

Microbial quality of improved drinking water sources: evidence from western Kenya and southern Vietnam

Caitlin A. Grady, Emmanuel C. Kipkorir, Kien Nguyen and E. R. Blatchley III

ABSTRACT

In recent decades, more than 2 billion people have gained access to improved drinking water sources thanks to extensive effort from governments, and public and private sector entities. Despite this progress, many water sector development interventions do not provide access to safe water or fail to be sustained for long-term use. The authors examined drinking water quality of previously implemented water improvement projects in three communities in western Kenya and three communities in southern Vietnam. The cross-sectional study of 219 households included measurements of viable *Escherichia coli*. High rates of *E. coli* prevalence in these improved water sources were found in many of the samples. These findings suggest that measures above and beyond the traditional 'improved source' definition may be necessary to ensure truly safe water throughout these regions.

Key words | contamination, drinking water, improved source, Kenya, Vietnam

Caitlin A. Grady (corresponding author)
Ecological Sciences and Engineering Program,
Purdue University, 550 Stadium Mall,
West Lafayette, IN 47907-2051,
USA
E-mail: grady3@purdue.edu

Caitlin A. Grady
E. R. Blatchley III
School of Civil Engineering,
Purdue University, West Lafayette, IN 47907,
USA

Emmanuel C. Kipkorir
School of Engineering,
Department of Civil and Structural Engineering,
University of Eldoret, Eldoret,
Kenya

Kien Nguyen
Research Center for Rural Development,
An Giang University, Long Xuyen,
Vietnam

E. R. Blatchley III
Division of Environmental and Ecological
Engineering, Purdue University,
West Lafayette, IN 47907,
USA

INTRODUCTION

Although some 780 million people still do not have access to improved drinking water (UNICEF & WHO 2013), international water development work has been widely touted as a major success story of the past two decades. Primarily across Africa and Asia, governments, non-governmental organizations, communities, private companies, and individuals have brought access to improved drinking water to over 2 billion people, or just under half of the 1990 world population and over one-quarter of today's population. These efforts have been so successful that the United Nations declared the Millennium Development Goal Target 7c accomplished as of 2010, 5 years ahead of schedule (UNICEF & WHO 2013). The Joint Monitoring Program of the World Health Organization and United Nations defines improved drinking water simply according to source type, which includes: a piped connection into the home, public taps or standpipes, tube wells or boreholes, protected dug

wells, protected springs, and rainwater collection (United Nations 2012). Although these source selections are intended to protect drinking water by the nature of their construction, this definition does not directly address finished water quality, and therefore has the potential to misrepresent the number of people with access to safe drinking water (UNICEF & WHO 2013; Baum *et al.* 2014).

Owing to a number of factors including time, funding, treatment intervention, cultural practices, and laboratory or field technological limitations, it is difficult to define a standard protocol of methodological approaches for evaluating water and sanitation interventions in developing countries. Effectiveness studies traditionally utilize engineering and water quality indicators (Lee & Schwab 2005; Duke *et al.* 2006; Sobsey *et al.* 2008), health epidemiological information (Reller *et al.* 2003; Clasen *et al.* 2007), household and community attributes gathered through social science

doi: 10.2166/wh.2014.206

methodology (Prokopy *et al.* 2008; Whittington *et al.* 2009; Peter & Nkambule 2012), or combinations of the three. Most of these effectiveness studies focus on one specific intervention or one implementation protocol and do not evaluate safe water access within a region as a whole. This article, instead of focusing on one implementation strategy, presents a summary of viable *Escherichia coli* concentration measurements for drinking water samples from improved sources in western Kenya and southern Vietnam. One previous study (Baum *et al.* 2014) has evaluated the relationship between improved water sources and *E. coli* concentrations in the Dominican Republic, concluding that the current estimate of safe water access may be overly optimistic. We aimed to add to their location-specific finding by measuring viable *E. coli* concentrations evaluations to settings in both east Africa and southeast Asia, thereby further expanding the current knowledge and status of improved water resources worldwide.

We sought to evaluate *E. coli* concentrations for samples collected from water treatment systems in three communities in Vietnam and three communities in Kenya. In Vietnam, 98% of urban residents and 94% of rural residents have access to improved water sources while in Kenya, the corresponding fractions are 82% and 55%, respectively (UNICEF & WHO 2014). While both countries are still considered to be developing, neither country is categorized as a 'least developed county'. Through measurements of viable *E. coli*, these household samples were classified according to the World Health Organization definitions of safe water in order to give a more complete picture of unimproved, improved, and safe water.

