2015 UN-Water Annual International Zaragoza Conference
15–17 January 2015
Water and Sustainable Development
From vision to action
UN WATER
WATER FOR LIFE 2005-2015

Risk Assessment as a Tool to Improve Water Quality and The Role of Institutions of Higher Education

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1. Water Quality Grand Challenges

It is often said "water is life" but it must also be said that *Water Quality is Health.* Of all the global struggles around the protection and restoration of water quality addressing waste, wastewater and sanitation to control waterborne pathogens, chemicals of emerging concerns and overloading of nutrients to water systems may be the most significant challenge and opportunity in the anthropocene.

The *Blue Planet* depends upon water, one of the most critical of all the world's life support systems. Water quantity and quality (access and management) are interlinked with our global biohealth servicing a sustainable plant, animal and human network. The understanding of water quality at larger scales, ground and surface water interactions impacted by land and climate is essential to our future investments for protection and restoration. In the last 60 years we have seen a great acceleration of population growth (in people and animals), landuse change, use of fertilizers, and water. This has led us into the anthropocene where continued water quality degradation as demonstrated by widespread recalcitrant chemical contamination, increased eutrophication, hazardous algal blooms and fecal contamination associated with microbial hazards and antibiotic resistance is a global phenomenon. This is exacerbated by climate change and extreme events. These directly affect health associated with disease, malnutrition and loss of economic development opportunities. There is a need to improve the investment in innovative treatment/infrastructure, resource recovery and better environmental protection policies which translates into improved water quality.

Drinking water and wastewater reuse goals and safety has advanced through the use of quantitative microbial risk assessment (QMRA) framework and the use of advanced diagnostic technology for monitoring pollution sources and specific hazards. With these data, management strategies with stakeholder involvement are more likely to move forward. However this framework and tools to implement risk assessment for wastewater and sanitation have not been addressed. It will be more important than ever to implement these key approaches in order to effectively and efficiently mitigate the impacts of an aging infrastructure (or lack thereof) and the global changes that are growing to improve the BioHealth of the planet in the future.

Along with the assessment and fixes there is a need to develop the human capacity to implement any stated water quality goals. Startling data presents the dramatic and grave situation in regard to human resources needed to fill technically trained personnel positions to meet the intentions for water and sanitation service delivery (from The 'Mind the Gap' study (2009), and the International Water Associations "Human resource capacity gaps in water and sanitation: Main findings and the way forward"). Academic institutions will need to provide these educational opportunities graduating hundreds to 100s of thousands of water scientists, engineers and technicians to remedy the severe state of affairs. These trained individuals will also have to be trained as trainers of others with varying educational backgrounds.

Thus our challenges to improve and provide water quality remain:

- ✓ How can we define the opportunities for improving global water quality and health as well as address fecal wastes, wastewater collection and treatment, reclamation to meet improved global surface water quality goals as well as the safety of drinking water through an integrated and adaptive risk analysis framework?
- ✓ How do we invest in water quality monitoring to achieve the best return on water improvements?
- ✓ How do we build the human resources needed to address these challenges?

2. Main Implementation Goals around the Risk Framework

We need to build water quality programs within Water Safety Plans and QMRA frameworks

Most of the water related programs have focused mainly on the quantitative aspect such as water supply and sanitation coverage, number of water facilities whereas water quality is often not addressed appropriately. Water quality that comprises drinking water (end of the tap quality), wastewater and sanitation treatment to reduce the sources of contaminants constitutes important features which are needed to address health, well-being and the environment. The challenge of water quality management is partly due to the lack of a comprehensive framework that allows the use of science to assist the policy of water quality management and translate the science into action. The inter-sectoral collaboration (public, private, users) in first assessing, protecting and restoring water quality is also a

challenging issue as in some countries the study and management of water systems are complex and not clear in terms of role and responsibilities.
We propose that by using risk frameworks for assessment and the water safety plans for implementation these will guide appropriate policies and investments to achieve change and improvement in water quality around the world. This will be tied to our ability to educate the next generation of water professionals, development of new advanced diagnostic tools, facilities and networks to collect the data with shared responsibilities at regional levels (Figure 1).

