Photo: Zakir Hossain/SXC

2010 World Water Week Best Poster Award

Pathways for Contamination of Groundwater in Rural Bangladesh

John Feighery, a PhD Candidate in Earth and Environmental Engineering at Columbia University, received the Best Poster Award at the 2010 World Water Week. We asked him to share some thoughts on the topic of his poster.

Approximately two billion people depend on groundwater for their drinking water because it is often easy to obtain and considered to be microbiologically safe. However, there is a growing consensus in the scientific literature that groundwater can become contaminated with pathogenic bacteria or virus and the degree of contamination found often cannot be predicted with current theories. Our group monitored over 100 shallow tube wells in rural Bangladesh each month for over a year with funding from the National Institutes of Health and found that in this area between 30 and 70 per cent of wells test positive for *E. coli*, an indicator for fecal contamination. This finding, combined with observations of the sanitation and water infrastructure, raise important questions about the safety and sustainability of shallow groundwater resources, even in an area considered to have improved sanitation.

Ubiquitous surface water contamination

While our main focus was on wells, we also monitored several surface water bodies such as drainage canals and ponds. Ponds are found throughout developed areas in Bangladesh because most households are raised above the low-lying flood plain by digging clay and silt from the surrounding area, leaving behind ponds that are used for water storage, bathing and aquaculture. The ponds and canals routinely contain between 100 and 100,000 culturable *E. coli* per 100 millilitres of water, which greatly exceeds the WHO guidelines for recreational (or "bathing") waters.

The simple fact that fecal contamination is present at such high levels is alarming, since the local population relies on ponds for bathing, washing clothes, and for some, washing dishes. However, another concern arises from the fact that this region is known for a high level of coverage by improved sanitation. Most households have access to a ventilated improved pit (VIP) latrine, which contains sewage in a separate concrete-lined tank. In addition to the high level of access, there is a thriving local economy for producing and installing relatively inexpensive latrines and enclosures. In a sense, the community is implementing many of the improved practices suggested by the World Health Organization and sanitation NGOs but receiving very little of the benefits, at least in terms of reduced risk due to microbial pathogens in the environment.

Groundwater

The contamination of the shallow groundwater aquifer might seem inevitable given the large number of highly contaminated ponds located just 15 metres above the pumping depth for some wells. However, our current knowledge of the processes that lead to the removal of these microbial contaminants, known as filtration theory, generally predict much shorter travel distances than are measured in the real environment. Much of this theory is based on laboratory tests using columns packed with different types of sediment or sand. To get a more accurate picture, we installed an array of samplers, referred to as drivepoint piezometers, at different depths below two ponds, a drainage canal, and a latrine tank.

Samples collected from the piezometer array at the peak of the 2009 monsoon season show that the fecal indicator bacteria, *E. coli*, does make it through the clay lining below these source areas in large numbers (up to 1,000 colony forming units per 100 millilitres). The profile of *E. coli* with depth obtained using this method is consistent with the simplest expression of filtration theory, which is that the concentration should decrease exponentially with depth along a flow line. The rate of decrease varied significantly throughout the 10-day period due to frequent rainfall events, but the repeat samples allowed us to place bounds on this value. Using the typical source concentration the range of possible depths for *E. coli* to be detectable at a well was calculated to be between 1 and 7 metres, based on the piezometer data.

Leaking latrines?

If ponds cannot explain the well contamination, then what about the many open-bottomed latrine tanks used for on-site sanitation? We investigated this question by installing another array beneath a working latrine tank that was in good condition and extended about 2 metres into the ground. This meant that the bottom of the tank was in the sandy, water-bearing portion of the aquifer and could therefore be a direct route to contamination. Some of the highest initial *E. coli* concentrations were measured in this setup (as high as 100,000 per 100 millilitres) and a similar exponential decrease with depth was found. However, even a source at this high level of contamination combined with the lowest removal rate measured would lead to a detectable depth of just 11 metres. The shallowest wells in the surrounding area are at 14 metres depth and have experienced *E. coli* levels 100 times higher than the detection limit, so it is very unlikely that latrines or ponds can fully explain the contamination observed.

