# Health impacts of expanding access to piped water in rural Vietnam: a post-implementation assessment

## Final Report

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**Abstract**
Access to "improved" water and sanitation is rapidly expanding in Vietnam. We examined one market-based, NGO-led piped water supply and sanitation program to assess the water quality, health, and other impacts of expanded coverage of specific interventions. This longitudinal, prospective cohort study includes 300 households in seven project areas in central Vietnam: 141 households who paid to connect to a piped water system; 83 households who paid to connect to a piped water system and who paid to install an improved, pour-flush latrine; and another group of 76 control households that did not invest in these specific improvements. The four-month study was intended to measure the impact of the NGO-led water and sanitation programs on households' drinking water quality and health against control households with a "basic" level of service characteristic of the project areas (majority access to improved drinking water sources and high access to sanitation options of various kinds). We found that: (i), households connected to a piped water supply had consistently improved drinking water quality over those relying on other, non-piped sources; (ii), households investing in a piped water connection (with or without an improved latrine) were at reduced risk of diarrheal diseases compared with households that did not invest in these; and (iii), households paid less per month for piped water and reported greater satisfaction with the service over available alternatives. Finally, although a connection to a piped water supply offers measurable benefits to households at relatively low cost, maintaining water quality and ensuring consistent operation and maintenance represent ongoing challenges to local service providers.

**Introduction**
The interconnected and persistent problems of unsafe drinking water, inadequate sanitation, and poor hygiene contribute to a massive global burden of diarrheal disease that disproportionately affects the poor, the elderly, the young, and those already suffering from other diseases or malnutrition. According to data published by the World Health Organization[1], diarrheal diseases are a leading cause of death in under 5s in Vietnam, having accounted for an estimated 14% of all deaths in that age group in 2004 (figure 1). The rapid expansion of water and sanitation infrastructure coverage currently underway there is expected to reduce this burden of disease: recent evidence suggests that increased water access (i.e., adequate water quantity), improved water quality (by household water treatment and safe storage), effective sanitation (e.g., sanitary latrines) and proper hygiene (e.g., handwashing at critical times), all contribute to reduced diarrheal disease in children, with typical reductions of between 25-45% for each intervention (figure 2)[2]. Indeed, access to "improved" water sources in Vietnam has increased from 52% of households in 1990 to 77% in 2000 to 92% in 2006[3], with similarly dramatic increases in sanitation coverage (figure 3).

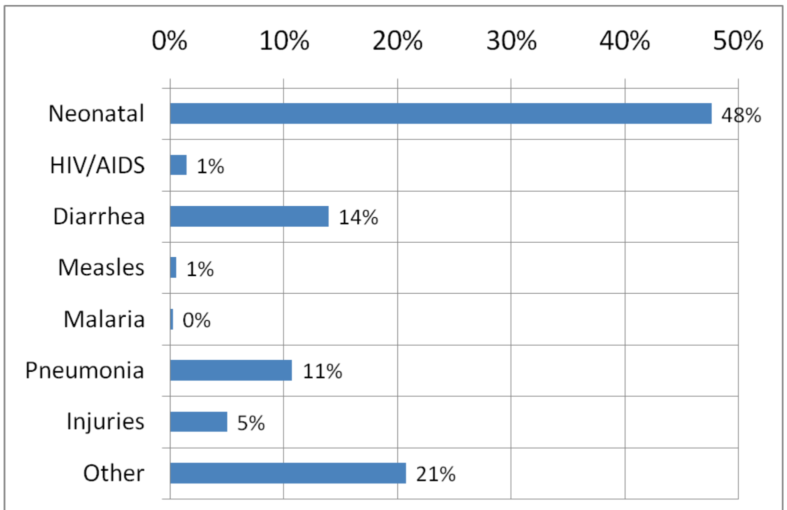

Figure 1. Causes of death in under 5s, Vietnam (2004)[4].

Study background
A major focus of NGO, government, and increasingly, private-sector led programs is increased access to water and sanitation improvements in the rapidly developing economies of Southeast Asia. WaterSHED partner East Meets West (EMW) has now installed over 8,000 piped water connections and hundreds of pour-flush latrines in central Vietnam (boxed text below). All schemes have been in villages with mean incomes of approximately US$1 per day, per person, as identified in a needs assessment conducted by EMW, but are based on the goal of reaching financial sustainability though low- or un-subsidized models for this critical infrastructure. In support of EMW's goal of exploring innovative methods for scaling up access to water and sanitation service delivery, a post-implementation assessment was carried out to evaluate a large-scale implementation of community piped water systems and improved sanitation. This was identified by EMW as a critical technical assistance (TA) activity to be conducted with the assistance

[1] WHO 2009, Global Health Statistics
[2] Clasen, T., Schmidt, W.P., Rabie, T., Roberts, I., and Cairncross, S. 2007. Interventions to improve water quality for preventing diarrhoea: systematic review and meta-analysis. *British Medical Journal* 334(7597):755-756.
[3] WHO 2009, Global Health Statistics [2] Clasen, T., Schmidt, W.P., Rabie, T., Roberts, I., and Cairncross, S. 2007. Interventions to improve water quality for preventing
[4] From WHO 2009 Global Health Statistics diarrhoea: systematic review and meta-analysis. *British Medical Journal* 334(7597):755-756.
[3] WHO 2009, Global Health Statistics
[4] From WHO 2009 Global Health Statistics

of USAID's Regional Development Mission-Asia (RDM/A)-supported *WaterSHED* Global Development Alliance.

