Integrating Quantitative Microbial Risk Assessment into Health Risk Management of Water Supply Systems in Norway

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Abstract

The management of health risk situations associated with possible disease outbreaks related to drinking water supply, largely depends on water sample analysis, hospital surveillance systems and in some cases on epidemiological studies. Water analysis takes time and large parts of the population may be at risk before the pathogen is detected. Hospital surveillance system and epidemiological studies are built on symptomatic disease incidences and thus do not provide rapid feedback mechanisms for ameliorative actions on water supply systems. In this paper, a conceptual framework for integrating Quantitative Microbial Risk Assessment for the assessment of health risk is presented. The risk model will allow for simulations of different scenarios, making risk situations that require remedial action, easier to foresee and monitoring strategies more accurate.

Sammendrag

Håndtering av risikosituasjoner i forbindelse med mulig sykdomsutbrudd som kan relateres til vannforsyning i Norge, er i stor grad basert på resultater fra vannanalyser, registrering av sykdomstilfeller eller i enkelte tilfeller på epidemiologiske undersøkelser. Vannanalyser tar tid og medfører at store deler av befolkningen kan bli smittet før smittestoffet er identifisert. Registrerte sykdomstilfeller eller epidemiologiske opplysninger tar lang tid og vil alltid være basert på symptomatiske tilfeller. De er derfor lite

egnet for rask tilbakemelding til de som opererer vannforsyningssystemet og som eventuelt kan avverge et omfattende sykdomsutbrudd. I denne artikkelen presenterer vi et konseptuelt rammeverk for integrering av kvantitativ mikrobiell risikovurdering i dette arbeidet. Risikomodellen vil gjøre det mulig å simulere ulike scenarier, og en kan dermed lettere forutsi hvilke situasjoner som krever tiltak fra vannverksoperatørene, samt hvilke deler av vannforsyningssystemet som bør ha prioritet i overvåkingsstrategien.

Introduction

Since the germ theory established the link between drinking water and disease, various innovative treatment systems have been developed to improve the quality of drinking water supply. From the sand filters of Robert Koch in the 1870s, to the novel discovery of chlorine disinfection by John Snow in 1895, to the latest advanced treatment technologies, significant reductions in waterborne diseases have been achieved in developed countries (Ashbolt, 2004). However, water treatment is still an on-going challenge due to the emergence of new waterborne pathogens that are resistant to some of the advanced water treatment steps (WHO, 2004). Today, the major concern is the enteric viruses and the chlorine resistant parasitic protozoa such as *Cryptosporidium* and *Giardia*, associated with waterborne disease outbreaks in developed countries. In Norway, the latter organisms have attracted much attention following the 2004 *Giardiasis* outbreak in Bergen and the most recent detection of *Giardia* and *Cryptosporidium* in the tap water of Oslo.

In the above cases, as with others, the microbial hazard could not be detected within the water supply management system. In the Oslo case, coliform bacteria was identified in several presence/absence tests by the laboratory of a private company, prompting the managers of the water supply system to do further sampling leading to the issue of a water boiling order (Aftenposten, 2007). In Bergen, high cases of *Giardiasis* infections recorded by medical doctors provided the signal for an investigation that eventually implicated the water supply system. Such delayed feedback mechanisms often lead to severe health consequences before corrective actions are taken by the managers of water supply systems as observed in the *Giardiasis* outbreak in Bergen (Nygård *et al.*, 2006). The question therefore is: how can a rapid feedback mechanism be established within the water supply system for the management of health risks? This paper addresses this question by exploring the integration of Quantitative Microbial Risk Assessment (QMRA) into water supply systems for the management of health risks in Norway.

QMRA Defined

Quantitative Microbial Risk Assessment (QMRA), a concept developed from chemical risk assessment, has over the years been used in studies to assess the microbial health risks associated with water supply systems.

The approach has also been built into the most recent World Health Organization guidelines for drinking water (WHO, 2004). According to Haas *et al*., (1999), QMRA is the application of the principles of risk assessment to assess the health risk associated with exposure to pathogenic microorganisms. It proceeds sequentially with:

a) hazard identification
b) exposure assessment
c) dose response relationship and
d) risk characterization

In the context of drinking water supply systems, hazard identification involves the identification of all pathogenic organisms (hazards) that could potentially be found in the raw and treated water. Exposure assessment determines the size and nature of the population connected to drinking water supply system and accounts for the amounts and duration of their exposure to the range of hazards in the drinking water. The dose response relationship aims at the mathematical characterization of the doses of hazards administered in the drinking water and the probability of infection or disease in the exposed population. Risk characterization is an integration of all the three steps to estimate the magnitude of the health risk in the exposed population expressed in probability terms. Health risk estimates are characterized as acceptable or unacceptable. Using diarrhoeal infections as an indicator, the WHO (2004) puts the acceptable risk of infection at 10^{-4} per person per year. This means that it is acceptable for 1 out of 10,000 persons per year to be infected by hazards in drinking water that could lead to diarrhoeal disease. What is considered as acceptable health risk is however still being debated and should be based on prevailing local circumstances.