METHODS

Site description

Samples were collected and analyzed between May and August 2011 in western Kenya and between February and April 2014 in southern Vietnam. The study designs and protocols were approved by the Purdue University Institutional Review Board (IRB #1105010852 and #1401014379). As shown in Figure 1, the sample sites in Vietnam included communities near An Phu, Tri Ton, and Bunh Thuy districts.

In Kenya, the villages nearby included Kipsinende, Ainabkoi, and Kapsabet.

For the sampling procedure in Vietnam, 35 samples from households in each village were collected for microbial analysis totaling 105. In Kenya, 119 households were identified for water sample collection for analysis. These households were distributed throughout each of the three communities and included between 35 and 40 samples per village. Both regions are dominated by agricultural land use, with small areas of urban development and other land cover including rangeland and forests. Sources of water contamination include agricultural runoff as well as human and animal waste. None of the villages has centralized human waste or sanitation facilities, though some specific households have access to improved sanitation such as a ventilated pit latrine. In addition, all of the households in Kenya had a point-of-use biosand filtration system and were sampled before and after filtration, thereby totaling 238 water samples. The household surveys were completed in order to identify the practices relating to water use and hygiene within the household.

Water quality methods

Household water quality was characterized by analyzing the concentration of viable *E. coli* in treated or stored water at the point of use in each household. Water was collected in sterile whirl-pack bags, and due to different field condition constraints, the samples were analyzed in using different, yet comparable analytical methods for viable *E. coli* in Kenya and Vietnam. In Kenya, the samples collected before and after the point-of-use biosand filters were stored in an ice chest with an approximate temperature of between 3 and 5 °C and brought to Moi University for analysis using a standardized membrane filtration assay, EPA Method 1103.1. In Vietnam, samples were collected and analyzed using the Compartment Bag Test developed by Aquagenx (Stauber *et al.* 2014). This method utilizes a chromogenic *E. coli* broth culture, which is mixed with the water sample for 20 minutes prior to pouring into the compartment bag (Stauber *et al.* 2014). After the sample is poured into a compartment bag, it is sealed with a two-piece plastic bag clip to isolate each compartment for incubation for 18–24 hours at

