energy use and associated carbon emissions. FitWater will assist decision makers in assessing the potential of wastewater treatment and reuse.

2. Data preparation and model simulation

The proposed FitWater has been validated with existing WWTPs in Canada and US and then, implemented for the screening of wastewater treatment trains and reuse options in a newly planned neighbourhood in the Okanagan Valley (BC, Canada). The methodology used in the application of FitWater is elaborated in the following sections.

2.1. Developing alternative treatment trains

Urban water reuse potential for various purposes can be evaluated using FitWater. Urban water reuses can broadly be classified into three categories based on the literature, such as Ahmed et al. (2002) and Asano et al. (2007). These categories may require different minimum grades of water quality, namely Classes A (Excellent), B (Good), and C (Moderate) as shown in Table 1.

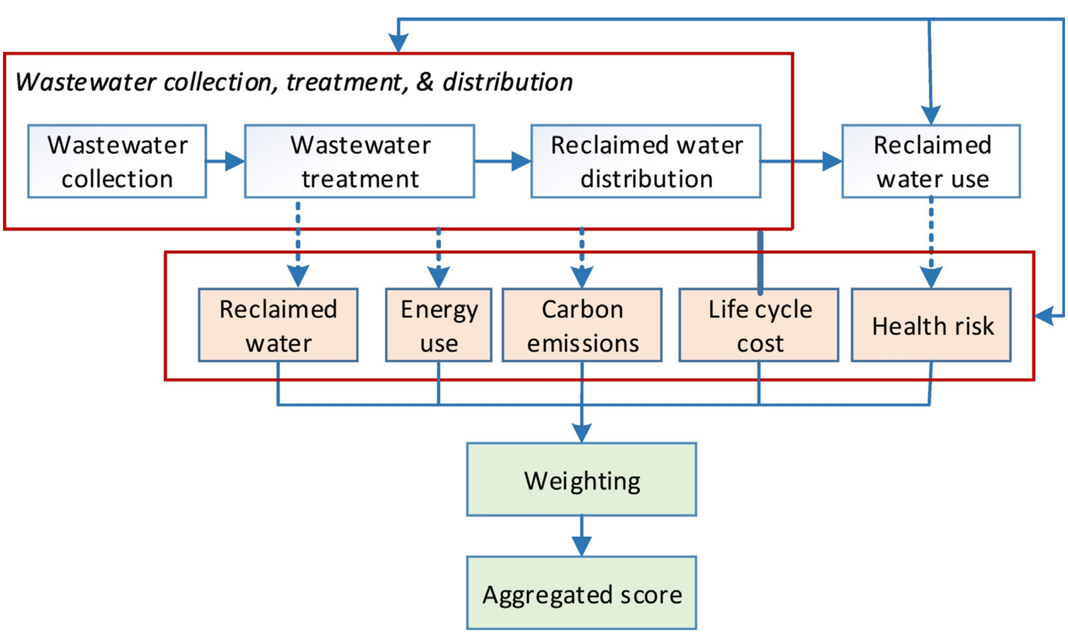

Fig. 1. Framework of FitWater tool.