African Journal of Microbiology Research Vol. 3(12) pp. 856-861 December, 2009
Available online http://www.academicjournals.org/ajmr
ISSN 1996-0808 ©2009 Academic Journals

Review

Public health significance of viral contamination of drinking water

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Accepted 26 October, 2009

Water-borne enteric viruses pose a threat to both human and animal life causing a wide range of illnesses. Groundwater is the commonest transmission route for these viruses. About 50% of groundwater related disease outbreaks are attributable to viruses. Recent studies in developed countries have focused on public water systems, unfortunately, without much attention to private household wells and storage facilities. This paper reviews disease outbreaks attributed to water-borne viruses, the public health significance of enteric viral diseases and problems encountered in the development of diagnostic assays. The objective of this review is to confer the rationale for more research to provide reliable baseline information on the significance of water-borne viruses in the developing world. Since the virological quality of drinking water can no longer be compromised, rapid and sensitive methods for detecting enteric viruses in drinking water, recreational water and their sources is a necessity. As a preventive measure, ground, surface and treated drinking water must be protected from viral contamination. Enforcement of legislative measures for regular viral monitoring of drinking water in the industry will ensure safety of consumers.

Key words: Enteric, viruses, diseases, outbreak, public, health, significance, diarrhoea.

INTRODUCTION

A wide variety of enteric viruses have been implicated in the aetiology of diarrhoea. Water-borne viruses are responsible for several outbreaks of gastroenteritis, respiratory diseases, neurological diseases and paralysis among others (Bosch, 1998; Griffin et al., 2003; Sack et al., 1997). The presence of enteric viruses in the water environment therefore has become a public health hazard as such new and advanced molecular assays are being developed to detect enteric viruses in the water environment in the developed world. Nevertheless, it is difficult to develop a meaningful risk assessment for any specific enteric virus because majority of these viruses do not grow well in cell culture (Griffin et al., 2003; Macler, 1993). However, the United States Environmental Protection Agency (U.S EPA) has proposed the use of a conceptual synthetic virus as a means of determining acceptable levels for human enteric viruses in water (Payment et al., 1997). This notwithstanding, it is necessary to put preventive measures against viral pollution of treated water and their sources.

Diarrhoeal disease is a major cause of infant morbidity and mortality. Out of 1.8 million people who die every year from diarrhoeal diseases, 90% are children under five years of age mostly in developing countries (WHO, 2004). Diarrhoea also represents an economic burden in developing countries. The causative agents of diarrhoea include a wide range of bacteria and viruses. The main objective of this review is to provide the rationale for more research to provide reliable baseline information on the public health significance of water-borne viruses in the developing world. Since the virological quality of drinking water can no longer be neglected, rapid and sensitive methods for detecting enteric viruses in drinking water,

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recreational water and their sources is a necessity. As a preventive measure, ground and surface water as well as treated drinking water must be protected from viral contamination. Legislative measures for regular viral monitoring as part of microbial risk assessment of drinking water in the industry should also be enforced by national quality monitoring bodies.

BURDEN OF DIARRHOEA

Diarrhoea is a major cause of childhood morbidity and mortality in developing countries. About a billion diarrhoeal cases occur each year among children below five years, resulting in approximately 2.5 million deaths (Kosek et al., 2003; O'Ryan et al., 2005). Diarrhoeal diseases are currently responsible for about 90% of all deaths of children under five years in developing countries (WHO/UNICEF, 2008). Between 2000 and 2003, 769,000 and 683,000 children under five years of age died in sub-Saharan Africa and South Asia respectively each year from diarrhoeal diseases (WHO/UNICEF, 2008). During the same period, only 700 children under five years of age died from diarrhoeal disease in developed countries (WHO/UNICEF, 2008). Diarrhoeal disease also represents an economic burden for developing countries where patients are treated with expensive intravenous fluids and ineffective herbal concoctions that may by themselves pose threats to the health of the patients. Although diarrhoeal disease is usually less harmful to adults than to children, it can also affect a country's economy by reducing work hours.

