Public Health Perspectives on Water Systems and Ecology

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Abstract Human health is directly linked to ecosystem functioning, including the dynamics within wetlands. Wetlands can act to initiate or mitigate biological and chemical contamination. In order to assess the potential health risk, investigations focus on potential exposure pathways and evidence that exposure events are actually linked to adverse health effects. This chapter provides a brief introduction to the principals of health risk assessment in relation to wetlands.

Keywords Public health · Human health · Health risk assessment · Epidemiology · Surveillance · Water-borne disease · Water-borne exposures · Contamination · Disability adjusted life years (DALYs) · Cholera · Human pathogens · Toxic substances · Wetland settings · Ecosystem services

Introduction

Protection of public health requires the maintenance of adequate quality, quantity, accessibility and continuity of water supplies for communities (World Health Organization 2006a). For this reason, the World Health Organisation (WHO) has stressed the importance of "continuous and vigilant public health assessment and review of the safety and acceptability of drinking-water supplies" (World Health Organization 1976). Although considerable effort and investment has been directed towards achieving this health objective, water-borne diseases—that is, those arising from pathogens or chemical contaminants transmitted through water supplies—remain a major cause of global disease (Tebbutt 1998). Over 1.1 billion people globally continue to consume unsafe drinking water (Rodgers et al. 2004; WHO

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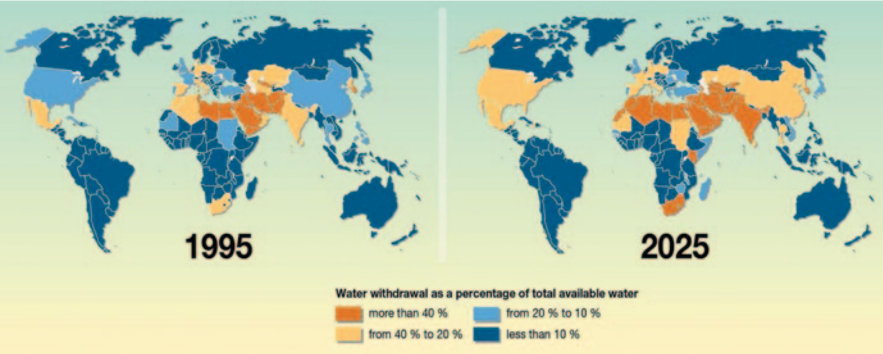

Fig. 1 Patterns of global water withdrawal (http://www.grida.no/publications/vg/water2/page/3289.aspx)

2004a) and a large proportion (88 %) of diarrhoeal illnesses has been attributed to unsafe water, sanitation and hygiene (WHO 2004b). In developing countries, diarrhoeal illnesses are ranked third in terms of the total burden of disease (with only HIV/AIDS and lower respiratory infections ranking higher) (WHO 2004a). Approximately 90 % of this disease burden occurs in children under the age of 5 years (Pruss et al. 2002) where severe malnutrition and lack of medical care compound the severity of the problem (Leclerc et al. 2002).

In recent decades, issues of global water availability and sustainability have become ever more pressing (Vörösmarty et al. 2010) (Fig. 1). The amount and quality of fresh water is decreasing, and aquifers, rivers and oceans are steadily becoming more degraded and depleted (Fig. 2 and 3). The construction of wells, dams, drains, canals and systems for irrigation have accelerated over the past century and contributed to serious disruptions in flow. Water contamination with chemicals or with infectious organisms is a significant cause of human disease globally.