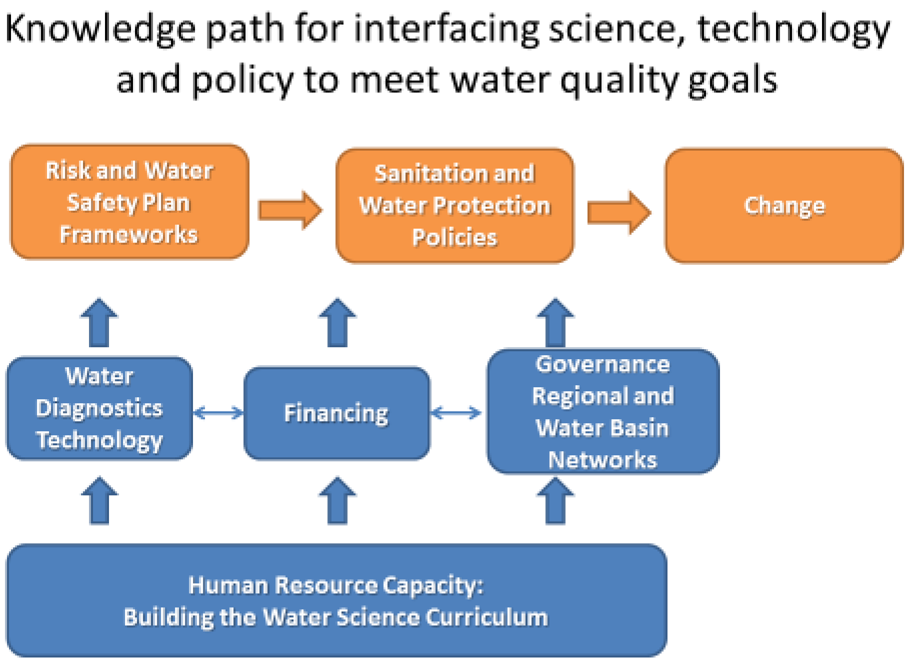

Figure 1

Water Safety Plans (WSP) and Quantitative Microbial Risk Assessment (QMRA) have been used as frameworks and working tools to assist in the decision making process for water quality management. QMRA is widely applied to assess health risk related to water consumption and exposure to drinking and recreational water pathways. The risk analysis (comprising risk assessment, management and communication) is a useful framework to systematically address water health risk. However application of WSP and QMRA remains difficult in developing countries due to the lack of capacity and their acceptance. This is particular difficult as health goals and targets associated with pathogen and contaminant reduction associated with sanitation and wastewater treatment has not been addressed.
The WSP and the risk analysis framework – in particular QMRA – can be used to integrate science and policy and promote the translation of science into action, applied in water quality domain. The risk framework involves defining the sanitation problem at the appropriate scale, identifying the hazards, understanding and testing for pathogens found in feces and sewage, surface or

groundwaters from local scales to the larger watersheds/basins for exposure assessment and linking these data to dose-response functions to provide probabilities of infection. This then guides risk management options (Figure 2).

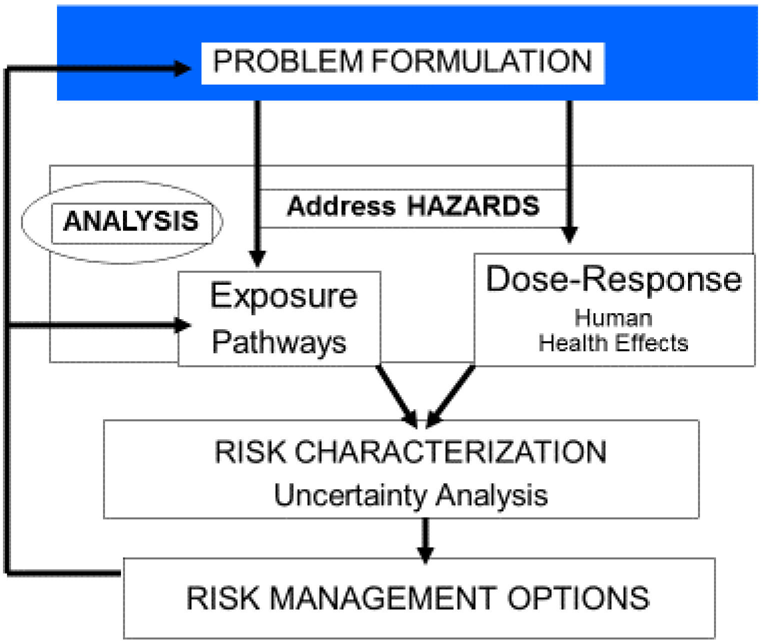

Figure 2

The capacity for undertaking WSP and QMRA can be built within academic institutions and once this has been done, the skills can be used for water quality management system to effectively apply QMRA framework to assess, predict and manage risk. A case study on water supply and sanitation system from Vietnam will be used as an example to discuss the above mentioned topics.

