BACKGROUND DOCUMENT

WORLD WATER FORUM TARGET 1.3.5
BUILDING THE EVIDENCE BASE AT THE WATER-HEALTH NEXUS

United Nations University Institute for Water, Environment and Health; HydroSciences Montpellier, Université de Montpellier; Kenya Medical Research Institute; National Institute of Health (Istituto Superiore di Sanità); World Health Organization
“By 2015 in parts of the world selected for high water-associated disease burdens set 10 solid research programmes on multi-exposure to water contaminants and aquatic environments (communicable, non-communicable diseases, malnutrition, injuries and accidents, psychosocial disorders).”

Target Co-ordinator:
Corinne Schuster-Wallace
Programme Officer, Water-Health Nexus
United Nations University Institute for Water, Environment and Health (UNU-INWEH)

Coordinating Group:
Claude Casellas, Hydrosciences Montpellier
Madeleine Fogde, Stockholm Environment Institute
Diana Karanja, Kenya Medical Research Institute
Corinne Schuster-Wallace, UNU-INWEH

Writing team:
Claude Casellas, HydroSciences Montpellier, Université de Montpellier
Sarah Dickin, UNU-INWEH/McMaster University
Enzo Funari, National Institute of Health (Istituto Superiore di Sanità)
Diana Karanja, Kenya Medical Research Institute
Katherine Pizzacalla, UNU-INWEH
Annette Prüss-Üstün, World Health Organization
Corinne Schuster-Wallace, UNU-INWEH

For further information contact:
Dr. Corinne Schuster-Wallace
UNU-INWEH
175 Longwood Road South
Suite 204, Hamilton Ontario
L8P 0A1 CANADA
Corinne.schusterwallace@unu.edu
+1 905 667 5511
Introduction

While significant research activities are being undertaken on key diseases, such as malaria and cholera, many water-related infectious diseases are not afforded this intensive study. Examples include some of the so-called neglected tropical diseases, such as schistosomiasis and chagas disease. Other threats include emerging zoonotic diseases such as VTEC *E. coli* strains and risks linked to watershed degradation such as toxic cyanobacteria. Non-infectious diseases associated with contamination from chemicals, such as pharmaceuticals and personal care products or nano-particles, require new knowledge regarding the transport and interactions of these compounds in the environment. These potential toxins are associated with a range of unknowns, including how to identify and remove them from drinking water and the health impacts of synergistic and derivative contaminants. Global environmental changes may affect exposure to contaminants and alter the conditions of transport, behavior and distribution through their bioavailability. Further, relationships between contaminants and environmental conditions such as temperature, precipitation and salinity should be considered in the context of climate change. Interactions between environmental processes and contaminants can increase the bioavailability, pathogenicity and general vulnerability of species (e.g. microorganisms) and alter their ability to adapt.

There is a real need for knowledge concerning the identification of critical thresholds and linkages, which is required to develop vulnerability assessments of communities and ecosystems. These questions need to be considered from the perspective of an integrated approach to risk assessment and health. Targeted research is essential to develop the evidence-base and tools for decision-making. In order to maximize the benefits, this research needs to bridge the gap between scientists and policy-makers, through stakeholder engagement and ongoing dialogue. This will ensure that the research process answers the questions that are most pressing and delivers the findings in the most appropriate way. Furthermore, it ensures identification of appropriate solutions that lead to willing uptake in practice rather than just publication within the scientific realm.

Context

Researchers working to combat transmission of water-related disease must approach the problem from diverse perspectives, including disease surveillance, water and sanitation service provision, drinking-water quality monitoring, water resource management, ecosystem services, and climate change risk assessment. Research must provide solutions, not only for biophysical challenges, such as environmental water scarcity, but must also address the social, demographic and political conditions which will aggravate conditions conducive to water-related disease transmission such as drought or flooding.