In response to these growing challenges, there has also been a widening in the scope and activities associated with public health. It has become more generally appreciated that human well-being must be conceptualised within a wider set of environmental processes. The future of our health ultimately depends on the interaction between our species and surrounding physical, chemical and biological environments. These examples of human reliance on the environment can be termed as ecosystem services, where an ecosystem service is defined as the benefits that humans obtain from ecosystems (Corvalán et al. 2005). Four types of ecosystem services are identified: supporting services (such as nutrient cycling), provisioning (such as production of food and fuel), regulating services (such as regulation of climate or disease) and cultural services (which includes recreational and educational uses) (Corvalán et al. 2005). In the context of wetlands, ecosystem services such as provision of drinking water, flood control, source of fuel for water boiling, water for agriculture, can have a dramatic impact on the health of human populations (Horwitz et al. 2012). (See Box 1) Wetlands provide all four ecosystem services (Fig. 4). Our relationship with the biotic world and biogeochemical cycles is in a

Fig. 2 Example of salinisation of river in Western Australia showing degradation of vegetation (Photo Peter Speldewinde)

Fig. 3 Over grazing by cattle causing degradation of waterbody (Photo Paul Close)

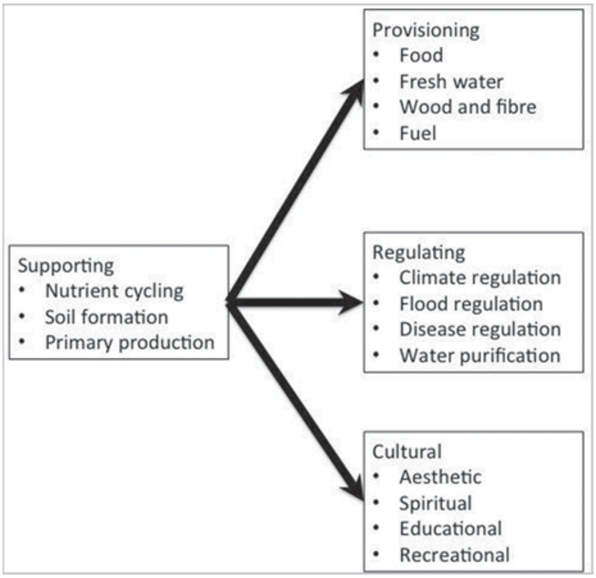

Fig. 4 Types of ecosystem services with examples of services provided. (Modified from the MEA Health Synthesis; Corvalán et al. 2005)

state of permanent flux that is made all the more variable by human interventions. These ideas have been formalised in various ecosystem and health approaches (Patz 2007; Aron and Patz 2001), which place the linkages between the environment and human well-being at their core. In the case of wetlands, three main health requirements are important: access to sufficient and safe water, provision of nutrition and social benefits (Horwitz et al. 2012). These can have direct health impacts (such as floods), ecosystem-mediated impacts (such as reduced food yields) or indirect health impacts (such as population displacement) (Corvalán et al. 2005).

Box 1: Cholera an Example of Ecosystem Services

Cholera is a water-borne disease caused by the bacterium *Vibrio cholera*. It is a disease which has strong environmental drivers which may be examined using the paradigm of ecosystem services. For example, high nutrient levels in the water combined with warm temperatures increases the levels of cholera in the water (regulating services) (Cottingham et al. 2003).

The chapter will provide a brief summary of the relationship between public (community) health and the water cycle (see Boxes 2 & 3). In the first section, a general overview of how water systems and ecologies relate to public health is provided, followed by a systematic approach for assessing health risks from water contaminants. The last two sections will examine how two vital public health activities—the application of epidemiological methods and the use of systems of surveillance—relate to water sources and supplies.

Box 2: Ecosystem and Human Pathogens

Land clearing in South East Asia has resulted in an increase in the human population in areas previously unpopulated or sparsely populated, an increase in potential breeding sites for mosquitoes and a reduction in biodiversity with reduced abundance of mosquito predators. With acceleration of the rate of land clearing there has been an increase in the number of reported malaria cases (Norris 2004). The reduction of biodiversity can lead to an increase in a range of other vector borne diseases, such as Lyme disease, Chagas disease and West Nile Encephalitis (Ostfeld and LoGiudice 2003). In environments with high species diversity, there are a greater proportion of incompetent hosts which attract vectors away from the most competent hosts therefore reducing the prevalence of the disease. Conversely, reduction of biodiversity can lead to a reduction in incompetent hosts and therefore an increase in the disease prevalence (Ostfeld and Keesing 2000).