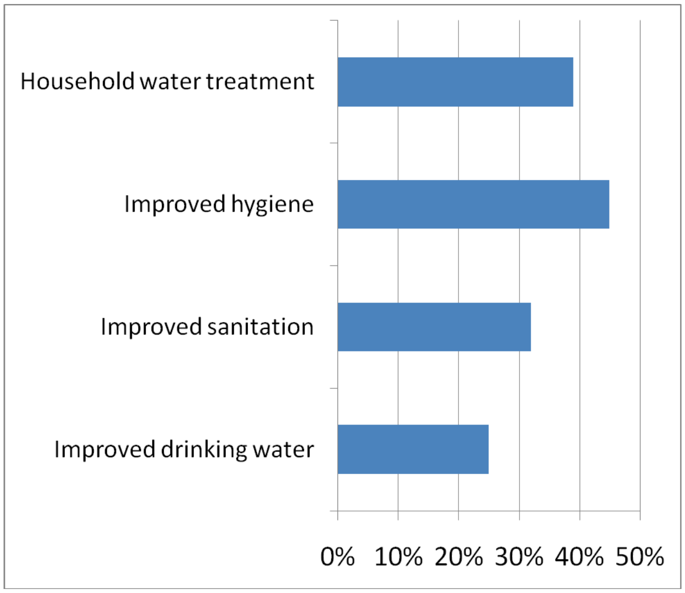


Figure 2. Diarrheal disease reduction from drinking water and sanitation improvements[5].

WaterSHED partner East Meets West (EMW) engages in consumer demand-driven water and sanitation programs in Vietnam, with particular interest in central and southern provinces.

*Overview of EMW GPOBA program*

- World Bank supported scheme providing capital to finance community piped water projects (GPOBA)
- Purpose: to rapidly expand **safe** drinking water supplies
- System costs are offset by community participation
- **Full or near full cost recovery through tariffs** (metered connections)
- Managed by either community boards or for-profit cooperatives, O&M from tariffs
- Latrine construction financed by EMW with 15% rebate
- **30,000 households connected with 112 gravity-flow water systems so far**
    - 80% initial subsidy to systems
    - 200 or more households required
- People's committee (CPC) governance & oversight
- Village selection based on **demand and needs assessment** – areas targeted where per capita income <US$1 per day

Stated goal: **"To improve the overall living environment, and decrease the number of waterborne diseases"**

[5] Fewtrell et al. 2005. Water, sanitation, and hygiene interventions to reduce diarrhoea in countries: a systematic review and meta-analysis.*Lancet Infectious* less developed *Diseases*.

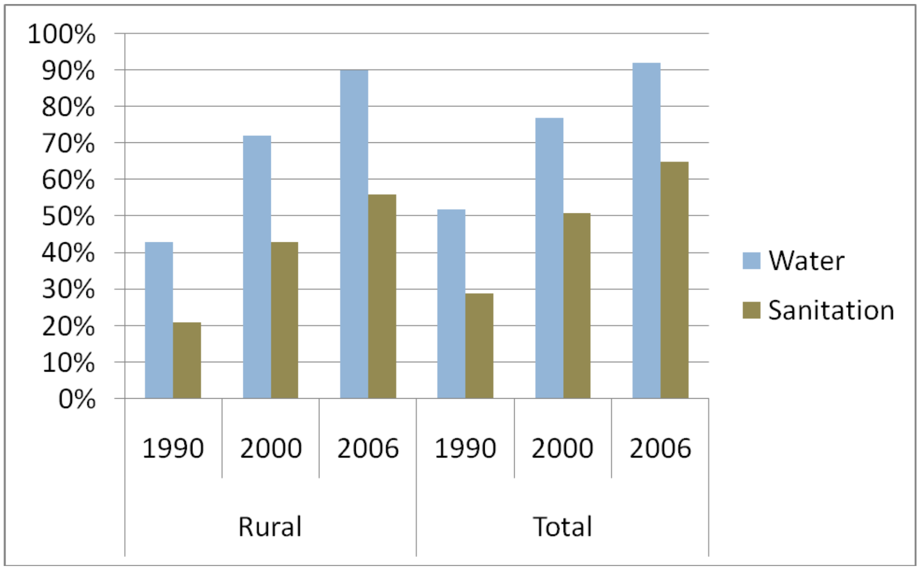

Figure 3. Coverage of “improved” water and sanitation in Vietnam, 1990-2006. Vietnam is on track to meet Goal 7, Target 7c of the MDGs.

Objectives

Objectives of this research included determining whether: (i) access to piped water systems presented health advantages over access to other “improved” water sources, (ii) systems consistently delivered safe drinking water, and (iii) access to new pour-flush latrines resulted in even greater health impacts. This assessment was intended to be an independent appraisal of the EMW model for the implementation of community piped water systems and improved sanitation, with the purpose of improving EMW’s model for commercially inspired approaches to providing water and sanitation infrastructure access. A separate study of sanitation investment was intended to identify factors that drive demand for consumer investment in sanitation improvements, specifically the pour-flush latrine option promoted by EMW.

