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Review

Salmonella in surface and drinking water: Occurrence and water-mediated transmission

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ABSTRACT

Salmonella is one of the leading causes of intestinal illness all over the world as well as the etiological agent of more severe systemic diseases such as typhoid and paratyphoid fevers. While water is known to be a common vehicle for the transmission of typhoidal *Salmonella* serovars, non-typhoidal salmonellae are mainly known as foodborne pathogens. This paper provides a brief review of the last ten years of peer reviewed publications on the prevalence of *Salmonella* in natural freshwaters and drinking waters, and on the relevance of these sources for *Salmonella* dissemination. In industrialized countries, *Salmonella* was rarely reported in water-borne outbreaks despite it being frequently detected in surface waters including recreational waters and waters used for irrigation or as a drinking water source. Consistent contamination with irrigation waters has been shown to be a common route of crop contamination in produces related *Salmonella* outbreaks. Multiple drug resistant (MDR) *Salmonella* strains, that represent an increased hazard for human health and that may contribute to the dissemination of drug resistances were also detected in surface water in developed countries. Surface runoff was shown to play a main role as driver of *Salmonella* load in surface waters. Accordingly, analysis of serovars indicated a mixed human and animal origin of *Salmonella* contribution to surface waters, emphasizing the role of wild life animals in water contamination. Data relating to *Salmonella* prevalence in surface and drinking water in developing countries are quite rare. Nevertheless, data on water-borne outbreaks as well as case control studies investigating the risk factors for endemic typhoid fever confirmed the relevance of water as source for the transmission of this disease. In addition epidemiological studies and *Salmonella* surveys, consistently provided an undeniable evidence of the relevance of MDR *Salmonella* Typhi strains in water-borne typhoid fever in developing countries.

Contents

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1. Introduction

One third of the world's population live in countries with some level of water stress and water scarcity is expected to increase in the next few years due to increases in human population, per capita consumption and the resulting impacts of human activity on the environment (Asano, Burton, Leverenz, Tsuchihashi, & Tchobanoglous, 2007). The availability of good quality water sources is therefore getting more and more limited and the impact of water-borne pathogens in human health is expected to be significant (Suresh & Smith, 2004). It is therefore critical to understand the relevance of natural and drinking water contribution to transmission of pathogenic microorganisms.

Salmonella is a ubiquitous enteric pathogen with a worldwide distribution that comprises a large number of serovars characterized by different host specificity and distribution. This microorganism is one of the leading causes of intestinal illness through the world as well as the etiological agent of more severe systemic diseases such as typhoid and paratyphoid fever (Pond, 2005). Zoonotic salmonellae are commonly described as foodborne pathogens, however, drinking water as well as natural waters are known to be an important source for the transmission of these enteric microorganisms (Ashbolt, 2004; Leclerc, Schwartzbrod, & Dei-Cas, 2002). *Salmonella*, just like other enteric bacteria, is spread by the fecal–oral route of contamination. This microorganism can enter the aquatic environment directly with feces of infected humans or animals or indirectly, e.g., via sewage discharge or agricultural land run off. Overall *Salmonella* spp. and subspecies can be found in a large variety of vertebrates. Beside humans, animal sources of *Salmonella* include pets, farm animals and wild animals; calves, poultry, pigs, sheep as well as wild birds (sea gull, pigeon) and reptiles can all be reservoirs of *Salmonella* (Dolejská, Bierosová, Kohoutová, Literák, & Cízek, 2009; Lightfoot, 2004; Wray & Wray, 2000). Plants, insects and algae were also found capable of harboring *Salmonella* and might be implicated in the transmission of this enteric pathogen (Byappanahalli et al., 2009; Guo, van Iersel, Chenn, Brackett, & Beuchat, 2002; Ishii et al., 2006; Natvig, Ingham, Ingham, Cooperband, & Roper, 2002).

Salmonellae are frequently found in environmental samples. They are usually present in large numbers in raw sewage (10^3–10^4 CFU/L) and can still be present in wastewater effluent after advanced secondary treatment including coagulation, filtration and disinfection (Maier, Pepper, & Gerba, 2000; Wéry, Lhoutellier, Ducray, Delgenès, & Godon, 2008). Soil and sediment were also found to harbor salmonellae (Abdel-Monem & Dowidar, 1990; Gorski et al., 2011; Tobias & Heinemeyer, 1994) and sediment particles are believed to function as a micro ecological niche enhancing salmonellae survival in lakes (Chandran et al., 2011). In the aquatic environment this pathogen has been repeatedly detected in various types of natural waters such as rivers, lakes, coastal waters, estuarine as well as contaminated ground water (Haley, Cole, & Lipp, 2009; Levantesi et al., 2010; Martinez-Urtaza et al., 2004; Martinez-Urtaza, Liebana, Garcia-Migura, Perez-Piñeiro, & Saco, 2004; Polo et al., 1999; Wilkes et al., 2009).