Box 3: Ecosystems and Recycling of Toxic Substances

The drying of the Aral Sea, due to the diversion of water from the sea for irrigation, and the over use of fertilisers and pesticides (combined with a declining regional economy), has been linked to increased rates of cancers, respiratory conditions, tuberculosis and infant mortality in a number of Central Asian states (Zetterstrom 1998; O'Hara et al. 2000; Crighton et al. 2003). These disorders have been attributed to the increase in airborne dust, a consequence of the drying of the sea, which is laden with residual pesticides and fertilisers.

Water Systems From a Public Health Perspective

Sources and Contamination Processes Maintaining water quality standards is one of the core functions of public health. The two principal forms of water that are available for human use are surface water and ground water. Surface water is the term used to describe any water body that stands or flows above ground, such as lakes, rivers, streams, and so-called impounded water, such as reservoirs and dams. The quality of surface water is sensitive to both the abiotic environment and human/animal activity. Microbial deterioration of surface water quality may result from discharging effluent, wastewater or stormwater into sources waters, faecal contamination of the water from nearby livestock and local fauna, or by humans that utilise surface water and surrounding catchment areas for recreational purposes. Microbial deterioration of water bodies can also occur due to the removal of ecosystem components, which would under normal circumstances reduce the levels of microbial contamination, such as the removal of riparian vegetation which filter nutrients and pathogens prior to surface run off entering water bodies (Barling and Moore 1994).

Groundwater for human use can be extracted from fully saturated soils and rocks through boreholes and wells, or it can be collected through natural outlets, such as springs (Percival et al. 2000). Soil layers provide a barrier to microbial contamination by filtering rain and surface water (Tebbutt 1998) and by enhancing pathogen die-off as water filters through to underlying aquifers. Despite the protection of groundwater because of its relative isolation, it is still possible for microbial and chemical contaminants to reach these sources. Contaminants enter groundwater through direct injection into wells, the leaching of soluble solids or liquids sprayed on the surface (e.g. slurry), leaking or broken sewer lines, seepage from waste reservoirs and landfills, septic tank effluents and infiltration of polluted surface water. Contamination of groundwater can also occur through indirect processes, such as the case of dryland salinity in Western Australia. Removal of deep rooted perennial vegetation has resulted in the rise of the water table which dissolves salts in the soil profile bringing them to the surface resulting in increased salinity of the water. This increase in salinity has been shown to have human health consequences such as increased rates of depression and co-morbid conditions (Speldewinde et al. 2009, 2011), and increased levels of Ross River Virus in the environment (Jardine et al. 2008).

In broad terms, contaminants may be classified according to whether they originate from *point* or *non-point* sources. Point sources are discrete locations—such as effluent outfalls—that release pollutants, whereas non-point sources are more diffuse (such as agricultural runoff) (Hodgson 2004). Agricultural practices are a major source of water contamination, including major human pathogens such as *Cryptosporidium*, *Giardia*, and Campylobacter. Wastes may be carried as direct runoff into surface waters or may collect in impoundments and thereby infiltrate groundwater. A range of manufacturing and industrial wastes and by-products, as well as commercial products, may be discharged into water systems. Well-documented examples include plasticisers and heat stabilisers, biocides, epoxy resins, bleaching chemicals and by-products, solvents, degreasers, dyes, chelating agents, polymers, polyaromatic hydrocarbons, polychlorinated biphenyls and phthalates.