*Summary of critical study questions*

- Are piped water supply systems delivering safe water to consumers?
- What are the health and other impacts associated with EMW’s water and sanitation programs?
- Are there areas for program improvement?

## Methods

Overview of methodology

This study had two phases: (i) an initial cross-sectional sampling and recruitment phase (1 month) and (ii) a longitudinal data collection phase (4 months). There were a total of four visits to 300 quasi-randomly selected households (divided between those with a piped water connection, those with a piped water connection as well as a pour-flush latrine, and control households with neither), where we collected interview data and water samples for microbial and other analyses in the laboratory. The three groups of households were compared to assess differences in health outcomes and other health-related indicators (e.g., water quality) potentially associated with water and sanitation improvements.

Sites, participation, and recruitment

This study was conducted in central Vietnam in collaboration with EMW. Communities were randomly selected from EMW focus areas, which were selected by EMW as resource-limited. From EMW intervention records, we randomly selected households from the list of all households investing in a water connection, a water connection and a pour-flush latrine (sanitation), or neither after receiving information about water and sanitation benefits and financing strategies from EMW's programs. Importantly, we allowed households that had invested in non-EMW-sponsored latrines (or built one themselves) in the second group. All household with piped water were connected to an EMW-sponsored system, however. We visited the selected households in a cluster-randomized order to introduce the study and determine eligibility. If the household was eligible, we presented the primary caregiver (senior female, charged with caring for children and collecting water) with the informed consent form. If the primary caregiver and the head of household (if different) consented to participate, the household would be enrolled in the study. All survey data was collected from the primary caregiver, who acted as the study's point of contact with the household. Of the >8,000 households initially identified by EMW records, we recruited 300 households in total: 141 households connected to a piped water supply system, 83 connected to a piped system and a pour-flush latrine, and 76 households who had received the EMW program offer but declined to invest in either. System details for the selected sites are given in table 1.

| Project name | Constructed | Management | Chlorine disinfection used at treatment plant |
|---|---|---|---|
| Duy Son | 2008 | cooperative | Yes |
| Tam Hoa Commune | 2002 | cooperative | No |
| Tam Anh Nam Commune | 2007 | people's committee | Yes |
| Que Xuan II Commune | 2006 | people's committee | Yes |
| Que Phu Commune | 2007 | people's committee | Yes |
| Binh Dao Commune | 2005 | cooperative | No |
| Binh Chanh, Thang Binh | 2008 | people's committee | Yes |

Table 1. Piped water projects included in this study.

*Summary of village and household selection*

- Villages included in the study must be:
  - In EMW program area, which have the following characteristics:
    - Rural communities near Da Nang, in Quang Nam Province
    - Limited social/economic stratification
    - Among the poorest areas in Vietnam (<US$1 per day)
    - Minimum 200 households
    - Demand for system & willingness to contribute in-kind and cash
    -
- Households included in the study must be:
  - In government records
  - Within the geographic boundaries of selected villages
  - Willingness to participate / informed consent
  - Additional households recruited for further study focusing on sanitation only

- Random selection of eligible households connected to piped water and sanitation, and controls (just outside coverage area)
  - Minimum group size for health impact study = 75 households to detect 30% difference in outcomes
  - Controls selected on basis of water source, SES, location

- Random selection of additional system households for stratification of water quality and other data across system types

Participants included household members ranging from children (newborns) to adults in the study areas. The participants were persons living in households within a village that EMW has implemented their community piped water system and in some cases sanitation program. The study population included three groups: households that had invested in a paid water connection, households that had invested both in a paid water connection and sanitation, and control households who decided not to invest in either water or sanitation improvements offered by EMW. Therefore, the complete study population included all of the members of the households from 300 households in central Vietnam.

Recruitment was performed at the village and household level. We worked in villages that EMW already had a presence in and therefore a relationship with the communities. In addition, before household recruitment began we discussed the purpose of our project with the village leaders in each community in order to gain their approval and support.

At the household level, the required criteria for participation in the study were: a willingness to participate and having invested in EMW piped water or both piped water and sanitation or was in the target area of these programs. For the first 300 households consented to participate in this study, each was presented with a narrative description of the project (both written and orally, by a native speaker of Vietnamese from the region with experience in household survey techniques) and asked to participate in a study entailing three additional household visits by the project team over the course of 4 months. The recruitment phase lasted 1 month. At any point in time, participants could unenroll in the study at their request with no consequences. All recruitment and informed consent procedures and documentation were reviewed and approved by the University of North Carolina – Chapel Hill Institutional Review Board and by local Vietnamese authorities before use in this study.

Assumptions and preliminary data that influenced sample size calculation

According to WHO[6] estimates, 10 - 14% of all deaths among children under 5 years of age were due to diarrheal diseases. Estimates of diarrheal disease morbidity in rural Vietnam are near 10% for a two-week recall period[7].

We used a baseline estimate of 10% in the sample size calculations, based on available national data. Based on systematic reviews by Esrey et al.[8], mean reductions of diarrheal diseases as a result of access to a household connection to piped drinking water and sanitation were assumed to be 30% - 60%. We based the sample size calculation on the detection of a risk ratio of 0.70 (that is, detection of a 30% reduction in risk of diarrhea experienced by those with access to piped drinking water). This detectable difference of 30% is considered to be very conservative given reported reductions in disease due to water and sanitation improvements.