Unlike epidemiological investigations QMRA allows for the assessment of health risk even at endemic levels hence providing an assessment of actual health risk levels. Also, as infections/disease are estimated using mathematical models, more rapid results can be obtained through QMRA given that data on the concentration and variability of pathogenic microorganisms is available. In the next section, we present and discuss a conceptual framework for the integration of this approach into water supply management.

Integration of QMRA into Health Risk Management in Water Supply Systems

Figure 1 shows the conceptual framework for the integration of QMRA into health risks management for water supply systems. The framework includes all the various elements of the water supply system as well as control points where QMRA could be applied to predict health risks under different scenarios. The selected control points are the inlet of the water treatment plant, treatment step and distribution network, which make up the water supply system and have been associated with waterborne disease outbreaks in Norway.

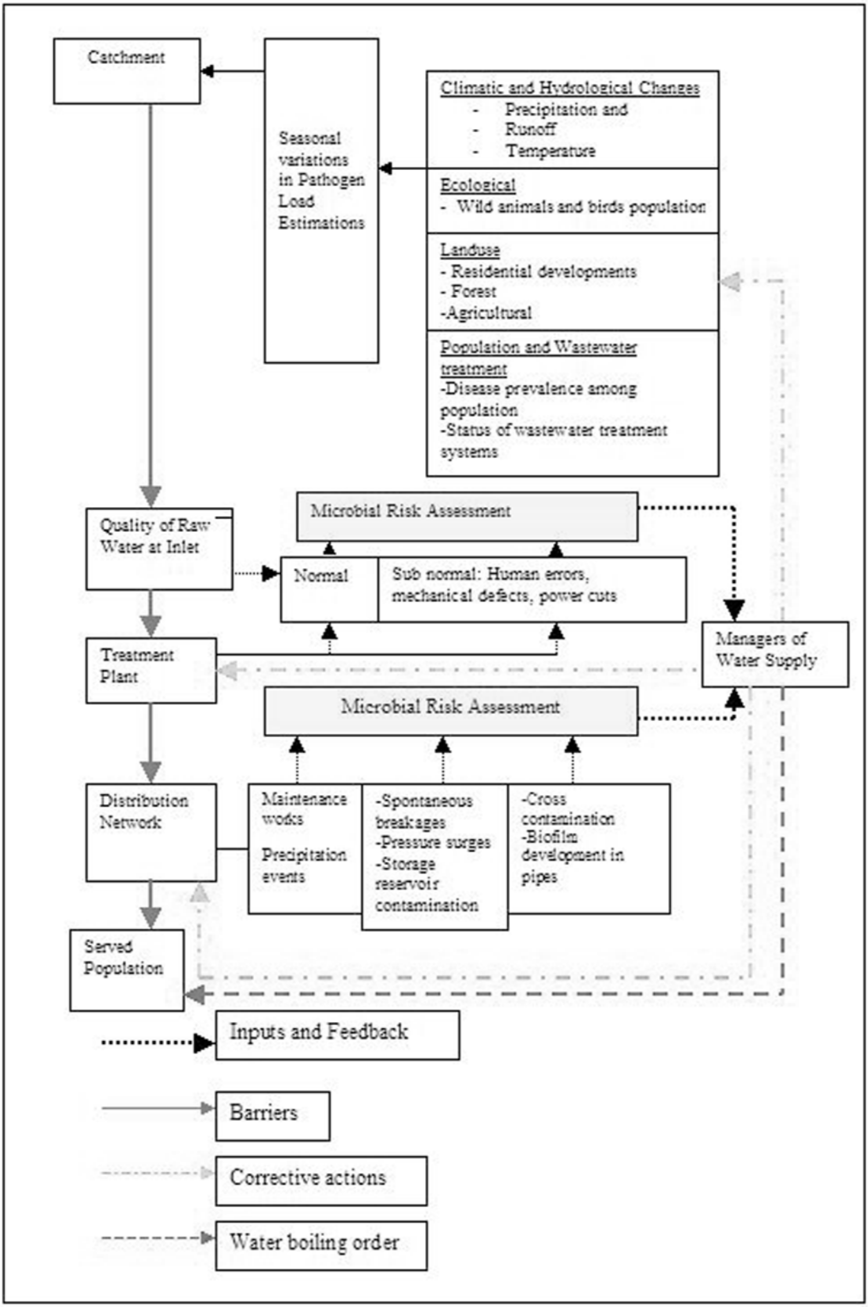

Figure 1. Conceptual Framework

From Raw Water Quality to Health Risk Estimation

From Figure 1, the inlet of the water supply system is the first control point where health risks could be assessed by taking the variations in the pathogen load into account. Variations in the pathogen load at this point are governed by a number of factors in the raw water catchment area. These factors include but not limited to climatic and ecological changes (Hunter, 2003), hydrological conditions (Ferguson *et al*., 2003), landuse changes and wastewater management (Charles *et al*., 2003). Short term pathogen peaks at the inlet influenced by these factors may elevate the risk for waterborne disease outbreaks (Åstrom *et al*., 2007). From 1975 to 2004, five water borne disease outbreaks including that of Bergen were associated with elevated pathogen load at the inlet of the water supply system. In the *Giardiasis* outbreak in Bergen, a leaking sewer was identified as the main cause of the source water contamination (Nygård *et al*., 2007). During events associated with elevated pathogen load at the inlet of the water supply system, QMRA can be applied to assess health risks by taking the barrier functions of the treatment steps into account. In Sweden, Åstrom *et al*., (2007) applied QMRA to estimate the health risk associated with elevated pathogen levels at the inlet of a water supply system.