3. Water Quality Investigative Monitoring

We need to invest in water quality diagnostics and investigative monitoring to achieve the best return on water improvements

Post 2015 Millenium Development Goals (MDG) include water quality for the first time because it is quite possible to improve sources that deliver unsafe water. Capacity building requires investment in training and equipment. As a minimum there is a need for at least one central laboratory in a country that provides the basis for ensuring that the quality of microbial and chemical analysis is adequate. MDG included microbial indicators and also arsenic and fluoride. Now as we move to the SDG other analysis is appropriate. Chemical analysis requires more sophisticated equipment and techniques. This is important because a relatively modest investment used properly can save a considerable amount of additional and unanticipated cost at a later stage. This investment also helps to underpin drinking water quality standards which provide the underpinning for the WHO Water Safety Plan approach.

What is monitoring? Monitoring can take a number of forms and the first and probably the most useful for chemical contaminants and pathogens is investigative monitoring to understand what important contaminants that might be present in a water supply or proposed water supply prior to improvement. For microbiological contaminants investigative monitoring or sampling is a very useful first step in characterizing the quality of a source but continued monitoring is also important for assessing changes in that source over time and for determining whether contamination is occurring after collection of the water and the need for household treatment. Ultimately microbial source tracking markers could be used to begin to identify human sewage sources relative to animal sources. Eventually pathogens would be tested on specific diagnostic levels. The transport and fate are linked into knowledge of geology and from sanitary surveys.

Operational monitoring is a means of checking that the system is working properly and is usually not laboratory based and is carried out locally using test kits or systems for parameters such as chlorine and turbidity. Turbidity measurement in the field requires the development of a robust and easy to use system that is cheap and is capable of reliably measuring at least to 1 NTU. Investment in the development of such a tool would be a huge benefit for relatively little outlay. And for those systems that are chlorinated the measurement of residuals can be quite fast, cheap and useful.

Why should we worry about investing in monitoring? Unless we know what the quality of the water is to start with it is difficult to ensure that improvements will deliver the required quality as well as quantity and convenience. For surface sources it is reasonable to assume that there will be the potential for faecal contamination but determining whether improvements can deliver the required quality to get the greatest return from the investment requires some information. For groundwater sources knowing whether the source is susceptible to contamination is also important. For chemical contaminants only analysis and investigative monitoring can tell us what the case is. The arsenic problem in Bangladesh is an example of where a relatively small investment would have delivered significant savings on the further investment required to deliver safe water. This is also true with several areas where fluoride is naturally present and there are other contaminants that are now causing concern because they are present at unusual concentrations in groundwater, such as manganese and in some wells, nitrate.

For pathogens, the goal is to protect ambient waters and ecosystem services in addition to drinking water and tying this to diagnostic monitoring feeds into the QMRA framework (Figure 3). This ensures that public funds are spent wisely targeting the problems areas and improving health.

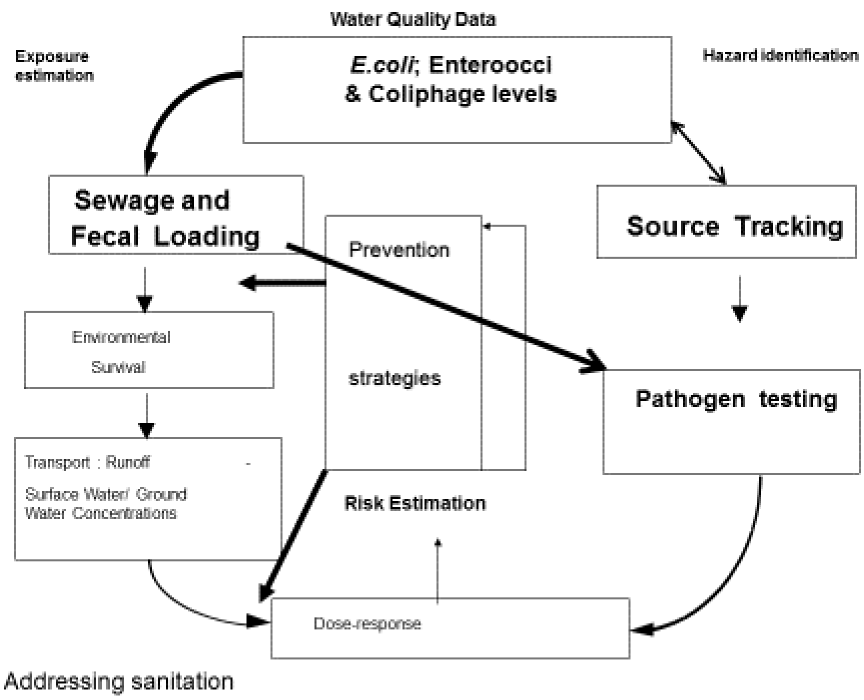

Figure 3

Prevention is usually the most cost effective means of delivering the requirement for safe water and to do this we require knowledge of the hazards. However, for many countries the capacity is inadequate and investment in the means for building capacity is essential if we are to move forward to delivering safe water in the post 2015 MDGs.