The sample size for the study was computed as 350 individuals (in each group) to detect a 30% difference in proportions (RR=0.70) between the study groups with 80% power and $\alpha = 0.05$, using the methods for analysis of binary outcomes in multiple groups with repeated observations as described by Diggle et al. (2002)[9]. Calculations account for limited clustering within households and clustering in individuals over time, which are potentially important in the analysis of diarrheal disease data (Leon 2004; Killip et al. 2004)[10,11]. Results of power analyses in EpiSheet and EpiInfo were in general agreement with these results.

Since the average household size in the region is approximately 5 individuals, this is approximately equal to 70 households. A minimum of seventy-five (75) households were needed for each study group at 4 visits each.

Data collection and handling

There were a total of four household visits to each household for data collection. Each household was visited once upon recruitment and then approximately three more times over three months. Initial household interviews were extensive (one hour) with subsequent brief follow-ups (15 minutes each) to monitor changing covariates, including water quality and water handling practices. Data for the 300 households were recorded for water use and handling practices; sanitation access and behavior; other water, sanitation and hygiene practices; and other covariates. A broad range of data on water, sanitation, and hygiene (WSH) were collected. Observational data, such as presence of soap in the home, types and numbers of water storage containers, and presence of animals or animal waste in the home, were collected to supplement interview data. A nested study of drivers of demand for investment in sanitation improvements was also part of the survey data collection. Pre-structured, pre-tested (by back-translation and use in focus groups and pilot interviews) questionnaires were prepared in Vietnamese prior to use in the study and implemented by a dedicated field staff. All survey instruments were developed with the assistance of East Meets West staff and carefully adapted to the local context.

Survey data were collected via verbally administered questionnaires and recorded onto data sheets. Households were given a code number as an identifier and personal information was kept in a locked file box. During active data collection, household surveys and water samples were identified by

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[6] WHO Statistical Information System (WHOSIS). www.who.int. Accessed 17 February 2009.

[7] Tang, K.H., Dibley, M., and Tuan, T. 2003. "Factors affecting utilization of health care services by mothers of children ill with diarrhea in rural Vietnam". *Southeast Asian Journal of Tropical Medicine and Public Health* 34(1): 187-198.

[8] Esrey, S.A., Feachem, R.G., and Hughes, J.M. 1985. "Interventions for the control of diarrheal diseases among young children: improving water supplies and excreta disposal facilities". *Bulletin of the World Health Organization* 63: 757–72.
Esrey, S.A. and Habicht, J.P. 1986. "Epidemiologic evidence for health benefits from improved water and sanitation in developing countries". *Epidemiologic Reviews* 8:117-128.

[9] Diggle P. J., Heagerty, P., Liang K.-Y., & Zeger S. L. (2002). *Analysis of longitudinal data (2nd ed.)* Oxford: Oxford UP.

[10] Leon AC. 2004. Sample-size requirements for comparisons of two groups on repeated observations of a binary outcome. *Eval Health Prof.* 2004 Mar;27(1):34-44.

[11] Killip, S., Mahfoud, Z., and Pearce, K. 2004. "What is an intracluster correlation coefficient? Crucial concepts for primary care researchers". *Annals of Family Medicine* 2(3): 204-208.

assigned number to eliminate personal information. Surveys and water quality data were entered daily into an EpiInfo and Excel spreadsheet (respectively) and copied into Stata version 8 or 9 for analysis, excluding the direct personal identifiers of the study participants.

Diarrheal disease data and analysis

A longitudinal diarrheal disease surveillance and household water quality monitoring survey was performed. The head of the household was asked to provide a one-week recall of diarrhea disease for herself and all members of her household. Diarrhea was clearly defined as three or more loose or watery stools in a 24-hour period and dysentery was defined as stool with the presence of blood, based on World Health Organization definitions. In addition to measures of health, questions were asked to determine usage of the water and/or sanitation intervention, water acquisition, treatment, storage and use practices and to document sanitation and hygiene conditions and practices – all possible covariates of use in the analysis of diarrheal disease data.

Diarrheal disease burdens were estimated using longitudinal prevalence, or the proportion of total observed person-time with the disease outcome in individuals.[21] Longitudinal prevalence is a diarrheal morbidity measure that has been shown to be strongly correlated with risk of mortality in children under 5 years of age[22] and may be better correlated with nutritional status than incidence measures.[21,22] Longitudinal prevalence measures also possess practical and analytical advantages over incidence measures, since case frequency and duration data (often difficult to obtain) are not collected.[23,24] For these reasons, an increasing number of studies incorporate this measure in intervention trials.[25--27] Not all individuals were followed for the same amount of time in this closed cohort due to missing observations and loss to follow up; longitudinal prevalence estimates for individuals were based on up to 28 days of observation (recall time), with weighted estimates for those individuals contributing less follow up time. Because a seven day recall period was used at each household visit and no data were collected on case duration or frequency, the longitudinal prevalence calculation for individuals had a resolution of seven days.

Risk ratios (RRs) were computed for each intervention group against the control group via a Poisson extension of generalized estimating equations (GEE), adjusting for clustering of diarrheal disease outcomes within households and within individuals over time.[28,29] The GEE model assumed that missing observations were Missing Completely at Random (MCAR).[30] All statistical analyses were performed in Intercooled Stata 8.1 software (Stata Corporation, College Station, TX, USA). All potential measured confounders, including water use and handling practices, socio-economic status, and sanitation and hygiene-related factors, were assessed in the analytical model through a series of stepwise regression analyses with forward selection and backward elimination. Confounders were identified based on an *a priori* change-in-effect criterion of 10%.

