Water research for the world

Introduction

Let's start with the United Nations Millennium Development Goals Report 2012. Remember the target? Halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation. Thanks to China and India the world has met the drinking water target in 2010, but the work is not done yet. The poorest lag behind, especially in Sub-Saharan Africa (Figure 1). Over 40 per cent of all people without improved drinking water live in sub-Saharan Africa. The gap between urban and rural areas still remains wide, with the number of people in rural areas without an improved water source *five times greater* than in urban areas. Rural-urban disparities in access to sanitation are even more pronounced than for access to drinking water. The number of people forced to resort to open defecation remains a widespread health hazard and a global scandal. Nearly 60 per cent of those practicing open defecation live in India.

In sub-Saharan Africa, 75 per cent of the households have to collect water from some distance. The time and energy devoted to this manner of water collection is considerable. For 25 sub-Saharan countries combined, it is estimated that 26 million hours are spend per day, which equals the working hours of the lifetimes of 300 people. An important note: water *quality* is not accounted for in United Nations report – so results may well be overestimated. But isn't that what it's all about? Providing *improved* water sources, not just any source.

Water is no mobile phone

In the landscape of technology development there is only very little attention for the poorest of the world, while the challenges are the greatest. Contamination of surface water bodies are extreme, caused by unregulated activities upstream. Groundwater

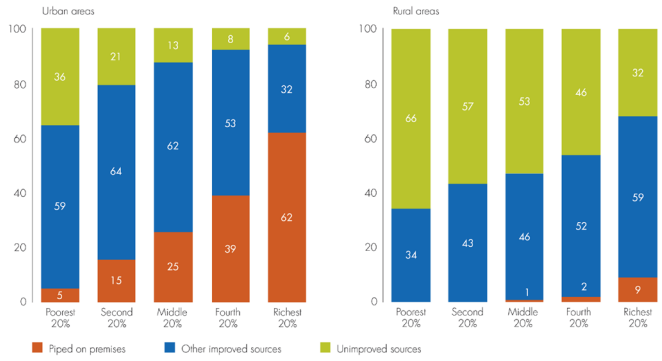

Figure 1 - Drinking water coverage by wealth quintiles, urban and rural residence, in sub-Saharan Africa (UN, 2012).



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is threatened by sea water intrusion, making it brackish and unhealthy to drink. People are more and more moving to densely populated megacities, where water supply does not reach the peri-urban areas. Safe water is not a mobile phone and it is not a gadget. It takes more maintenance than electricity only; it takes *on-site* knowledge, (water) quality control and long-term commitment.

But can't Africa's "mobile decade" perhaps help the rural poor towards reaching the target to safe water and basic sanitation? Examples have already illustrated mobile phone use for monitoring water points and latrines in the slums in Kenya (Majidata, 2012), or providing information about water quality in arsenic-contaminated areas in Bangladesh (trial of Grameenphone), or for the payment of water bills across Kenya, Tanzania, Uganda and Zambia (Oxford University). Many water service providers are unable to meet the needs of a rapidly growing population as they remain trapped in a vicious cycle of poor operational performance and low cost recovery (Global Water Forum, 2012). Since 2009 at least a dozen water service providers in East Africa have launched a 'mobile money' bill payment service with global mobile network operators, such as Safaricom/Vodacom and Airtel.



Figure 2 - How can the poorest benefit from Africa's "mobile decade"? (The Economist, November 2012).

The Economists (November 2012; Figure 2) questions how useful mobile phone can be to someone living on less than $2.50 a day, the World Bank's standard benchmark of poverty. Researchers in Kenya found that people will skip a meal so that they can keep their phone in credit. So although smart phones improve the quality of lives of the poor undeniably - by connecting people and access to information – it does not necessarily improve health standards.

Water research for the world

The initiative Water Research for the World is oriented towards solving global water challenges with enthusiastic TU Delft BSc and MSc students, and involving PhD students from low- and middle income countries. This way, knowledge is gained of water challenges *that matter*, by increasing generic fundamental understanding, but also by solving relevant water problems for the country of origin. So, who better to fill a few pages in this Vakantiecursus book than the PhD students themselves? In the following paragraphs two PhD research projects are introduced, jointly initiated by Delft University of Technology with a university in Colombia (Universidad del Valle) and in Bangladesh (University of Dhaka). Both projects commenced in 2011 and are executed partially in the Netherlands and partially in the country of origin.

Coca-Cola rivers in Colombia

In rural and some urban areas of Colombia safe drinking water supply is threatened by water quality problems in surface water, i.e., approximately 80% of the water supply in Colombia depends on surface water. Progressive deterioration of the surface water is mainly caused by the fast urbanization, in combination with the lack of integration between water management and spatial planning, inappropriate land use, poor protection of the river basins, discharges from domestic and industrial wastewater treatment plants, mining, deforestation processes and improper management.