The main factors for high incidence of diarrhoeal cases are consumption of poisoned food and water resulting from inadequate sanitation such as improper waste disposal. The direct causes include a variety of pathogenic microorganisms. The range of bacteria that have been implicated in the aetiology of diarrhoeal disease include enterotoxigenic *Escherichia coli*, *Salmonella, Shigella, Cholera,* and other vibrio bacteria as well as parasites like *Cryptosporidium* and *Giardia* (Pedalino et al., 2003). A broad range of viruses have also been implicated in the aetiology of diarrhoeal disease (Sack et al., 1997) of which the most important is rotavirus. Rotaviruses have been estimated to cause 25 - 35% of all cases of severe diarrhoeal disease (Glass et al., 2005). Astroviruses, caliciviruses and some strains of adenoviruses (types 40 and 41) have also been associated with diarrhoeal disease (Pedalino et al., 2003; Poocharoen et al., 1986; Sebire et al., 2004).

Burden of water-borne viruses

According to Catley-Carlson (1993), Hillel Shuval illustrated the impact of water-borne diseases based on authentic estimates during the 1993 Stockholm water symposium that about 50,000 people in the world die each day due to water-borne diseases. Examples include the outbreak of 300,000 cases of hepatitis A virus (HAV) and 25,000 cases of viral gastroenteritis in Shanghai, China (Halliday et al., 1991).

In 1991, an outbreak of 79,000 cases of hepatitis E virus (HEV) in Kanpur, India was ascribed to polluted drinking water (Grabow et al., 1994). Between 1980 and 1994, 28 reported outbreaks and 11,195 confirmed cases of water-borne viral diseases were reported in the United States. Of these, 9,038 cases were attributed to the Norwalk-Like Viruses (NLVs) and 396 cases were attributed to HAV. Hepatitis A virus outbreaks have occurred in day-care centres and institutions due to a breakdown in hygienic conditions or the contamination of food and /or water. An outbreak of gastroenteritis among adults arising from rotavirus contamination of a municipal water supply was reported by Hopkins et al. (1984).

From 1974 to the end of 1995, there were 21 reported outbreaks and 1,358 confirmed cases of water-borne illness caused by enteric viruses in Canada mostly due to contamination of public drinking water supplies (Health Canada Food-borne and Water-borne Disease in Canada, Annual Summaries 1974 - 1995).

Two severe outbreaks of neurological diseases and rapid death in Asia have also been reported and were attributed to enteric viruses (Hsiung and Wang, 2000). In August 1998, a large outbreak of viral related gastroenteritis occurred in a Swiss Village where more than 50% of inhabitants were affected. A survey conducted within the village showed that one out of every two drinking water samples was contaminated with enteric viruses (Hafliger et al., 2000).

An investigation conducted in Egypt revealed that enteric virus load 1km away from two plants was almost the same as the raw water (Ali et al., 2004). Human astrovirus (1- 5, 7 and 8) was detected and typed in 16 out of 21 environmental samples in Pretoria (Nadan et al., 2003). This study demonstrated the prevalence of enteric viruses in sludge and rivers, which could persist and contaminate conventional treated water and their sources. Two severe norovirus gastroenteritis outbreaks also occurred in South Africa and are often referred to as de “Christmas” and “Grootbrak”. Both outbreaks were attributed to contaminated drinking water and foods such as oysters and salads (Wolfaardt et al., 1995). This might have being as a result of fishing from contaminated rivers caused by improper sewage disposal and the use of wastewater for vegetable gardening.

After replicating in the human gut, enteric viruses are excreted into sewage and may be dispersed into the water environment if sewage is not adequately treated. Viral numbers have been detected in concentrations in excess of 10^3 – 10^4 viral particles /L of wastewater (Toze, 1997). Outbreaks in the early 1990s illustrated the role of improper human sewage discharge in propagating norovirus disease (Berg et al., 2000; CDC, 1997). In Durham, New Hampshire, Chapron et al. (2000) also detected astroviruses and adenoviruses in 48.3 and 51.7% of surface water samples, respectively.