Urban runoff contains a complex mixture of microbiological and chemical contaminants (Gray and Becker 2002). For example, large quantities of hydrocarbons are emitted into the atmosphere and can be washed into water systems. Stormwater (primarily rain from roofs, roads and other surfaces that passes into the drainage system) often contains various debris, animal faeces, oils/grease, soil, metals from road surfaces, pesticides and fertilisers from roadsides.

The Burden of Water-Borne Disease The major microbiological risks arising from human contact with water sources are infection from viruses, bacteria, protozoa and helminths. Human microbial pathogens found in water are often enteric in origin. Important water-borne agents in industrialised countries include the bacteria *Campylobacter*, *Salmonella*, *Shigella* and *E.coli,* the parasites (protozoa) *Crypto-*

sporidium and *Giardia* and the viral agents Hepatitis A, Norwalk virus and rotaviruses. Enteric pathogens enter the environment in the faeces of infected hosts and can enter water either directly through defecation into water, contamination with sewage effluent, or from run-off from soil and other land surfaces. For example, in 1998 *Cryptosporidium* and *Giardia* cysts were found in the water supply of Sydney, Australia. The occurrence of the pathogens in the water supply was attributed to the presence of cattle within the catchment combined with unseasonal high stream flow (Hawkins et al. 2000).

The dynamics of water-borne disease transmission are highly complex and dependent upon multiple variables. One crucial factor is that of pathogen persistence in water. The pathogen must be able to resist environmental stresses and maintain viability while water-borne; otherwise the ability to infect new hosts becomes greatly diminished (WHO 2004b). Persistence in water also relates to temperature, ultraviolet radiation, nutrient availability, chlorine concentration (WHO 2004b), sedimentation, predation, dilution, pH, and the magnitude of pollution loading from discharges and their degree of treatment (McFeters 1990; Olson and Hurst 1990). Human intervention in ecosystems can impact on these stresses, for example clearing of riparian vegetation removes shade and therefore increases water temperature, while increasing the amount of ultraviolet radiation and amount of nutrients entering the water body through surface water runoff. Because of the complicated interactions between the pathogen, environment and the human host, water-borne pathogen ecology remains poorly understood for many microorganisms.

The greatest threats to human health are posed by pathogens with high infectivity, those which can survive or proliferate in water, or those which are resistant to decay or degradation. A number of pathogens remain highly stable through the formation of cysts or spores. For example, *Cryptosporidium parvum* typically has considerable potential to cause gastroenteritis (Havelaar and Melse 2003), given that it is reasonably infective and resistant to chlorination (National Water Quality Management Strategy 2006). *Cryptosporidium* oocysts are widely distributed in source waters across the globe, with oocyst concentration typically high in areas of poor water quality (e.g. areas located near agricultural activity) (Hansen and Ongerth 1991; Lechevallier et al. 1991).

Through the introduction of water sanitation procedures, waterborne diseases in industrialised countries have continually declined since the mid-nineteenth century (Herwaldt et al. 1991; Fewtrell and Bartram 2001). However, more recently, several industrialised countries have noted increases in the number of waterborne disease outbreaks (Lee et al. 2002a). Numerous reasons for these increases have been identified, including water system failures (Moore et al. 1993; Kramer et al. 1996; Levy et al. 1998; Barwick et al. 2000; Lee et al. 2002b), decaying water treatment and supply infrastructure, and the emergence (or improved detection) of new, previously unrecognised, resistant or more virulent organisms (Fewtrell and Bartram 2001).