Cauca river

As a result, river waters show a dramatic increase of particulate matter. The Cauca river water in Colombia can be characterized as highly

turbid (up to 10,000 NTU; Montoya et al., 2011), especially in the beginning of the raining season (Figure 3). Erosion is considered the main contributor to turbidity, which is accelerated by human activities that alter soil vegetation coverage (e.g., deforestation, vegetation burning, inadequate agricultural techniques, extensive livestock).

Additionally, Cauca river water was found to be contaminated by heavy metals, such as mercury and lead, mainly due to mining activities. The CVC (Corporación Autónoma Regional del Valle del Cauca – Regional Corporation of the Valle del Cauca) has developed a monitoring campaign since 1980 with 19 monitoring sampling points along the Cauca river. Several quality parameters are analyzed in the water, including heavy metals such as cyanide, copper, zinc, chrome, nickel, lead and mercury. The data show a progressive increment in lead and mercury concentrations from less than 60 µg/L in 2006 to 318 µg/L in 2009 for lead, and from less than 0.3 µg/L in 2006 to less than 5 µg/L in 2009 for mercury (CVC, 2011). This behavior is expected, considering that the development plan for Cauca's department is incorporated in the "Encouragement of productive development" program, which supports mining projects identified under the Mining-Environmental Plan of Cauca. Such programs embrace actions aimed at the exploration, exploitation, adjustment, and construction of infrastructure at the indigenous territories in the department (UPME, 2006). This situation, in addition to the industries and to the leachate discharges, promotes the water contamination with mercury and lead, which has been reported in water/sediment and fish studies.

River bank filtration

In a preliminary assessment river bank filtration (RBF) has been selected as an attractive communal alternative for the removal of extreme turbidity from surface water in Colombia. Also, it is expected that suspended solids act as the primary transport mechanism for heavy metals like mercury and lead (Bourg et al., 1989; Zhu et al., 2005; Miretzky et al., 2005). For over 100 years, RBF has been used in Europe to supply water to public and industrial level, using as sources of rivers like the Rhine, Elbe, Seine and Danube. Although RBF has proven to be effective in Europe and U.S., no experiences in Latin-American communities exist. Main differences to be considered are:

- environmental conditions;
- poor river basin management;
- socio-cultural perceptions and attitudes;
- high turbidity levels as a result of erosion.



Figure 3 - Cauca river valley in Colombia.

An Indian study showed the potential of RBF for the removal of highly turbid waters, as Thakur and Ojha (2010) obtained turbidity removal between 99 and 99.9% without any problems of obstruction in the bed with river water containing 2,500 NTU. Although RBF has shown to be a suitable technology, with relatively low-cost investment, operation and maintenance, it is crucial to investigate the long-term effects on porous media clogging by highly turbid waters. The PhD research of Juan Pablo Gutierrez Marin focuses on (i) characterization of sediments in the Cauca river (Figure 4); (ii) sediment transport during RBF; and (iii) co-removal of heavy metals. The ultimate objective is to understand the fate of sediments and heavy metals during soil passage *and* develop an appropriate (community) technology for implementation along the river Cauca in Colombia.

Reactive transport modeling in Bangladesh

Subsurface arsenic removal (SAR) is a technology where oxic and anoxic -or even anaerobic- conditions are intermittently applied to the aquifer material around the well by injecting aerated water into the subsurface (van Halem et al., 2010). Oxidation and adsorption of Fe(II) are dominant processes, but other (trace) compounds can be subsequently bound to the precipitated iron hydroxide surfaces as well. More water with reduced iron/arsenic concentrations can be abstracted (volume V) than is being injected (volume Vi), i.e., this volumetric ratio (V/Vi) determines the efficiency of the system. A pilot study was executed in the Comilla district (Bangladesh), specifically selected for its low phosphate concentrations, to study the removal of arsenic (269 µg/L) from groundwater.

Field experiments in Comilla

Three exploratory experiments were carried out to determine the effect of operational parameters on subsurface arsenic removal (Figure 5). In experiment 1, it was shown that Fe and As removal in the subsurface during SAR operation increases with injection volume: larger volumes of injection water result in a higher extraction efficiency than smaller volumes of injection water. In experiment 2 the multiple consecutive injection extraction cycles resulted higher extraction efficiency by providing more freshly precipitated HFO (hydrous ferric oxides) sorption sites for better removal of arsenic in the subsurface. In experiment 3, increased contact time between the oxidized zone and reduced native groundwater during extraction process resulted in better arsenic removal. The results of all three exploratory experiments need to be confirmed by additional experiments. In order to determine the potential reason behind such inefficiencies for arsenic removal, sorption behavior of arsenic on HFO, extent of arsenic and other element sorption on HFO, and most importantly dominant chemical reactions and processes occurring during SAR operation it is necessary to develop a reactive transport model (RTM). Also in an ideal setting, arsenic concentrations are measured continuously in the extracted water and a new volume of aerated water is injected when the concentration surpasses