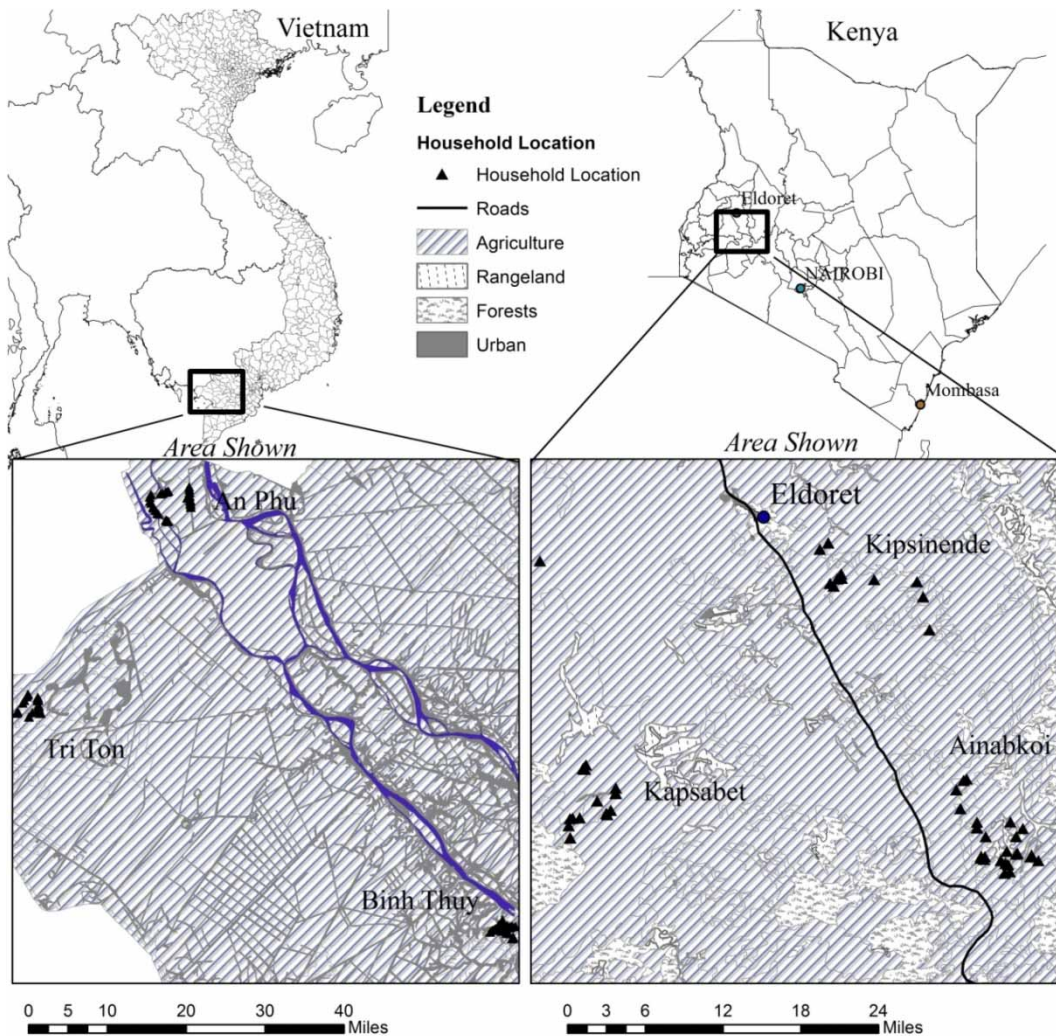


Figure 1 | Sampling locations for six communities in Kenya and Vietnam.

approximately 35 °C. After incubation, the presence of *E. coli* in each of five bag compartments of known volume can be determined through a blue-green color due to the hydrolysis of the β -glucuronide substrate (Stauber *et al.* 2014). A most probable number calculator is then used to estimate the concentration of viable *E. coli* in the original sample. Both sets of samples were processed within approximately 6 hours of the point of collection. Viable *E. coli* were measured, because they are a commonly utilized indicator for fecal contamination used by the United Nations, the World Health Organization, and a variety of other organizations worldwide (WHO 2011). Both methods ultimately indicate an estimate of *E. coli*

coliform present in the sample and have been shown to produce results consistent with each other (Stauber *et al.* 2014).

RESULTS

Of the 105 samples from Vietnam, 102 were from improved water sources, of which piped water was the most prevalent (65%) and rainwater (10%) was the second most common. In Kenya, 16 samples were from unimproved sources and 103 samples from improved sources, where rainwater (40%) and protected wells (32%) were the most common

sources of improved water. The results were categorized according to the WHO guidelines for drinking water quality, which articulate *E. coli* risk levels as described in Table 1.

As shown in Figure 2, only about 18% of samples from either Kenya or Vietnam showed no measurable *E. coli* colonies detected. In Kenya, roughly 61% of all improved source samples contained high-risk or very high-risk levels of *E. coli*. In Vietnam, high or very high-risk designations were observed in roughly 67% of samples. While there was only one instance of a Vietnamese household with a

point-of-use filtration technology (ceramic filter, 0 *E. coli*), all of the piped water on premises was treated with chlorine at a central facility prior to distribution, yet some of these samples still experienced microbial contamination either from household secondary contamination or contamination at some point during the treatment and distribution process.

Point-of-use biosand filters were present at all households sampled in each of the three villages in Kenya. To evaluate both the improved sources of water as well as the biosand filters, water samples from both pre- and post-filter (point-of-use) were collected. As summarized in Table 2, the biosand filters did contribute to an overall reduction of the concentration of viable *E. coli*, but did not yield samples with water quality that consistently met the WHO definition of safe water.

These results point to an overall trend of decreasing, yet still present viable *E. coli* concentrations in drinking water of households in these three communities in Western Kenya. For example, it appears that, for both improved and unimproved water sources, the water samples, which fall within the very high-risk category before the filter, are

Table 1 | Risk classifications for *E. coli* most probable number (MPN)/100 mL^a

WHO classification	<i>E. coli</i> MPN/100 mL
Safe/low risk	<1
Questionable safety/intermediate risk	1–10
Unsafe/high risk	10–100
Unsafe/very high risk	>100

^aWorld Health Organization risk classification (WHO 2011).