There has been a growing international focus on the development of guidelines or regulations for chemical parameters in water systems. Many chemicals are in low concentrations, but pose a potential risk from chronic exposures or bioaccumulation. For example, pesticides commonly enter water systems from agricultural activities, via influxes of stormwater, or direct disposal by households or commercial premises. During the last few decades, there has been growing evidence of hormonally-related abnormalities in a wide range of species (Matthiessen 2003). These have included invertebrates (Oehlmann and Schulte-Oehlmann 2003), fish (Jobling and Tyler 2003), aquatic mammals (Fossi and Marsili 2003), reptiles (Guillette et al. 2007; Guillette and Iguchi 2003) and birds (Giesy et al. 2003). Chemical contaminants are believed to be responsible for many of these abnormalities, acting via mechanisms leading to alteration in endocrine function. This phenomenon, known generally as 'endocrine disruption', has been identified by the World Health Organisation as an issue of global concern (World Health Organization 2005). The chemicals implicated have been collectively termed 'endocrine disrupting chemicals' (EDCs), or simply 'endocrine disruptors'. Pharmaceutically-active compounds (PhACs) are another group of compounds that have led to concerns about adverse health outcomes (National Water Quality Management Strategy 2008; Toze 2006; Kolpin et al. 2002). As well as directly impacting on human health through direct ingestion these chemicals can have indirect impacts on human health through ecosystem services, such as decreases in fish catches.

Principles of Health Risk Assessment

Risk is defined by The National Water Quality Management Strategy (National Water Quality Management Strategy 2006) as "The likelihood of a hazard causing harm in exposed populations in a specified time frame, including the magnitude of that harm." In general, any assessment of risk to community health seeks to estimate the potential impact of an activity or process on a specified human population within a specified time period (in the past, now and/or in the future). There is usually an emphasis on evaluating factors in the environment that impact on disease in order to make prevention of disease possible.

In general terms, health risk assessments may be conceptualised as an investigation of (i) *exposure pathways:* whether there are multiple and/or interacting hazards (e.g. from various sources); the routes of exposure; and projected contaminant intakes in at-risk populations; coupled with (ii) *evidence on the progression to health end-points:* for example, toxicological analyses (such as animal/*in vitro* studies) and/or epidemiology analyses (studies in human populations) may be used to assess whether the hazards are likely to produce any adverse health effects, to explore the relationship between toxicant 'dose' and occurrence of a particular disease, and to calculate rates of disease in the given population.

The formal methods for assessing risks arising from water contaminants include:

- Epidemiological investigations (refer to 3.4 below)
- Qualitative risk assessment (with risk ranking): Qualitative assessments usually combine an indication of the likelihood of identified hazards causing harm (in exposed populations or receiving environments in a specified timeframe) with the severity of the consequences characterised using a categorical scale (e.g. low; moderate; high; very high).

- Quantitative Microbial Risk Assessment (QMRA) (National Research Council (U.S.). Committee to Evaluate the Viability of Augmenting Potable Water Supplies with Reclaimed Water 1998; EnHealth Council 2002): QMRA is a mathematical risk assessment model that can accurately predict the risk associated with exposure to pathogens (mainly bacteria, viruses and protozoa) in water sources (Haas et al. 1999; Havelaar and Melse 2003). A full assessment progresses through a number of stages: Hazard assessment; Exposure assessment; Dose-response analysis; Risk characterisation.
- Risk assessment for chemical contaminants progresses through similar stages to those for microorganisms (European Commission Brussels 2003). Hazard assessment investigates the inherent properties of chemicals by collecting and comparing relevant data on, for example, physical state, volatility and mobility as well as potential for degradation, bioaccumulation and toxicity. Models are used to assess the distribution of contaminants in the environment (soil, water, air) and in tissue (animals, humans). Estimations of human health risks from exposure to specific chemicals are generally based on extrapolations of the results of toxicological experiments on animals. These extrapolations provide standard human 'dose-response' relationships for the chemicals. The validity of the data and the weight-of-evidence of various toxicity data are assessed. For example, the International Agency for Research on Cancer (IARC) grades hazards according to various likelihoods of whether they are carcinogenic.