Table 1. Diseases caused by human enteric viruses.

Enteric virus	illness
Parvovirus	Gastroenteritis
Coronavirus	Gastroenteritis, respiratory disease
Echovirus	Meningitis, encephalitis, rash, gastroenteritis
Adenovirus	Gastroenteritis, respiratory disease, conjunctivitis
Reoviruses	Gastroenteritis, respiratory disease
Enterovirus 71	Guillain-Barré Syndrome, aseptic meningitis
Torovirus	Gastroenteritis
Hepatitis A and E Viruses	Hepatitis
Poliovirus	Poliomyelitis
Coxsackie virus	Meningitis, respiratory disease
Astrovirus, calicivirus, rotavirus	Gastroenteritis
Coxsackievirus B	Meningitis, encephalitis, diabetes mellitus

PUBLIC HEALTH SIGNIFICANCE OF ENTERIC VIRAL DISEASES

The consequence of enteric viruses as causative agents of important human diseases cannot be overrated. Since the discovery of NLVs in 1972 (Kapikian et al., 1972) and rotavirus in 1973 (Bishop et al., 1973), the viral aetiology of acute non-bacterial gastroenteritis has been well established. Although rotavirus is the leading cause of severe diarrhoea among children (Parashar et al., 1998), data from various studies demonstrate that NLVs might also play an important role in infant gastroenteritis (Pang et al., 1999). Enterovirus 71 (EV71) which was discovered in 1974 in patients with severe neurological disease (Ho, 2000; Thong, 2000) has propensity to cause paralytic disease, as do Coxsackievirus A7 and Entero 70 (Muir et al., 1996). The most commonly implicating viral agents of serious infections with neurological involvement or even fatal disease are polioviruses and EV71. Table 1 summarises some common diseases caused by enteric viruses.

Studies have revealed the presence of viruses in raw; surface and ground water and treated drinking water meeting quality standards for coliform bacteria (Cho et al., 2000; Gerba and Rose, 1990). For instance, work carried out in Germany showed that even though micro-biological parameters such as *E. coli*, *enterococci* and *coliphages* indicated acceptable microbiological water quality, the virological data of this study suggested that surface waters might still be sources for enteric viral infections (Pusch et al., 2005). These studies also reveal-ed that several outbreaks were caused by tap water contaminated with viruses in spite of compliance with water treatment procedures, an indication that viruses are being introduced into ground waters and treated water.

Low concentrations of all types of bacteriophages in groundwater have also limited their power to be used to predict the presence of enteric viruses. Common treat-ment processes, including chlorination, have not been shown to completely eliminate enteric viruses in sewage (De Leon and Jaykus, 1997). In fact, findings have confirmed that depending upon the treatment methods for domestic sewage, only between 50 and 99.99% of these viruses can be inactivated (Gerba, 1983). Therefore, the potential exists that an infectious virus will remain after treatment of sewage and possibly contaminate source water or treated drinking water.

The presence of enteric viruses in the water environ-ment is a public health hazard. Enteric viruses can cause illnesses in susceptible individuals even at low viral loads. A low viral dose, typically between 1 and 50 infectious particles is enough to cause illness (Moe, 1991). The water environment (source, drinking and recreational water) therefore poses a risk in the transmission of enteric viruses not only because there is uncertainty on acceptable virus levels but also due to the fact that enteric viruses are resistant to commonly employed disinfection methods. Generally, there is also a failure to report and investigate outbreaks of mild gastrointestinal disease, especially in the developing world. This makes it more difficult to source track the transmission of these viruses, to determine the risks associated with their occurrence and consequently preclude the institution of preventive measures against enteric viral transmission from domestic sources.