Water quality data and analysis

Drinking water samples were collected from all households in the study at each visit. Households were sampled for at least two types of water: stored household water from control households or water as delivered via the household/yard tap for other households *and* stored, treated drinking water (usually, boiled water). If households used another source or treatment step for drinking water at the time of the visit, a sample of this water was also collected. The primary caregiver was asked to collect a sample of water in a sample collection container as if it were a household drinking cup. Free and residual chlorine were measured *at the time of sampling* in the field by colorimetric analysis. Samples were kept cool (4$^{o}$C) and transported as quickly as possible to the laboratory in Ho Chi Minh City (arriving by 9am the morning following sampling), where analysis was performed as soon as possible, in all cases within 24 hours of sample collection. Total coliforms (TC) and *Escherichia coli* were microbial indicators used in this study, using membrane filtration techniques and IDEXX Colilert® consistent with methods described in *Standard Methods for the Examination of Water and Wastewater*[12], with concentrations reported as colony-forming

[12] Eaton, A.D., Clesceri, L.S., Rice, E.W., Greenberg, A.E., Franson, M.A.H. (eds.) (2005) *Standard Methods for the Examination of Water & Wastewater*, 21st edn. American Public Health Association, American Water Works Association, Water Environment Federation.

units (cfu) per 100 mL. All samples were processed in duplicate using a minimum of two dilutions, three replicates each, with positive and negative controls. Turbidity and pH of the water samples were also measured.

Data collected for water quality and from household surveys were initially analyzed using stratified or tabular analysis to assess for trends (microbial concentrations and turbidity in water and diarrheal disease prevalence by group) and in the longitudinal phase of the study for differences between the three groups. Logistic regression models were used to analyze for differences in diarrheal disease longitudinal prevalence in user households compared to non-user households of the piped water system and improved sanitation. In addition, the data were stratified by covariates that were hypothesized to have had an effect on diarrheal disease such as SES, age, system type, presence of disinfection or other treatment. To determine correlation of water quality with health impact, water quality data was analyzed as a continuous variable initially. In addition, the water quality variable (e.g. *E. coli* bacteria concentration) was used as an ordinal variable based on standard levels of contamination (e.g., <1, 1-10, 11-100, 101-1000, 1001+ organisms per 100 ml) in GEE regression with diarrheal disease as the dependent variable.

Independence

As a critical program review, this technical assistance activity maintained important separation from EMW during data collection and analysis. Microbiological analyses were performed under WaterSHED supervision at a local lab co-located with EMW in Ho Chi Minh City and staffed with those unaffiliated with the original EMW implementation program. All household visits and subsequent data collection were performed by a team of local Vietnamese staff with training by both WaterSHED and EMW.

## Results & discussion

Water sources and user satisfaction

Households were asked to name their most important (usually, not the only) source of water during the wet and dry seasons (table 1). They were then asked to report whether they were "very satisfied", "satisfied", "unsatisfied", or "very unsatisfied" with their currently available choices. Problems cited by respondents included intermittent service in the piped water supply (100% reported this, table 2) and other factors. Control households did report good access to and satisfaction with some well water sources, which may explain why some chose not to connect to available systems.

Piped water in itself provides a valued service to users, since the alternative is collection of water outside the home, usually with non-negligible time and cost to households. Data presented in tables 5 and 6 show that respondents connected to piped water supply systems used significantly more water – which may be associated with better hygiene[13] – and paid less for it, both per liter and per month. In terms of meeting daily water needs, respondents valued the convenience of a household tap.

*Summary of water access*

- 70% of control households had access to "improved" water supply: a protected tube well
  - 47% were "unsatisfied" with the quality/quantity of water versus 19% of those connected to the piped water system
  - Only 1.3% of control households reported having enough water to meet basic needs
- All households stored some water in the home
  - Unsafe storage and unsafe water collection was observed, but equal between groups
- Control households paid approximately twice as much per $m^3$ for half to a third less water

Water storage

Due to intermittent service and the high proportion of those choosing to treat some drinking water, all households stored water at the household level in one or more containers. A variety of data on water collection, storage, and handling practices were recorded for each household (key data are presented in table 5). The data collection team noted whether one or more containers were uncovered at the time of the household visit and whether water was collected from storage containers via a tap or by pouring ("safe collection") or by dipping cups, hands, or some other utensil into the water ("unsafe collection"). No significant differences in water storage or handling were observed between the three groups.