In the field of water and heath, the risk assessment models described above have been extended using the Stockholm Framework (World Health Organization 2006c), which incorporates the concept of *disability adjusted life years (DALYs)* to assess health outcomes from different disease exposure routes (Fig. 5). The DALY is a metric that considers health burden in terms of years of life lost (due to premature death) and years "lost" to disability, with different "weights" assigned to medical conditions depending on their severity. When deriving DALYs for individual hazards, both acute public health effects (such as diarrhoeal disease and even death) and chronic public health effects (such as cancer) are considered (National water quality management strategy 2006). DALYs have been used extensively by agencies such as the World Health Organization (WHO) to assess disease burdens and to identify intervention priorities associated with a broad range of environmental hazards (WHO 2004b).

The information gathered from risk assessment help to inform the next stage: *risk management,* or the process of evaluating possible action and alternatives and then implementing these in response to the risk assessment. This requires careful consideration of the options and strategies to reduce risk taking into account all factors including practicality, social and political implications. A common intervention is exposure control, in which the hazard of concern is controlled at source or at some point in the exposure pathway.

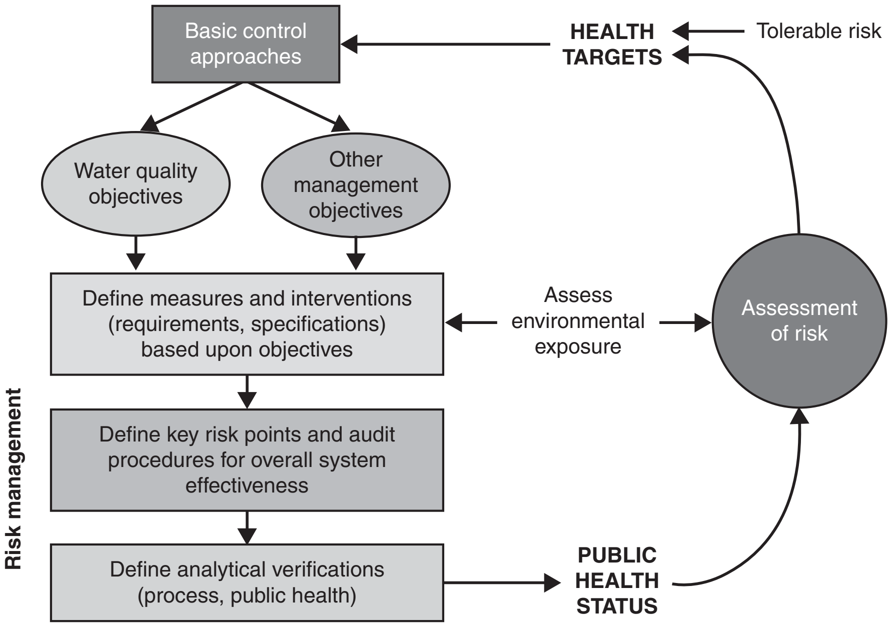

Fig. 5 Outline of Stockholm Framework for risk assessment. (World Health Organization 2006b)

Principles of Epidemiology in Relation to Water-Borne Exposures

Common Measures Used in Epidemiology Epidemiology is the study of disease patterns in populations. In a public health context, there is often an emphasis on discovering the causes, determinants or risk factors of a disease in order to make prevention possible (Gordis 2009; Rothman et al. 2008; Szklo and Nieto 2007). There are many epidemiological study designs and techniques, but the key questions usually relate to: *how and when do we measure the exposure and health effect*, and *which populations should we select and compare?* Analyses are conducted (in an attempt) to indicate the degree of risk that an individual (or population) with a particular exposure pattern, lifestyle, genetic profile or other determinant has of contracting a specific disease.

Epidemiologists often report their findings as the *magnitude of association* between exposure and disease: these estimates may be based on *absolute differences* (obtained by subtracting disease rates in the unexposed from rates in the exposed) or *relative differences or ratios* (obtained by dividing disease rates in the exposed by rates in the unexposed) (Hennekens et al. 1987). A common measure of risk is the relative risk, which indicates how many times more likely "exposed" persons (such as residents of a wetland with high levels of nutrient contamination which cause in-

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