In developed countries where many infectious diseases such as cholera have been eradicated due to better sanitation conditions, waterborne disease outbreaks are still a public health threat. A relatively new concern is the input of pharmaceutical and personal care products into watersheds, such as birth control pills, estrogen replacement therapies, or chemotherapy agents. Some of these pharmaceutical products have been linked to detrimental effects on aquatic life, such as hormone disruption and growth
defects\textsuperscript{1}. However, for many of these potential contaminants there is little known about how they are transported or their life-span once released into waterways. In addition, the synergistic effects, accumulation, and possible long-term health impacts of these products on human populations requires attention.

Agriculture is another major source of chemical contamination to water supplies. Chemicals such as phosphates and nitrates resulting from over-fertilization, as well as pesticides, have significant impacts on water quality. The Great Lakes region in North America has faced many of these challenges due to heavy agriculture, as well industry and urban uses of the ecosystem\textsuperscript{2}. In addition, extensive growth of cyanobacteria can result in eutrophication from nutrient rich agricultural runoff\textsuperscript{3}. Some types of cyanobacteria which flourish in these conditions produce toxins that present a risk to human health. Industry, such as petroleum refineries and chemical factories, produce organic and inorganic chemicals, such as heavy metals, which contribute a further source of chemical contamination to water supplies. Some pollutants, such as persistent organic pollutants (POPs) are resistant to breakdown in the environment. Heavy metals may enter the environment, either from direct output or indirectly through industrial processes. For example, timber harvesting in the Amazon has resulted in erosion of mercury rich soil. The bioaccumulation that occurs in fish created a health risk for local populations depending on fish as a source of food\textsuperscript{4}.

Chemical contamination is a growing concern in developing regions, where water practitioners are still faced with many infectious disease challenges. In these areas regulation, monitoring or enforcement of standards is needed to protect food and water supplies from exceeding maximum safe levels of chemical contaminants. Wastewater reuse for purposes such as small-scale agriculture is an important mechanism for food and water security, but managed improperly can be especially risky, introducing chemical as well as biological risks. Workers as well as consumers of produce are exposed to helminth eggs and other pathogenic microorganisms from untreated waste. In many developing countries, these contaminants present a multi-exposure situation that requires innovative approaches to reduce risk to both acute and chronic health outcomes.

In developed regions, emerging waterborne infections such as Cryptosporidium and E. coli O157:H7 are now impacting the safety of water supplies. In many municipalities, public private partnerships (PPPs) are implemented to meet the large investment capital required to supply the population’s water needs. While this is often seen as an effective and efficient way to fund water provision, challenges exist in establishing regulations for water quality monitoring and removal technologies. This has resulted in a


number of water-related disease outbreaks in countries such as Canada and the United States (eg. the Walkerton tragedy of 2000). Water resource managers must have access to tools, policies and information to ensure transparency in water treatment and distribution practices and thus safe water for users.

At a global level, water-related disease transmission is occurring in the context of large-scale environmental changes, particularly climate change. The widespread impact of these changes will exacerbate the demand for scarce water resources and threaten human health and wellbeing. Climate change is impacting every part of the water cycle, with consequences for the Earth’s ecosystems and human communities. While uncertainty surrounds our understanding of how complex climate change processes will manifest within the water cycle, many trends have been identified. Importantly, existing water stressed areas will become more stressed. Further, changing patterns of precipitation, temperature, and extreme events will affect the natural environment, including river and groundwater flows. This will impact the quantity of these resources, and in some contexts lead to degradation of water quality. According to the IPCC, the negative effects of climate change on freshwater systems are greater than any benefits. This has critical consequences at a global level, as humans depend on freshwater sources for survival and economic activities.

Moreover, geographical range and endemic locations of different water-related illnesses will be affected within a changing climate. Understanding these changes is especially critical for vector-borne diseases like dengue and malaria, where mosquito populations are likely to expand to regions where warmer temperature conditions are developing. Water-related diseases are shifting ranges with increasing temperatures in the oceans and freshwater bodies. For example, the expected range of Vibrio parahaemolyticus shifted significantly, causing an unprecedented outbreak in Alaska due to seafood-associated gastroenteritis. Poorly understood processes, such as consequences of sea temperature rise on antimicrobial resistance, multiple exposures and the impact of environmental processes on virulence and toxicity of pathogens are key gaps in the literature.