[13] Clasen, T., Schmidt, W.P., Rabie, T., Roberts, I., and Cairncross, S. 2007. Interventions to improve water quality for preventing diarrhoea: systematic review and meta-analysis. *British Medical Journal* 334(7597):755-756.

| Group | Water sources in order of importance, dry season | Water sources in order of importance, rainy season | Reporting satisfied or very satisfied with quantity and/or quality of water |
|---|---|---|---|
| Control (no piped water or latrine) | Protected tube well (72%), protected shallow well (9.2%), unprotected shallow well (18%) | Protected tube well (69%), protected shallow well (9.2%), unprotected shallow well (17%), bottled water (1%), rain water (1%) | 53% |
| Piped water only | EMW piped water supply (96%), protected tube well (4%) | EMW piped water supply (92%), protected tube well (6.7%), protected shallow well (1%), unprotected shallow well (1%) | 82% |
| Piped water + sanitation | EMW piped water supply (98%), protected tube well (1%), protected shallow well (1%) | EMW piped water supply (95%), protected tube well (3.7%), protected shallow well (1%) | 80% |

Table 1. Water sources by season and overall satisfaction of sources available, by group.

| | Piped water | Piped water + improved sanitation | Control | Statistically significant difference between groups? |
|---|---|---|---|---|
| Households | 141 | 83 | 76 | Yes |
| Persons per household | 5.1 | 4.9 | 4.9 | No |
| Homeownership, % | 72% | 72% | 49% | Yes |
| Single parent household, % | 8.5% | 6.1% | 16% | Yes |
| Mean land owned or rented, *soa* | 1700 (95% CI 1400 - 2100)* | 1300 (95% CI 1000 - 1600)* | 1200 (95% CI 900 – 1400)* | No |
| Bedrooms in house | 2.2 | 1.7 | 2.1 | No |
| Mean electricity bill per month, VND | 77,000 (95% CI 65,000 – 88,000)* | 52,000 (95% CI 40,000 – 64,000)* | 65,000 (95% CI 53,000 – 77,000)* | No |
| Education of primary caregiver | | | | No |
| No school | 1.4% | 1.2% | 1.5% | |
| Primary school | 15% | 22% | 17% | |
| Some secondary school | 53% | 57% | 52% | |
| Secondary school | 21% | 16% | 20% | |
| Some university/technical or higher | 8.7% | 3.7% | 11% | |
| Education of household head | | | | No |
| No school | 1% | 1% | 1% | |
| Primary school | 29% | 39% | 20% | |
| Some secondary school | 22% | 18% | 23% | |
| Secondary school | 36% | 26% | 38% | |
| Some university/technical or higher | 12% | 16% | 18% | |
| House construction wealth indicators | | | | No |
| Sheet metal roof | 39% | 27% | 41% | |
| Earth floors | 3.6% | 3.7% | 12% | |
| Thatch or bamboo walls | 1.4% | 2.4% | 6.6% | |

Table 2. Summary of socioeconomic and demographic data for the three study groups.
*95% confidence intervals (CIs).

Demographics and socioeconomic data

Groups being compared were assessed for differences in demographics or socioeconomic status and some of the important measured variables are shown in table 2. These were measured as covariates in the analysis to examine the potential associations between dependent variables (diarrheal disease, household drinking water quality) and primary independent variables (study group, access to water and sanitation). No clear differences stand out between these groups, although some evidence points to control households being somewhat poorer (as indicated by key wealth-related variables) than those investing in EMW programs. No measured variables met criteria for confounding, however. One of the reasons for collecting these and other data is to assess targeting of programs and the possibility of refining the marketing approach of EMW and other providers of water and sanitation products and services. Although a variety of factors potentially related to increased adoption of or investment in water and sanitation were measured (table 2 presents a fraction of these), no hard conclusions are available from these data. Data from this study may be used in concert with other systematically collected data to better characterize drivers of demand for water and sanitation products and services in this population.

Water quality

*Summary of household drinking water quality*

- Households connected to a piped water supply had consistently improved drinking water quality over those relying on other sources, with a greater number and percentage of samples that meet definitions of “safe” or “low risk” water
- No differences in household drinking water quality were detected between households served with piped drinking water versus those who also invested in the EMW-sponsored sanitation intervention
- Although providing improved water quality over alternative sources, piped water systems still delivered an **unacceptably high level of microbial indicator bacteria (TC and *E. coli*), suggesting persistent fecal contamination**
    - US Standard: <1 TC/100ml; International guideline: <1 *E. coli*/100ml

Drinking water quality as measured by microbial counts of TC and *E. coli* were clearly related to study group and thus access to water and/or sanitation improvements, without accounting for other differences between groups (tables 3 and 4). When comparing *E. coli* data only, the intervention groups were not statistically meaningfully different, but both were over the control group data. This holds true for TC as well as the same microbial indicators in the boiled water samples (tables 3 and 4).

All households reported boiling some or all household drinking water and most were able to supply a sample during the household visit. Anecdotal evidence tells us that water may only be boiled for tea, and may only be consumed by certain members of the household at certain times (and critically, may not be for consumption by children).

| | Geometric mean total coliform (per 100ml) | Geometric mean *E. coli* (per 100ml) |
|---|---|---|
| Control | 1,500 (95% CI 1,000 – 2,300) | 74 (95% CI 50 – 110) |
| Piped water | 230 (95% CI 160 – 330) | 13 (95% CI 10 – 17) |
| Piped water + sanitation | 180 (95% CI 130 – 230) | 24 (95% CI 19 – 31) |

Table 3. Summary of household drinking water quality (not boiled).