4. Case Study on VIRUS Hazards in EU associated with the fecal pollution

The management and use of water and water resources has been the focus of European Union (EU) water policy for many years. Regulations like the Nitrate Directive (91/676/EEC) or the Urban Waste Water Directive (91/14/EEC) to name only two were complemented and integrated latter on by the Water Frame Directive (2000/60/EC) which acted as an umbrella piece of legislation that embraced all the water Directives. These Directives target the quality of water bodies with the aim of ensuring a sustainable use of water resources protecting the ecosystems and the human health.

It is well known that improperly treated wastewater may lead to the transmission of human viruses that are excreted in feces and urine at high concentrations. Distribution and burden of several infectious diseases may shift and human exposure may differ under the predicted climate change scenarios. Integrated river basin management is a key tool to mitigate the possible impacts of future climate change on the quality of water resources.

Recent advances in the concentration methods and new molecular approaches, as qPCR and metagenomics, provide sensitive and exhaustive analytical tools. Such developments allow a better understanding of the dissemination of viruses as fecal contaminants in aquatic environments. Identifying sources of microbial contamination via Microbial Source Tracking (MST) plays a key role in risk assessment and the design of remediation strategies. Following an 18-month surveillance program within the EU-FP7-funded VIROCLIME project, specific MST tools were used to assess human markers such as adenoviruses (HAdV) and JC polyomaviruses (JCPyV) (indicators of fecal contamination of human origin) and porcine and bovine markers such as porcine adenoviruses (PAdV) and bovine polyomaviruses (BPyV) via quantification with real-time PCR to analyze surface water collected from five sites within different climatic zones: the Negro River (Brazil), Glafkos River (Greece), Tisza River (Hungary), Llobregat River (Spain) and Umea¨lven River (Sweden). The utility of the viral MST tools and the prevalence and abundance of specific human and animal viruses in the five river catchments and adjacent seawater, which is impacted by riverine contributions from the upstream catchments, were examined. The results concerning human and animal targets presented in this study demonstrate the specificity and applicability of the viral quantitative parameters developed to widely divergent geographical areas and their high interest as new indicators of human and animal fecal contamination in water and as MST tools.

In the project VIROCLIME, the dissemination of viral pathogens in river catchments were studied. The Llobregat River basin is representative of a region, with very high vulnerability to water scarcity, typical of Mediterranean catchments. The river basin, whose area is 4950 km^2, is inhabited by 5 million people, which constitute more than half of the Catalan population. Treated urban sewage, industrial activities and agricultural runoff affect the quality of river water, which is the main source of water abstraction to produce drinking water for Barcelona and its metropolitan area. In fact, urban water supply constitutes more than 60% of the total water demand. The annual average river discharge volume is 690 hm^3, of which over 40% consists of effluents from the approximately 50 wastewater treatment plants (WWTP) located along the basin (annual mean discharges: 300 hm^3). Human adenoviruses (HAdV) and JC polyomavirus (JCPyV) have been proposed as specific human fecal indicators based on their high prevalence in any of the geographical areas analyzed. Indeed, they have been widely used to survey the water quality and trace fecal pollution in the environment. Among all waterborne viral pathogens, noroviruses are recognized as the major causes of self-limiting viral gastroenteritis. Furthermore, NoV GII is believed to be the most significant aetiological agent in documented recreational water-borne outbreaks, followed by adenoviruses. Hepatitis E virus (HEV) has also a water-borne route of transmission and although it is endemic in low-income countries, producing acute and self-limited hepatitis, it also circulates in industrialized countries. The Merkel cell PyV (MCPyV), is associated to Merkel cell carcinomas.

By using qPCR the viral for the quantification of viral pathogens and indicators we defined a picture of the dissemination of fecal contamination. The parameters analyzed are the viruses, HAdV, JCPyV, MCPyV, NoV GGII and HEV together with two Fecal Indicator Bacteria (FIB), *Escherichia coli* (EC) and Intestinal Enterococci (IE). During a surveillance period, river samples from the Llobregat River and seawater samples were collected, processed and analyzed. Considering that the main viral inputs may come from raw or treated wastewater, several WWTP influent and effluent water samples were also analyzed to study the dissemination as fecal contaminants.