The processes by which biological and chemical contaminants occur and are transmitted in the environment are distributed in complex systems and they cannot be studied in isolation. For example, challenges such as food security, land use shift and desertification link back to safe water and sanitation. As decreased productivity increases, fertilizer use increases water contamination risks. With changes in water availability, the agricultural sector increases fertilizer use and use of wastewater for irrigation, both of which can increase the water contamination risks mentioned above.

In order for policy-makers to be equipped with the tools necessary to combat this growing list of water-related health concerns, access to current research is essential to ensure evidence-based decision-making. Along similar lines, a 2012 WHO World Health Report⁵ will focus on the theme “No Health without Research” and will aim to encourage countries to increase investments in strengthening their national health research systems.

Article 9 of the UNECE Protocol on Water and Health has identified this need and agrees to encourage “Research into, and development of, cost-effective means and techniques for the prevention, control and reduction of water-related disease” and “development of integrated information systems to handle information about long-term trends, current concerns and past problems and successful solutions to them in the field of water and health, and provision of such information to competent authorities”¹⁰. The third World Water Development Report has also noted the importance of improving access to research and information, noting that “reliable and accurate water resources information and data, by reducing uncertainty about water resources, help decision makers make more reliable and politically persuasive assessments of water risks. More detailed and accurate information also guides better choices on needed infrastructure and makes public institutions more accountable for the impacts of their actions”¹¹.

Beyond policy-makers, knowledge needs to be disseminated to ensure that stakeholders at all levels have the capacity to participate in solving water-health issues. A recent ODI report has emphasized the role of knowledge providers in supporting “people to acquire the required skills and tools to analyze and use the information provided and, furthermore, to give them the ability to access independently further information from a variety of sources”¹². Moreover, the WHO publication Decision-Making in Environmental Health notes that often knowledge is not effectively translated into action, particularly in developing countries, and in many cases environmental hazards exceed national or international guidelines, yet action taken to resolve these issues is limited¹³. To address this gap, research needs to be communicated more effectively to the decision-makers who have the power to use it to shape policy.

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Water Management and Health

It is critical to manage water in the environment in order to reduce the burden of disease. While water quality is paramount for ensuring human health, anthropogenic changes to watersheds not only degrade quality but create environments for vectors and reduce ecosystem services that buffer against these changes. As we move into a less certain future, it is essential to understand the complex relationships impacting chemical and biological water contamination, as well as vectorborne diseases, to ensure that decisions are not only based in evidence, but that interventions are appropriate and synergistic to ensure maximum health protection from all water-related diseases.

Contamination pathways

Contamination of drinking water can occur at one or more stages of sourcing and distribution, from source water contamination to post-collection and point of use contamination. Contamination can also be anthropogenic or come from natural sources, with some sources being more significant than others. Contamination pathways also differ between surface water and ground water sources, and can arise from industrial or sewage treatment works discharges and run off from agricultural land or roads.

Humans can also be exposed to chemicals contaminants through direct contact with skin, inhalation, and ingestion of contaminated freshwater fish or seafood. The consumption of crops that have been treated with pesticides or improperly treated wastewater, as well as livestock that have accumulated contaminants through the food chain are also exposure pathways. Some chemical contaminants have been shown to cause adverse health effects in humans as a consequence of long-term exposure through drinking-water (e.g., arsenic, fluoride, disinfection byproducts). Only in a few cases have chemicals been associated with acute effects (e.g., nitrate in drinking waters; methyl mercury in seafood). However, mercury and persistent organic pollutants have reached levels of concern in seafood in some geographic areas. The importance of each exposure pathway depends on the pathogen or chemical type, as well as possible interactions.

In some developing countries chemical substances used in hospitals for healthcare and medical research are discharged in the same way as urban effluents into the communal drainage network without prior treatment. Contamination also arises from badly sited latrines and septic tanks in relation to water wells.