| | Piped water | Piped water + improved sanitation | Control | Statistically significant difference between groups? |
|---|---|---|---|---|
| Untreated household water | | | | |
| Mean *E. coli* per 100ml (cfu) | 13 (95% CI 10 – 17) | 24 (95% CI 19 – 31) | 74 (95% CI 50 – 110) | Yes |
| Mean TC per 100ml (cfu) | 230 (95% CI 160 – 330) | 180 (95% CI 130 – 230) | 1500 (95% CI 1000 – 2300) | Yes |
| Boiled household water | | | | |
| Mean *E. coli* per 100ml (cfu) | 5.5 (95% CI 2.4 – 12) | 9.9 (95% CI 6.3 – 16) | 9.5 (95% CI 5.6 – 16) | No |
| Mean TC per 100ml (cfu) | 16 (95% CI 9.4 – 28) | 27 (95% CI 19 – 38) | 43 (95% CI 23 – 79) | No |
| Mean turbidity per 100ml (NTU) | 2.4 (95% CI 2.2 – 2.7) | 2.2 (95% CI 1.9 – 2.5) | 2.7 (95% CI 1.7 – 3.6) | No |
| % with boiled water in household at time of visit | 90% | 91% | 92% | No |
| % reporting intermittent service** | 100% | 100% | - | n/a |
| Residual chlorine in water | 0% | 0% | 0% | No |

Table 4. Water quality data by group, including boiled water samples.
*Mean was 1.8 outages per month reported (both groups)

No free or total chlorine residuals were detected in piped water samples from EMW-sponsored systems (detection limit: 0.1 mg/l) in over 1200 samples (table 4). An incomplete and unsystematic inspection of the treatment systems suggests that chlorine dosing is inconsistent and possibly also added too early in the treatment train at the sedimentation step (rather than directly before pumping to the distribution network) to avoid "chlorine taste in the water", which may be seen as highly objectionable in this population. A more careful examination of disinfection practices is therefore recommended to ensure that a disinfectant residual is maintained throughout the distribution system. These results, though showing that piped water systems are clearly delivering improved quality of water, indicate that microbial counts are still much too high to be considered "safe", defined variously as <1 cfu TC/100ml (USA), <1 cfu *E. coli*/100ml (WHO historical standard). Specifically, we recommend a Water Safety Plan approach to identifying and controlling risks to these systems, an approach that is outlined in the *Guidelines for Drinking-water Quality, 3rd Ed*.[14]. Because the delivery of safe water may be related to ongoing operation and maintenance issues (constrained by government-mandated maximum tariffs), a possible way forward would be the expanded coverage of household water treatment options in project areas.

[14] WHO (World Health Organization). 2006. WHO Guidelines for Drinking Water Quality, 3rd edition. Geneva: World Health Organization. Available online at http://www.who.int.

| | **Piped water** | **Piped water + improved sanitation** | **Control** | **Statistically significant difference between groups?** |
|---|---|---|---|---|
| All samples<br><1 cfu/100ml *E. coli* ("safe") | 88% | 76% | 79% | No |
| All samples<br><10 cfu/100ml *E. coli* ("low risk") | 95% | 88% | 88% | No |
| Water use per month (liters) | 4700 (95% CI 2600 – 4900) | 5600 (95% CI 5400 – 5800) | 1800 (95% CI 1100 – 2600) | Yes |
| Cost of water per month (USD) | 0.70 (95% CI 0.67 – 0.73) | 0.82 (95% CI 0.79 – 0.85) | 0.92 (95% CI 0.83 – 1.0) | Yes |
| Unsafe water storage | 53% | 49% | 39% | No |
| Unsafe water collection observed | 46% | 43% | 32% | No |
| Uncovered water storage | 8.4% | 8.8% | 9.2% | No |
| Mean liters treated/day | 6.6 (95% CI 5.9 – 7.3) | 7.3 (95% CI 6.7 – 7.9) | 6.0 (95% CI 5.4 – 6.6) | No |
| By boiling | 90% | 91% | 92% | No |
| By settling | 41% | 33% | 17% | Yes |
| By ceramic filter | 1.2% | 13% | 7.9% | Yes |
| Respondent cites health as primary motivation for water treatment (unprompted) | 64% | 45% | 58% | No |

Table 5. Key data on water access, water safety, and water handling across study groups.

| | Piped water | Piped water + improved sanitation | Control | Statistically significant difference between groups? |
|---|---|---|---|---|
| Water access (volume) meets daily needs | 65% | 72% | 1.3% | Yes |
| Can regularly taste chlorine in water | 14% | 17% | 0% | Yes |
| Access to a latrine | 99% | 97% | 99% | No |
| Handwashing reported "always" at critical points | 60% | 65% | 58% | No |
| Report washing with soap | 63% | 59% | 57% | No |
| Soap available in house at time of visit | 81% | 82% | 75% | No |

Table 6. Water, sanitation, and hygiene covariates.

Effects of system operation and treatment on household water quality

*Summary system operation and impacts on water quality*

- No difference in water quality among systems that chlorinate and do not
- Geometric mean *E. coli* /100 ml count in water with chlorination: 11 (95% CI 8.1 – 16) versus without: 13 (95% CI 9.1 – 18)
- 100% of connected households report intermittent service, a mean 1.8 times per month
- 0 samples positive for free chlorine (0.01 mg/l detection limit)
- Operators dosing chlorine at the beginning of the treatment train – not at the end
- Water system managers have no incentive to properly dose chlorine
    - They ultimately sell less water, leading to a loss in revenue (all connections are metered)
    - Negative feedback from consumers
- Chlorination was associated with less water use per month
    - 4100 (95% CI 3800 – 4400) liters per month (un-chlorinated) versus 3400 (95% CI 3100 – 3800) liters per month (chlorinated)
- 1 microbial water test required every 6 months