Even though the mortality of many water-borne diseases is relatively low, the socio-economic impact of even non-fatal water-borne disease infections is pheno-menal. The annual cost of outpatient care for pediatric diarrheoa in the United States has been estimated to be between $0.6 and $1.0 billion. Twenty-one percent (21%) of the annual cost of pediatric diarrheoa in the United States is attributed to rotavirus infection (Avendano et al., 1993). The public health and socio-economic burden of pathogenic microorganisms in drinking water have been reviewed to be greater than the impact of diseases associated with the chemical quality of water (Bern and Glass, 1994; von Schirnding et al., 1993).

Figure 1. A broken pipe from construction work (Noguchi Memorial Institute for Medical Research, Legon, Accra, 2006). Arrow indicates direction of leakage on pipe.

Figure 2. A broken pipe submerged in sewage water (Danquah circle, Accra, 2006). Arrow indicates direction of leakage or breakage on pipe.

Figure 3. A broken metal distribution pipe (Danquah circle, Accra, 2006). Arrow indicates direction of leakage or breakage on pipe.

Figure 4. A broken pipe from improper sealing at a joint (New Fadama, Accra, 2006). Arrow indicates direction of leakage or breakage on pipe.

SOURCES OF VIRAL CONTAMINATION OF DRINKING WATER

A variety of means through which viruses may be introduced into ground waters have being identified. They include, leaking septic tanks, landfills and artificial aquifer recharge of ground waters with wastewaters. Treated drinking water may also be contaminated with viruses through sewage, wastewater treatment facilities, runoffs from farmlands, homes and yards, leakages of pipes, floods and discharges from industrial processes. Other ways include a variety of industrial processes as well as defective well casings (Center and Knox, 1991; Chapron et al., 2000). In most developing countries, most potable water pipes are made of plastic and are often subjected to various degrees of physical damage (Figure 1), aggravated by poor urban planning and drainage systems (Figures 2, 3, 4) which predispose treated water to contamination with sewage.

Although contaminated food and water have been associated with outbreaks, the risks attributed to drinking water contamination in the transmission of viruses have not been fully assessed in developing countries like Ghana. Much has been reported on the physico-chemical and bacteriological contaminants. However, little information exists on the viral contamination. This is probably due to the absence of infrastructure and /or technology for assessing viral contamination of drinking water sources for the detection and recording of such infections in developing countries.

ASSESSMENT OF VIROLOGICAL QUALITY OF DRINKING WATER

New and advanced molecular assays are being developed to help detect enteric viruses in drinking water and their sources. Molecular methods employed include RT-PCR, Nucleic acid hybridization assays and DNA sequencing techniques. At least 37 different human enteric viruses with over 100 species have been isolated from the water environment around the world (Bosch, 1998; Tsai et al., 1994). Selecting appropriate risk management options is especially difficult due to poor knowledge of virus removal and inactivation during treatment of drinking water (Macler, 1993).

The U.S EPA has proposed the use of a conceptual synthetic virus for determining acceptable levels of human enteric viruses. The proposed model virus combines the characteristics of various enteric viruses. This model relies upon dose-response data for rotavirus as a surrogate for other infectious enteric viruses. However, there are some limitations to the use of this method to assess exposure risk. For example, preparing a cell culture of viruses from water has efficiency less than 100% (Payment et al., 1997). Furthermore, risk assessment models assume a random distribution of viruses. In fact, available data suggest that micro organisms do not occur randomly in water but are clustered (Gale, 1996). Lastly, the model is based upon risk of infection rather than risk of illness. The manifestation of symptoms involves a complex interaction dependent on the age and immune status of the infected individual, the virus strain and virulence. Thus the search goes on.

Conclusion

Since the occurrence of viruses in treated drinking water can no longer be ignored, it is necessary to use more effective disinfection methods e.g. ultraviolet disinfection. Increase in chlorine dosage should be considered by water companies. Legislative measures for regular viral monitoring of drinking water should be enforced by the national quality monitoring bodies. It is also necessary to conduct epidemiological studies relating virus occurrence in water to a defined health end-point. Cell culture and quantitative RT-PCR, large sample volumes and sequential analysis of viral genomes would also be required to provide reliable baseline information.

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