Gaps exist in knowledge of multi-exposure pathways to both biological and chemical contaminants in waterways. This is particularly in relation to defining behavior of contaminants, adaptability to these contaminants as well as development of databases and tools to support analysis and risk assessment. Moreover, there is a scarcity of data and analyses investigating the socio-demographic determinants associated with disease patterns. This includes, for example, the unequal distribution of exposure to contaminants, which probably differ considerably between developed and developing nations.

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Knowledge of this can define the global magnitude of population groups that are most exposed or most vulnerable to environmental risks.

**Water Quality Standards**
The quality of drinking water and associated risks vary from country to country. Ideally, drinking water should contain no contaminants, but realistically it can be generally expected to contain at least a slight amount of certain contaminants, which do not cause harm to human health. Standards are therefore set to ensure that drinking water supplies do not cause harm to human health within the geographical context. Safety of drinking water is therefore judged on the basis of national standards or international guidelines, with the most important of these being WHO Guidelines for Drinking Water Quality. The US EPA is in charge of setting standards for micro-organisms, disinfectants, disinfectant by products, radionuclides, inorganic and organic chemicals, many of which do not necessarily create a health hazard. Water standards generally differ between community-managed supplies, public water supplies and individual managed supplies such as wells. Given the relationship between source water quality, water quality standards and water treatment costs, it is important to understand human risks for all sectors of the population, both in an individual and synergistic contaminant context.

**Chemical contaminants**
Chemicals are an essential part of our daily life: they have strong beneficial impacts on our wellbeing, health and economy. Nevertheless, their use has been frequently associated with environmental degradation and human diseases. Water bodies are the final recipient of high amounts of a number of chemicals derived from many anthropogenic activities. In both developed and developing countries chemical input from sources such as industry and agriculture threatens the safety of valuable watersheds. Depending on their use, disposal modalities and intrinsic physico-chemical properties, many substances can contaminate internal, transitional, coastal and marine waters. Moreover waters may contain inorganic (e.g., arsenic, fluoride) and organic (e.g., toxins from cyanobacteria) chemicals of natural origin at levels of human health concern. Chemical contamination of drinking water is an important growing concern in developing regions where adequate management measures should be promoted to reduce the burden of diseases associated with known contaminants. More developed countries have to face the problem of long-term exposure to contaminants from industrial, agricultural and other activities, which often occur simultaneously in waters. This issue is further complicated by the awareness of the importance of pollutants of emerging interest (e.g., pharmaceuticals, pesticides used in non-agricultural areas, chemicals that interact with the endocrine system, personal care products, surfactants, nanomaterials). Some of these products have been linked to detrimental effects on aquatic life, such as hormone disruption and growth defects, thus altering the environmental quality and the ecosystem as a whole.

For many water contaminants there is limited information on how they are transported and their persistence once released into waterways. In addition, little information is available on the long-term health impacts of these products, often found as a variable mixture, on human populations. Further uncertainties pertain to the possible influence of climate changes. Regions where higher frequencies of
intense rainfalls are predicted will experience a growing impact of polluted urban storm flows and flushing of agricultural pollutants into watersheds. In regions with hotter, drier weather, river flows will diminish thus reducing their contaminant dilution capability. Differential susceptibility of human populations is another issue of concern and uncertainty.

In this situation it is particularly important to identify practical remedial and preventive measures as well as fill the key gaps with ongoing research initiatives. The availability of scientific data on contaminant impacts and especially the knowledge of contaminant behavior represent two of these key gaps. Other gaps are represented by the inadequacy of tools to predict risk and the definition of sound policy for evaluation, and implementation, of risk reduction. Moreover, there is a need for adequate controls at the sources of chemical contamination in order to reduce the burden of water contamination. Other measures are included in the WHO Water Safety Plans approach, giving special emphasis to the need for technological upgrading. Another area that needs to be revisited involves issues associated with monitoring activities. It is not practical, economically affordable or even efficient to analyze hundreds of chemicals in a water body; new approaches to identifying presence/absence or levels of contamination should be encouraged\textsuperscript{15}.