From Treatment Steps to Health Risk Estimation

The above waterborne disease outbreaks and incidences recorded in Norway shows that treatment steps as barriers against pathogenic microorganisms may not adequately safeguard public health especially for the enteric viruses. For instance, UV radiation step considered being an effective barrier against *Giardia* and *Cryptosporidium* at 5mJ.cm^{-2} and 10mJ.cm^{-2} respectively (WHO, 2004) requires a dose of 167mJ.cm^{-2} for a 99% inactivation of Adenovirus type 2, 15, 40,41 and even higher for type 40 (Hijnen *et al*., 2006) This means that even under normal operational conditions of the treatment steps, pathogens could still be present in the treated water and potentially lead to an outbreak depending on the initial concentration at the inlet (Westrell et al., 2003; Åstrom *et al*., 2007). This assertion is supported by the identification of *Giardia* and *Cryptosporidium* in Oslo's treated water (Aftenposten, 2007) and the *Giardiasis* outbreak in Bergen. Also significantly related to waterborne disease outbreaks are failures in water treatment steps. A classical and widely referenced case is the *Cryptosporidiosis* outbreak in 1993 in Milwaukee, Wisconsin in the United States which led to 400,000 illnesses and 100 deaths (MacKenzie *et al*., 1994). Ineffective filtration in the treatment steps was partly implicated for the outbreak. In Norway, non-functional chlorination steps were associated with the waterborne disease outbreak in Gran in 1978 and Jørstadmoen in 1993; while lack of chlorination was associated with the oubreak in Klæbu in 1995 and Søgner in 1997 (Wasteson and Kapperud,1998).

From the above, two scenarios could be simulated with QMRA to provide rapid feedback (Figure 1). These are events of normal operation and failures in the water treatment steps. The former scenario is especially important during events associated with elevated pathogen loads at the inlet of the plant due to, for example, wastewater system breakdown and intense runoffs in catchment area. On the other hand, the former scenario is often associated with factors and events such as human errors, power cuts and mechanical defects. The health risks associated with these events can be assessed with QMRA by taking their frequency and duration into account (Westrell *et al.*, 2003).

<u>From the Distribution Network to Health Risk Estimation</u>

Waterborne disease outbreaks caused by deficiencies in the distribution network is one of the major health risk management challenges for water supply systems in Norway and other developed countries. From 1981 to 1986, four waterborne disease outbreaks were associated with contamination of the distribution network in Norway (Wasteson and Kapperud, 1998). Havelaar (1994) identified contamination of elements of the distribution network (pipe network and storage reservoirs) as the primary hazard in water supply systems. A similar finding was made by Westrell *et al.*, (2004) in a hazard analysis for a water supply system in Sweden. Events in the distribution network often cited for waterborne disease outbreaks include spontaneous breakages, pressure surges, maintenance work (Kirmeyer *et al.*, 2001), contamination of storage reservoirs (Wasteson and Kapperud, 1998; Clark, 1996) and cross connection (Lahti and Hiisvirta, 1995). In a recent epidemiological survey, maintenance work on pipes of some water supply systems was found to correlate with diarrhoeal incidences in Norway (Nygård *et al.*, 2007). The accumulation of pathogens in biofilms on the internal surface of pipelines has also been cited in the literature but not yet implicated in any major waterborne disease outbreak in Norway.

The health risks associated with the above deficient events in the pipe network can be simulated with QMRA by taking into account their frequency and duration (Westrell, 2004). Scenarios such as prolonged precipitation, pressure surges and maintenance works on pipelines could be simulated to estimate their potential health risks using QMRA. However, such a simulation as with the others has to be supported by microbial data of water samples taken during these events in the distribution network. Where this is not possible, reasonable assumptions can be made for the level of pathogen intrusion for the health risk estimation (Westrell *et al.*, 2004).

Conclusion

QMRA offers possibilities for the assessment of health risk at the most critical points of health hazards in the water supply system. The output generated from the assessment makes it possible for rapid decisions and corrective actions to be taken to forestall major disease outbreaks. Also endemic health risk levels associated with water supply systems that are not covered by hospital surveillance systems and epidemiological investigations are obtainable from QMRA.

However, the application of QMRA requires better data inputs that will describe the uncertainty and variability of the waterborne pathogens for accurate predictions of health outcomes. Also, there are limited dose-response relationships characterization for a wide range of pathogenic microorganisms that could potentially be transmitted through drinking water. As QMRA is a fairly new approach in the water sector, it is imperative that more investigations on its efficacy in health risk management in water supply systems be undertaken in Norway. Any breakthrough on the accurate application of the approach would in no doubt contribute significantly towards mitigating water borne disease outbreaks associated with the country's water supply systems.

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