Science of the Total Environment 645 (2018) 993–1002

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Review

Quantitative microbial risk assessment and its applications in small water systems: A review

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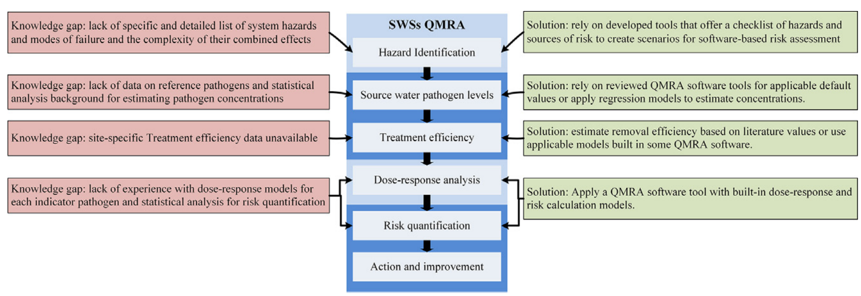
HIGHLIGHTS

- QMRA is valuable for SWSs to enhance water safety and identify sources of risk.
- Pathogen removal by typical small water system technologies is reviewed.
- Knowledge gap for successful implementation of QMRA in SWSs is discussed.
- Framework of QMRA application in SWSs is proposed to deal with limited data.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 7 March 2018
Received in revised form 7 June 2018
Accepted 16 July 2018
Available online xxxx

Editor: Paola Verlicchi

Keywords:
QMRA
Limited data
Framework
Knowledge gap
Small water systems

ABSTRACT

Quantitative microbial risk assessment (QMRA) has been mainstreamed in many large municipal water systems as part of a paradigm shift in the drinking water industry towards water safety planning and risk-based system assessment. Small water systems (SWSs) are generally more vulnerable to typical water system hazards, and consequently have a higher risk of waterborne disease outbreak. In this paper, a review of experiences in implementing QMRA in SWSs helps elaborate the sources of risks and highlights some of the challenges facing SWSs in developed countries. A critical review of the important elements for practical implementation of QMRA was conducted. The investigation focuses on aspects related to challenges in identifying relevant hazards to SWSs to create failure scenarios, acquiring monitoring data for pathogens' concentrations in source water, estimating treatment efficiencies of typical small system technologies, and access to software tools to support successful implementation. The review helped outline ways through which SWSs can overcome the identified challenges in implementing QMRA. An adjusted framework for implementing QMRA for small water systems was formulated and discussed.

Contents

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https://doi.org/10.1016/j.scitotenv.2018.07.228
0048-9697/

1. Introduction

1.1. Small drinking water systems

Small water systems (SWSs) may include small community systems and non-community facilities like schools, libraries, restaurants, campgrounds, gas stations, etc. (US EPA, 2009). The definition of small water systems varies globally. In developed countries, they commonly refer to water systems that serve smaller population, have fewer connections, or have smaller amount of water distributed. For example, Health Canada defines small systems as those serving <5000 individuals, and each province defines SWSs differently (Moffat and Struck, 2011). US Environmental Protection Agency (US EPA) has defined SWSs as those serving 3300 or fewer people (US EPA, 2009) while Europe categorizes them based on the group of people who is responsible for their operation and management and the users they supply (WHO, 2011a). In Europe, 30% population live in rural area and rely on small-scale water supplies (WHO, 2011a). Over 15 million households in the U.S. (about 15% of the total population) are living on their private wells as drinking water resources (USEPA, 2006). In Canada, about 12% of the Canadian population (~4.1 million) are served by private water supplies (PWSs), and 4.9% (~1.7 million) are served by small water supplies which are serving <1000 people (Statistics Canada, 2011).

Compared to large municipal water systems, SWSs are facing a number of challenges to meet water quality regulations and standards, including inadequate treatment and infrastructure, poor source water quality, lack of effective operation and maintenance, and lack of financial and human resources (Hrudey and Hrudey, 2007; Hunter et al., 2009, 2011). As a result, customers served by SWSs may be at more risk of waterborne diseases than those served by large municipal drinking water systems (Murphy et al., 2016). For example, small water systems are estimated to be responsible for 103,320 acute gastrointestinal illness cases annually in Canada (Murphy et al., 2016). Therefore, ensuring drinking water safety in terms of microbiological quality in small water systems has become an increasing concern.

1.2. Quantitative microbial risk assessment and water safety

Quantitative microbial risk assessment (QMRA) has become a valuable tool for assessing the microbial safety of drinking water (Payment et al., 2000; Pintar et al., 2012; Smeets et al., 2010). The major steps of a QMRA have been well defined, it includes: hazard identification, exposure assessment, dose-response modeling, and risk characterization (Haas et al., 1999; Hamouda et al., 2016) as shown in Fig. 1. QMRA uses raw water quality indicators (i.e., concentration of pathogens) and treatment barrier performance (i.e., pathogen removal/inactivation by treatment) to estimate the microbial risk from the exposure to a particular pathogen. Limited studies have been conducted to assess microbial risk from distribution systems (Blokker et al., 2014; Schijven et al., 2016). Assessing the risk of every waterborne pathogen is impractical and time-consuming, in addition the dose-response information is not available for many pathogens, particularly in developing countries (Howard et al., 2006a, 2006b, 2007). QMRA studies are therefore typically confined to a few selected reference pathogens such as *Cryptosporidium*, *Giardia*, Norovirus, Rotavirus, *Campylobacter*, and *E. coli* O157:

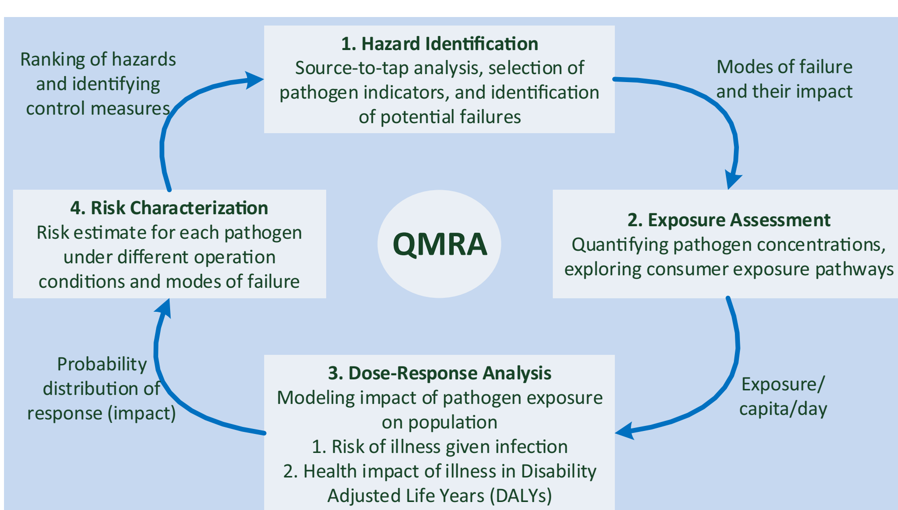

Fig. 1. QMRA framework.