Risk assessment procedures should be updated taking into consideration that human exposure to a chemical is not limited to water but other sources (eg. food, air). Exposure generally occurs not to a single contaminant in water but to various combinations of contaminant mixtures. This requires new research programs that go beyond investigating simple processes involving single contaminants to approaches that consider the integrated nature of contaminant occurrence, transport and human exposure\textsuperscript{16}.

\textit{Biological contaminants}
Microbiological contamination of drinking water is still a prime concern for millions of people throughout the world, in both developed and developing nations. WHO estimates that 120 million people lack access to safe drinking-water in the European Region, with the situation of access to sanitation not being any better, resulting in waterborne diseases like diarrhoeal diseases, typhoid fever and hepatitis A. Although many waterborne pathogens are virtually unknown in developed nations, they still cause a significant number of deaths globally, particularly in children, and negatively impact economic development due to productive time lost to illness in many subsistence economies. Indeed, many countries experience depressed GDP as a result of health impacts associated with lack of access to safe drinking water and adequate sanitation.

The agents of waterborne diseases include bacteria such as \textit{E. coli}, viruses such as hepatitis viruses, adenoviruses and enteroviruses, and protozoa such as \textit{giardia} and \textit{cryptosporidium}. Contamination of

water by pathogens causing diarrhoeal disease by faecal matter is the most important for drinking water quality in many developing regions. There is a significant difference between the types of biological contaminants that are common between developed and developing countries, with different potential pathogens emerging in both regions.

Vectorborne Diseases
Vectorborne diseases, such as malaria, dengue and schistosomiasis contribute significantly to annual global morbidity and mortality rates. While not directly linked to water quality, control of these diseases falls in large part to control of the vector habitat which in this case is tied to water. These habitats are already changing, with malaria cases presenting in previously malaria-free regions (e.g. Nairobi, Kenya). Other vectorborne diseases are exacerbated by changes in water quantity, such as trachoma, which increases with decreased hygiene, and lymphatic filariasis, which increases with increased rice production, a mechanism for increasing food security in many regions. From a research perspective, important synergies may exist between these diseases and other water-related illnesses. Given that many of these diseases are considered neglected and in general their ranges are expanding, it is critical to understand any synergies, both in terms of illness and co-existence in the environment (e.g. cholera and cyanobacteria in algae).

Multi-exposure: Implications for Health
Due to complex interactions between chemicals and the environment, efforts to assess human and ecosystem exposure to contaminants must examine multiple contaminants from multiple sources and through multiple exposure pathways. For example, exposure may be from several sources through one route, or multiple routes for a single contaminant. Interactions of contaminants occur in the environment as well as in the body, so pathways must be examined at these different levels. Chemical contaminants can be changed into metabolites in the body or degradation products in the environment and these may have different impacts than the original contaminant. In addition to multi-exposure from chemical contaminants, in many developing regions these are compounded by exposure to biological contamination and/or facilitation of infection through exposure to other pathogens.

Exposure to multiple chemical or biological contaminants contributes to increased vulnerability of human populations and ecosystems. The simultaneous or sequential exposure to environmental stress should be considered in a process of cumulative risk assessment. Three fundamental and interrelated questions must be addressed in the process of cumulative risk assessment:

a) What are the most important complex contaminant matrices to consider in relation to the target human population or ecosystem to protect?

b) What is the nature (duration, frequency) and magnitude (concentration or exposure dose) of cumulative exposure?

c) What are the mechanisms of action (e.g. toxicokinetic or toxicodynamic) and the effects on exposed populations (e.g. additive models, synergistic or antagonistic)?