The results observed on the dissemination of the virus showed high genome copy numbers of human adenovirus (HAdV) and JC polyomavirus (JCPyV) in urban wastewater. Human Merkel Cell polyomavirus (MCPyV) was detected in 75% of the raw wastewater samples. This virus was found in 29% and 18% of river water and seawater samples, respectively. A seasonal distribution in the norovirus genogroup II (NoV GGII) occurrence was observed. Presence of human hepatitis E virus (HEV) in wastewater samples was 10% when analyzed by nested PCR (nPCR). The data obtained indicates that human fecal contamination is widely dispersed in the environment despite sanitation. Thus the type of treatment and log reductions for viral pathogens through wastewater is warranted.

In climate change scenarios for the Mediterranean region, wastewater management would be the key to prevent environmental dispersion of human fecal pathogens. Acceptable water quality levels may be guaranteed only if wastewater containment and treatment are fully operational when floods or extreme rainfalls occur. Projections for the Llobregat River catchment, estimate general warming and an increase of total precipitation amounts during the winter months and persistent decreases from May to October. Thus, river- and sea-water quality appears vulnerable when considering climate scenarios for the Mediterranean region.

Specific Outcomes and Approaches based on the pathogen water diagnostic study

1. The analysis of risk associated to the contamination by viral pathogens demonstrated disease potential and ongoing development of data on viral contamination and stability
2. Viruses are originated from wastewater and management of these sources is necessary. Two to three log reductions would be recommended to prevent environmental dispersion of human fecal pathogens. This would also be recommended as this region moves toward wastewater reclamation and reuse as well as other resource recovery efforts associated with wastewater treatment..
3. Acceptable water quality levels may be guaranteed only if wastewater containment and treatment are fully operational when floods or extreme

rainfalls occur, thus treatment must be resilient to high flows and climate extremes.

4. Application of viral MST tools for the identification of the main sources of contamination in water are viable diagnostic technologies that can be implemented in regional laboratories.

5. Capacity and Human Resources Development

We need to train analysts to test for pathogens in water sources using a multidisciplinary holistic approach within new water science curricula

The training and education of scientists and technicians in the art of measuring and achieving a desirable water quality requires attention to the technology to be applied and technical skills required but should include the interpretation and implications of test results, economic aspects and resource management. The programme should be a mix of theoretical modules and hands-on learning-by-doing training. The analysis of water for pathogens can, however, not be addressed in isolation and the training programme should also include basic modules on water and water resource management. This will equip trainees with the necessary skills to build national and institutional capacity to ensure a sustainable programme.

There should also be opportunities for continuing profession development – either in the country of origin or in regional centres of excellence. The training of scientists/analysts from the African region will, however, present challenges as many trainees will come from resource-poor settings and equipping them with skills for pathogen testing in their countries of origin will create expectations which may or may not be economically feasible. In addition, the scientific, educational backgrounds and communication skills of the potential trainees may vary from region to region, a factor which will need to be taken into account in curriculum development. The curriculum should also create and awareness of and interest in water-related education and training as a variety of factors, including lack of infrastructure, limited career options and technological and academic isolation may hamper sustainable development. Another obstacle to be addressed is the financial commitment for such training programme(s). Agreements between Research Councils from partnering countries contribute to such training programmes, but these are available for only a small number of African countries. To implement a sustainable training programme for the African region a more dedicated and sustainable funding model needs to be developed.

The use of online courses and tools and capacity to reach a larger audience should be finances. Global water quality centers of excellence should be established to achieve testing and educational opportunities to meet the needs for human resources in the water arena. Otherwise it is doubtful whether the global goals for safe water and sanitation can be achieved.

6. Recommendations

- ✓ Establish regional Centres of Excellence
- ✓ Create networks between cooperative organizations, to get stable cooperation between public health institutions in these areas, universities and also water companies.
- ✓ Use the risk analysis framework integrate science and policy and promote the translation of science into action around sewage sources.
- ✓ Use advanced technology for water diagnostics to improve resolution of the evidence for decision making, including MST tools for the identification of the source of contamination.
- ✓ Assess global water quality and health using QMRA framework for wastewater treatment. Develop QMRA frameworks for high rain/flood events.
- ✓ Develop the 21st century water curriculum for future water scientists, technicians and engineers.
- ✓ Improve wastewater management and the recycle/reuse to address future drought and safe water availability. Obtain 2 to 3 log removal of viruses as a goal for treatment. Address high flow events. This will protect and restore water-related ecosystems.