In addition to its widespread occurrence, elevated survival capacities in non-host environment have been reported for *Salmonella* (Winfield & Groisman, 2003). The growth of *Salmonella* in non-host environments such as wastewater sludge and compost has also been reported (Zaleski, Josephson, Gerba, & Pepper, 2005) and the growth of *Salmonella* in water supplies is also considered possible, due to its ability to colonize surfaces and replicate in biofilms of distribution system pipes (Jones & Bradshaw, 1996). However, standard disinfection procedures used in drinking water treatment processes are active against salmonellae (Cicmanec, Smith, & Carr, 2004).

Taxonomically the genus *Salmonella* comprises two species namely *S. bongori* and *S. enterica*. The species *S. enterica* is further differentiated in to six subspecies (*enterica*, *salamae*, *arizonae*, *diarizonae*, *indica* and *houtenae*) among which the *S. enterica* subspecies *enterica* is mainly associated to human and other warm blooded vertebrates. Traditionally members of the genus *Salmonella* are clustered in serovars according to their flagellar (h) and somatic (o) antigens. Currently over 2400 *Salmonella* serovars have been described but only about 50 serovars, all within the subspecies *enterica*, are common causes of infections in humans and warm blooded animals (Popoff, 2001). *Salmonella* serovars have different host specificity, diverse geographic distribution, and cause different syndromes. On the basis of the clinical syndromes caused *Salmonella* are divided in to two distinct groups namely the typhoidal and non-typhoidal *Salmonella* serovars (Pond, 2005).

Enteric fevers, typhoid and paratyphoid fever are severe, contagious systemic diseases caused by the infection of the serovars Typhi and Paratyphi. Even though not common in developed countries, enteric fevers remain an important and persistent health problem in less industrialized nations. Overall, in 2003 an annual incidence of approximately 17 million cases of typhoid and paratyphoid fevers was reported worldwide (Kindhauser, 2003). Differently from other *Salmonella* serovars, Typhi and Paratyphi are host adapted and can only infect humans; stools of infected persons are therefore the original source of contaminations for these pathogens. Water contaminated with feces of human cases and carriers is one of the main vehicles of typhoid fever infections.

Differently from typhoidal *Salmonella* strains, non-typhoidal salmonellae, the ubiquitous subtypes found in a number of animal species, are more frequently associated to foodborne than to water-borne transmission. These zoonotic *Salmonella* serovars tend to cause acute but usually self-limiting gastroenteritis. In some patients, however, these same serovars can cause severe systemic diseases such as osteomyelitis, pneumonia and meningitis (Pond, 2005). Severe and invasive presentations of non-typhoidal salmonellosis in Africa are common in children with co-morbidities (Graham, 2002) and immune compromised HIV infected adults (Gordon, 2008). Notably the emergence of MDR strains of *Salmonella* Enteriditis and Typhimurium was associated to the observed incidence of invasive salmonellosis (Gordon & Graham, 2008).

The increased frequency of MDR *Salmonella* strains in human infections is an emerging issue of major health concern (Lightfoot, 2004; Lynch et al., 2009; Pond, 2005). As a consequence, the possible role of fecally contaminated waters in the dissemination of MDR *Salmonella*, both typhoidal and non-typhoidal, as well as antibiotic resistance genes though horizontal gene transfer is of great interest. This issue is of particular concern in developing countries where the common use of untreated, low quality water as drinking water sources together with inappropriate use and self-prescribing of antibiotics increase the risk of drug resistance and the probability of wide dissemination of resistant strains of high human health concern (Oluyege, Dada, & Odeyemi, 2009; Srikantiah et al., 2007).

Overall, the above reported characteristics suggest that water might be an important source for the transmission of all salmonellae, not only for the typhoid serovars. An increased knowledge on the prevalence, diversity and survival of this enteric bacterium in the environment, together with a proper assessment, trough effective