Environmental changes such as climate change are likely to change the inputs of chemicals and biological contaminants into watersheds, and these changes may also affect the chemical form of
certain contaminants. Climate patterns such as rainfall and temperature trends have a direct impact on contaminant loads; however there are also indirect impacts of global environmental changes which must be considered. For example, predicted changes in the prevalence and activity of agricultural pests and diseases may affect the effectiveness of pesticides. Increased use of pesticides and other biocides, or introduction of stronger chemicals may be implemented, with potential impacts on human health. The future interactions of these changing multi-exposure pathways must be considered to increase our understanding of chemical and biological contaminant risks.

Due to the complex nature of contaminant multi-exposure, there are many scientific questions that are poorly resolved. There is a need to develop tools and methods to better assess the interactions and health impacts of these processes. There is also a gap in our understanding of contaminant thresholds and barriers in the context of multiple exposures. There is a real need for knowledge concerning the identification of critical thresholds to consider in assessing the vulnerability of populations and ecosystems. Increased understanding of the mechanisms of action, such as activation of receptors, and compounds that act as agonists or activators is needed. Furthermore, better understanding of the impacts of synergies of multiple contaminants on physiology, such as damage to organ systems is critical. These questions need to be considered from the perspective of an integrated approach to risk assessment and health.

Several overarching gaps in the literature have been identified as themes for further research:
1) multi-exposure assessment approaches;
2) environmental fate and behavior through interactions with environmental conditions; and,
3) synergies or antagonisms of mechanisms of action or effects assessment.

Water-Related Disease in the context of Global Environmental Change

Global environmental change includes large-scale processes such as climate change, shifting land use patterns including agricultural intensification, ecosystem degradation and desertification, and biodiversity loss. These global environmental changes will have a variety of impacts on water security, such as increased demand and competition for existing water resources, degradation of water quality from increased population density and economic activity and decreased natural recharge of groundwater aquifers.

Climate change especially is expected to negatively impact health through its effect on water supplies. Changes in precipitation or frequency of floods and droughts may impact the capacity of certain water supplies to provide access to safe water. Mounting evidence demonstrates that large scale precipitation events are major triggers in outbreaks of waterborne diseases and result in public health needs that often exceed or overwhelm local response capacity. In developed countries, a number of reported

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waterborne disease outbreaks of pathogens such as *Giardia*, *Cryptosporidium*, and *E. coli* have been linked to precipitation events. Climate change is expected to affect the frequency and intensity of these types of extreme weather events, increasing the incidence of waterborne disease.

Changes in climate, land use and ecosystem processes are also expected to affect water-related disease transmission cycles. For instance, changes resulting in altered population levels of hosts, vectors or environmental stages of a pathogen can affect the transmission rate at which pathogens circulate between hosts, vectors and environment. Growing population density and urbanization will place increased pressures on aging and deteriorating water treatment infrastructure, which increases vulnerability to waterborne disease outbreaks.

This contributes to potentially increasing stresses on water resources that are already changing in new and unpredictable ways, and to increasing human exposure to current and emerging water-related diseases. Although countries with highly developed water treatment and sanitation infrastructure may be less vulnerable to the above risks, the uncertainty associated with global environmental change adds an element of complexity to the issue. Developing countries will be especially vulnerable to global environmental changes that impact water-related disease, and more research is required to better assess the risks and evaluate mitigation and adaption strategies.

**The Role of WASH at the Water-Health Nexus**

Lack of access to safe water and adequate sanitation as well as poor hygiene are some of the most important threats to human well-being. Water, sanitation and hygiene are estimated to cause approximately 3.4 million deaths per year, representing 5.8% of all deaths worldwide (based on 2004 data). A large proportion of these deaths could be prevented by improvements in the management of water and excreta, as 2.6 billion people worldwide lack access to safe sanitation and nearly 1 billion people do not have access to safe drinking water.

Of the 2.5 million deaths caused by diarrhoea each year, 1.9 million of those could be prevented. Moreover, these repeated cases of diarrhoea caused by poor water, sanitation and hygiene accounts for 50% of childhood malnutrition. These poor health conditions have significant consequences for economic productivity and school absenteeism.