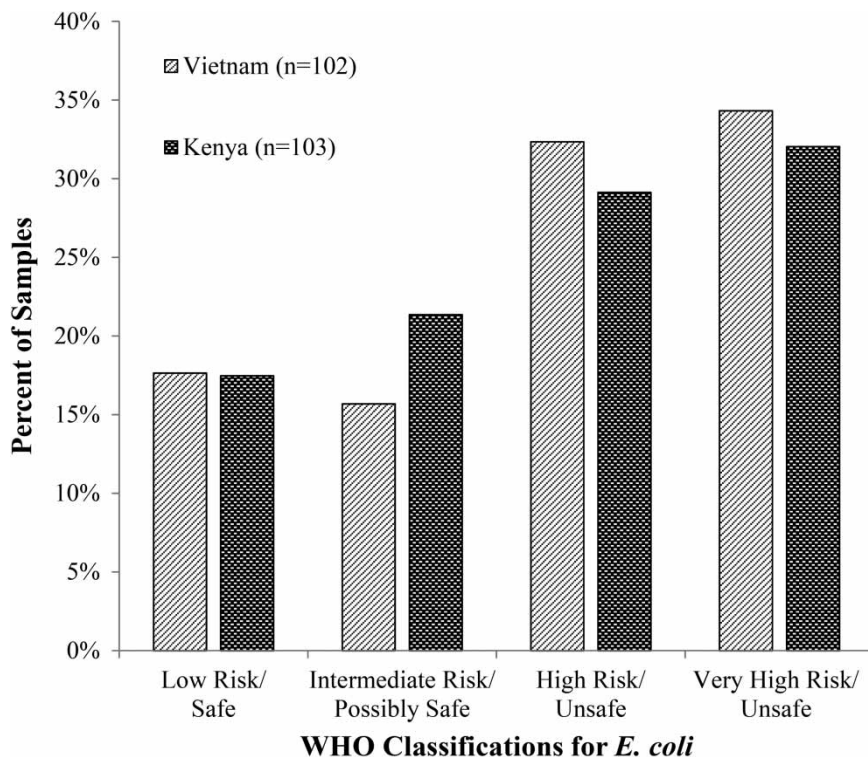


Figure 2 | Percentage of improved source samples with associated *E. coli* risk.

Table 2 | Variation in percent of *E. coli* presence between pre- and post-filtration of improved and unimproved water sources in Kenya

<i>E. coli</i> risk categories	Improved sources (n = 103)		Unimproved sources (n = 16)	
	Pre-filter (%)	Post-filter (%)	Pre-filter (%)	Post-filter (%)
Low risk/safe	17.6	24.3	6.3	6.3
Intermediate risk/ possibly safe	21.6	30.1	0.0	18.8
High risk/unsafe	28.4	35.9	25.0	50.0
Very high risk/unsafe	32.4	9.7	68.8	25.0

then distributed between lower categories after the biosand filter.

DISCUSSION AND CONCLUSION

These results show that *E. coli* are prevalent in improved water samples in all six communities in Kenya and Vietnam. These findings indicate that improved drinking water, as defined by the WHO, does not necessarily indicate safe drinking water. These data also contribute to a deeper understanding of the relationship between the categories of 'improved' and 'unimproved' and measures of fecal indicator bacteria.

Of particular interest is the presence of microbial contamination in the Vietnamese communities because these samples include a large percentage of piped water supplies. Even though this study did not determine the cause of contamination, throughout the data collection, multiple observations of broken and leaking pipes, as well as pipes that were in direct contact with surface water, were observed. These distribution problems can lead to contamination within the distribution system (LeChevallier et al. 2003; Bhunia et al. 2009). In Kenya, high rates of microbial contamination both before a secondary point-of-use treatment as well as after were also found. This could be due to the general performance of biosand filters, which can range from 0 to 99.7% reduction in typical households (Stauber et al. 2006) or secondary contamination occurring in the household prior to consumption. These results therefore also

highlight the importance of safe storage education and household hygiene education, both of which can contribute to a lower level of secondary contamination.

In addition, as supported by other recent literature (Baum et al. 2014), these results illustrate a need to consider water quality in addition to water source characteristics when classifying water as 'improved' or 'unimproved'. Although monitoring water quality is often limited by resources and capacities in developing and emerging countries, it is difficult to determine water safety without these measures. In recent years, there have also been tremendous gains in field-stable, rapid *E. coli* test kits (Stauber et al. 2014). These gains now allow microbial water quality testing to move out of the domain of scientist-specific knowledge and into the practitioner field skill set. The tremendous progress that has been made in the water development community over recent decades is truly revolutionary, considering so many of the other Millennium Development Challenges are far from being accomplished. As we look towards the post-2015 development agenda, however, it is important to consider the limited scope of the current 'improved' sources definition and how the international community defines and provides water access to people worldwide.

ACKNOWLEDGMENTS

This study was supported by the National Science Foundation Graduate Research Fellowship (DGE-1333468) and by the Borlaug Graduate Fellowship USAID (Grant 206766). We would like to thank Hach Instruments for donating portable turbidimeters, Aqua Clara International, Prof. Emmanuel C. Kipkorir, Moi University for field coordination in Kenya, and the staff and students of the Research Center for Rural Development at An Giang University for support in Vietnam. The authors would also like to thank all of the study participants who consented to allowing research team members into their communities and homes. This research was performed under approval of Moi University's Institutional Research and Ethics Committee, FAN: IREC 000629 and Purdue University's Institutional Review Board, #1105010852 and #1401014379.

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First received 21 August 2014; accepted in revised form 13 November 2014. Available online 8 December 2014