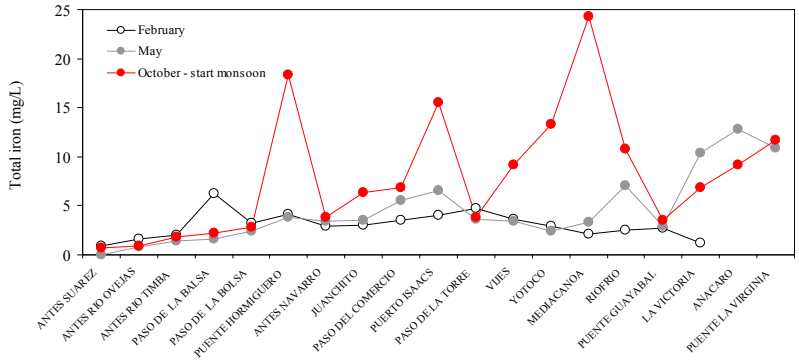

Figure 4 - Seasonal variations in total iron concentrations in the Cauca river at nineteen sampling points of CVC.



Figure 5 - Field study with subsurface arsenic removal in Comilla, Bangladesh.

the drinking water standard. In reality this is, of course, not possible. A more realistic scenario is to consume a pre-set volume after which the injection tank is refilled, water is aerated and re-injected. Determination of this pre-set volume to be used for consumption requires further experiments and reactive transport modeling.

Phreeqc modeling

In this study, a reactive transport model (RTM) is being developed by PhD researcher Mohammad Moshiur Rahman to simulate the SAR field results using PHREEQC (Parkhurst and Appelo, 1999. The RTM consists of a 1-D radial flow setting which is able to simulate subsequent SAR cycles. The model consists of equilibrium based reactions for the speciation of all major cations and anions, as well as kinetically simulated oxidation/dissolution reactions, surface complexation reactions, and cation exchange processes. The model simulates the simultaneous precipitation of Fe-hydroxides, SOM oxidation (soil organic matter), and the dissolution of carbonates (calcite). Sorption of dissolved Fe(II), arsenic, bicarbonate and other complexes on the Fe-hydroxide precipitates and the subsequent desorption during extraction phase, is also part of the simulations (Figure 6). The kinetic expressions used for the simulation of oxidation and dissolution reactions will possibly be able to determine reaction parameters. These expressions with calibrated parameters can then subsequently be used for prediction purposes and scenario modeling. The general objective of this RTM is to understand dominant processes potential to be taking place

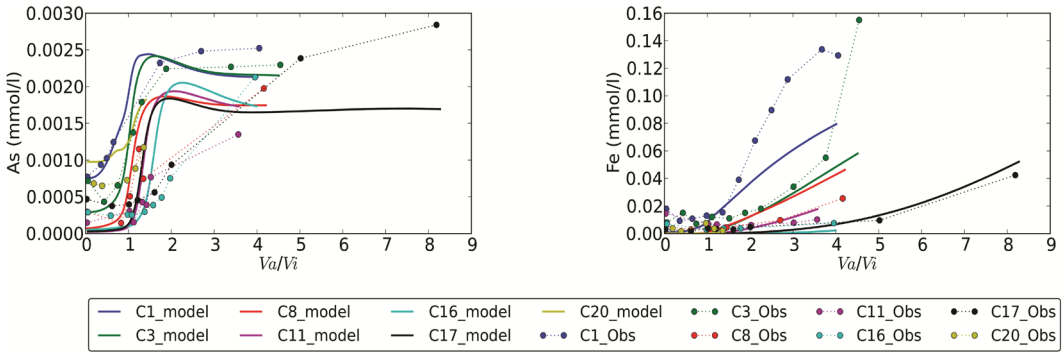

Figure 6 - Observed and model output for arsenic and iron during extraction phases of cycle 1, 3, 8, 11, 16, 17, and 20.

in the presently studied aquifer, as well as their quantification based on equilibrium based speciation reaction and kinetic rate expressions. Another important objective of this RTM is the determination of a pre-set volume to be used for consumption by the local people.

Concluding remarks

Access to safe drinking water sources is still a worldwide challenge, mainly affecting the poorest. The Netherlands is famous for its (drinking) water expertise and many in the water sector are involved in international initiatives. The aim is to link this expertise to academic education (capacity building) and water research (knowledge generation) in developing countries. We invite you to join the Water Research for the World initiative. With your company you can adopt a technology, research theme or even a PhD researcher; this will generate knowledgeable partners around the world. You can also think big, but start small through crowd sponsoring. Everyone donates a little and together we do a lot. For more information visit www.sanitaryengineering.tudelft.nl.

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