This absence leaves many people, especially children, particularly vulnerable to disease. Most notably, children are at risk of mortality from diarrhoea, as well as cholera, dysentery, worms, trachoma, pneumonia and malnutrition. Some of the water-associated disease burden is associated with water

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21 Ibid.
resource management, and is mainly composed of malaria, dengue, Japanese encephalitis and other vector-borne diseases. This burden estimate does not yet include health impacts from chemicals, which are more difficult to quantify.

Unsafe or inadequate access to water also causes indirect health impacts. Time lost by illness, or by collecting water for the household could instead have been dedicated to education, income generation or child care, which are in return associated with better health.

Access to water and sanitation along with improved hygiene practices has been statistically proven to reduce mortality rates. Improved sanitation and hand-washing have been reported to reduce diarrhoea by 30-40% each\(^\text{22}\). Water treatment at household level has been reported to reduce diarrhoea by 19% after one year of introduction of the treatment, and 44% in the shorter term\(^\text{23}\). The benefits of improvements at the water source have been less well documented, with a mean reduction of 18% in diarrhoea. The impacts of water on health are closely related to the access to improved sanitary facilities, wastewater treatment and associated hygiene practices. Poor sanitation threatens to contaminate water supplies, and may reduce the benefits of hygiene associated with water availability due to frequent recontamination with faecal-oral pathogens.

Under-five mortality has been shown to decrease by 1.17 and 1.66 per 1000 deaths for every quartile increase in water access and sanitation access respectively. Similar findings have also been made with increased access to water and sanitation and infant and maternal mortality rates\(^\text{24}\). Unsafe water leading to repeated diarrhoea episodes also increases the risk of underweight birth in children, a major cause of infant mortality in low-income countries. However, the relationship between the quantity of water available, distance to water source, resulting hygiene practices and health impacts would benefit from a stronger evidence base. In addition, the links have not yet been well quantified in many cases. Improved knowledge about all these specific linkages would allow decision-makers to design more effective programs.

Water, sanitation and hygiene not only reduce mortality, but they improve well-being. Women’s well-being is particularly compromised when water and sanitation facilities are not easily accessible. In many developing countries where clean drinking water sources are not widely available, women spend hours every day carrying water for household use, putting a large physical strain on their bodies. Without safe sanitation facilities available, over 1 billion people practice open defecation. For women, this practice leaves them vulnerable to physical and sexual assault, particularly for those who wait until nightfall to relieve themselves.


\(^{23}\) Ibid.

Knowledge gaps are even wider when it comes to the interaction between the management of water resources and vector-borne disease such as malaria or dengue. Although studies have shown that for example close fitting water storage lids and regular cleaning of water storage containers significantly reduces the vector of Dengue, the *Aedes aegypti* mosquito, the full potential of prevention of diseases through the sound management of water resources (in addition to treatment of disease alone) has not yet been deployed.

Knowledge gaps affecting more wide-spread efforts to reduce health impacts also concern advocacy and information about the risks to health of unsafe water, effective solutions and their implementation. Furthermore much remains to be understood regarding health behaviour change and sustaining water, sanitation and hygiene interventions that often require considerable effort from individuals and households.

While the overall benefits of safe water supplies and sound management of water resources are well recognized, specific aspects would benefit from a stronger evidence base, and better information/advocacy. This would enable more cost-effective and targeted designs of water programmes, and possibly higher prioritization.

**The Road to Marseille**

**Key messages**

- Research is important to build an evidence base for informed decision making and interventions
- We live in a complex world and systems-based transdisciplinary research is the way forward to address the challenges of waterborne contaminant health risks.

**Key Gaps**

- Multi-exposure pathways, interactions, and behaviours in the environment and implications for human health in developing and developed countries
- Impacts of global environmental change, especially on bioavailability, survival, infectivity and pathogenicity of contaminants
- Monitoring and surveillance tools for better evaluation and implementation (e.g. multi-disciplinary datasets; monitoring networks; surrogate measures)
- Improved dissemination of existing knowledge (e.g. through centralized knowledge portals)