Implications for sanitation quality

The high levels of surface water contamination measured throughout the year are cause for concern due to both the immediate health implications and the indication of a failure in the sanitation system. One of the primary benefits of installing a sanitation system is to reduce the potential disease vectors arising from contact with excreta. Yet in this region, with a high level of access to improved sanitation, the residents are likely to continue to experience transmission of diarrheal disease through their contact with contaminated surface water. More effort is needed to determine the root causes of the failures observed in this latrine-based system, which is used extensively throughout South Asia and is being promoted in many other regions. Some of the immediately obvious issues are the quality of tank construction, the siting of tanks near water bodies, and the long-term maintenance and clean-out strategies.

The fact that existing theories cannot explain the degree of well contamination does not necessarily mean that it is not the result of infiltration by the polluted surface water bodies. In fact, we believe that in light of the seasonal pattern of *E. coli* levels, infiltration might be occurring through other pathways.

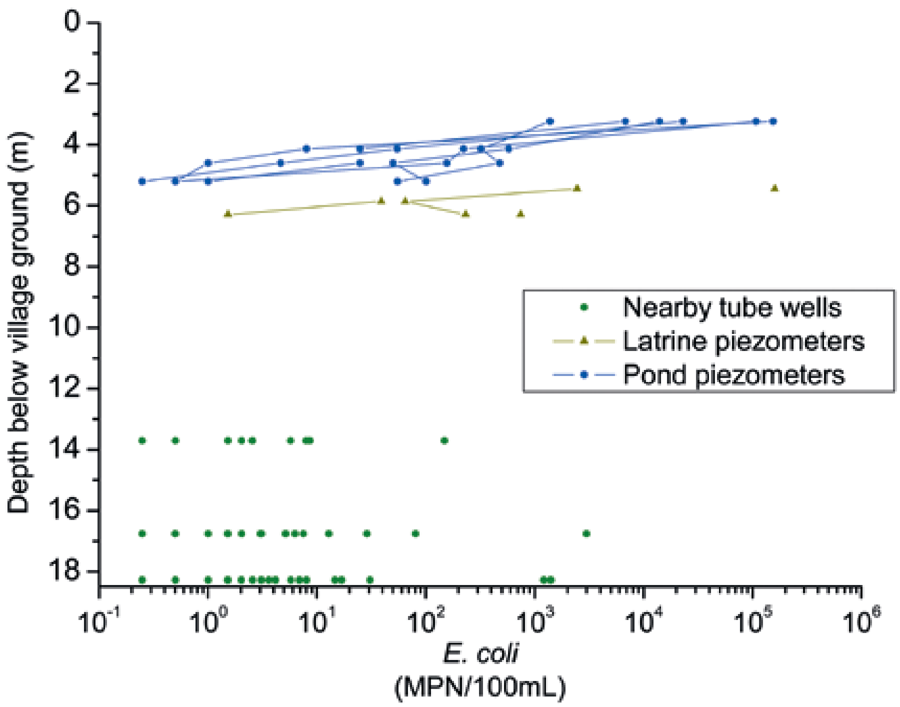

Figure 1 depicts the key findings of the field experiments. When the four measured concentrations on several sampling occasions are connected by lines (blue lines and points), the decrease with depth is approximately linear on a logarithmic scale. The measurements below latrines are also shown (tan lines). These data predict a relatively rapid decrease in *E. coli* concentrations with depth. The slope of these lines shows that transport to even the most shallow wells is not likely. Nearby tube well concentrations (green points) taken over one year are shown at the bottom.

Photo: John Feighery

Figure 2 depicts a typical example of a failing latrine tank leaking into a pond.

These might include preferential flow, in which some portion of water moves very quickly through cracks or highly permeable layers. Another explanation is that the wells themselves, which are not generally sealed with grout or cement, may act as conduits for direct contamination by surface runoff. Resolving the question of which pathways are causing the degradation observed in this aquifer will require additional research. The information is vitally needed since new well installation is proceeding at a rapid pace in Bangladesh to avoid exposure to high arsenic levels found in many existing wells. On a broader scale, many of the world's rapidly developing megacities rely heavily on access to untreated groundwater to serve their growing populations. In planning or managing these distributed water systems, it is clear that we should consider the water supply and sanitation infrastructure as an integrated system that must function together to provide safe drinking water.

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