Tables 4, 5, and 6 provide a summary of key water quality statistics. Five of the seven water systems in this study employed chlorine disinfection (table 1), primarily at the beginning of the treatment train rather than at the end. As a result, no samples of water taken at the household level were positive for free chlorine (detection limit 0.01 mg/l). With no disinfectant residual, poor operation and maintenance can lead to system contamination and the delivery of unsafe water. In an analysis of the impact of chlorination as practiced in these systems on water quality as delivered, we did not detect a measurable difference in microbial counts between households in systems that received chlorination and those that did not (figure 4, mean 13 *E. coli*/100ml versus 11 *E. coli*/100ml). 100% of respondents indicated that intermittent service – a strong risk factor for system contamination – occurred regularly, an average of 1.8 times per month (all systems, pooled). Anecdotal evidence suggested that water operators did not have an incentive to maintain a disinfectant residual in the water delivery system due to a strong consumer dislike of chlorine taste in water; in fact, we found that systems that used chlorination sold significantly less volume of water per household, which could result in less revenue for operators. In these systems where microbiological quality monitoring is infrequent (every 6 months), maximum tariffs limit investment in other forms of water treatment/disinfection, and user distaste for disinfectant is widespread, alternative approaches to ensuring the safety of drinking water may hold promise. Among them is expanded coverage of household water treatment as a secondary step to protect consumers.

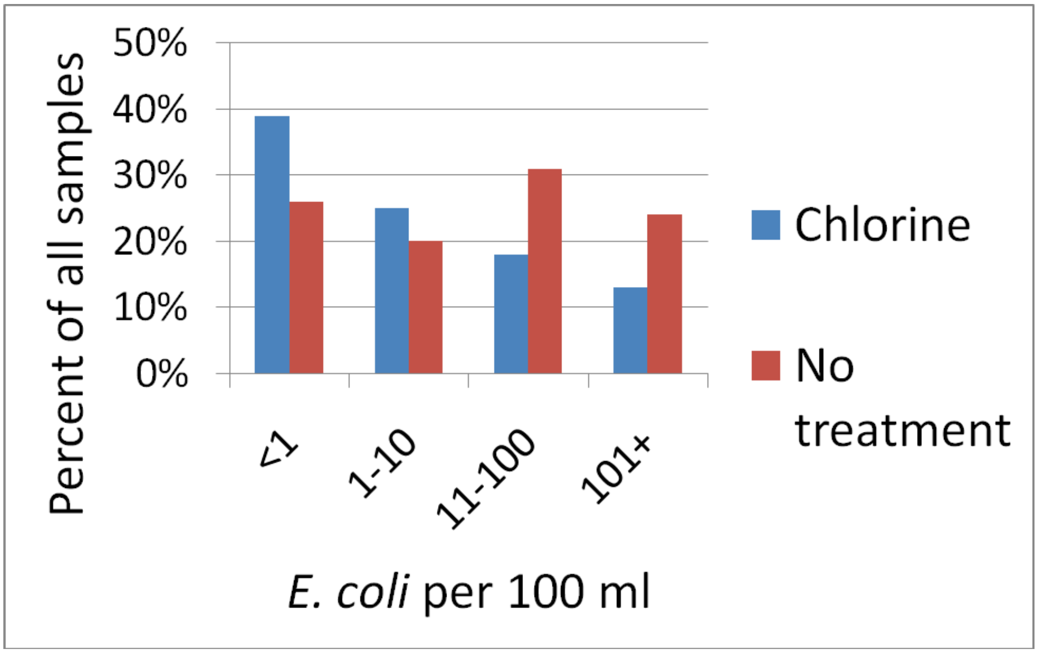

Figure 4. Chlorine disinfection impacts on water quality. Chlorination as practiced in these water systems did not impact water quality measures, including for *E. coli*.

Sanitation and hygiene covariates

A summary of key sanitation and hygiene data is presented in table 6. No significant differences were detected between groups on measured parameters. All three groups had high access to sanitation – the most common variety was a pour-flush latrine – and handwashing and soap access data were similar. A follow-on analysis to this activity is a careful examination of the differences in motivation and behaviors related to sanitation access in this population, particularly relating to the EMW sanitation program. These sanitation and hygiene data were not used as dependent variables in an analysis of health impacts but this may be a subsequent step in this activity.

Boiling

*Summary of boiling analysis*

- 90.2% of households had stored boiled water at the time of visit
    - 92% of control households, 90% of households with piped water, and 91% of households with piped water and sanitation
    - Clasen et al. 2008 reported 90.1% nationally
- Means liters treated = 7.2 liters per day, almost exclusively using wood as fuel
- Apart from drinking, 62% use boiled water for making formula or preparing food, 61% for washing/hygiene
- In practice, often used only for tea and may not represent the bulk of water used for drinking
- In this analysis we compared water samples from boiled and unboiled household drinking water
- Mean $\log_{10}$ reduction of *E. coli* = 2.1 (95% CI 1.7 – 2.6, n = 128), or **99%**
    - No difference between groups
- Mean $\log_{10}$ reduction of TC = 3.1 (95% CI 2.8 – 3.5, n = 373), or **99.9%**
    - No difference between groups
- These results suggest that boiling is an effective means of treating water, but that improper storage of boiled water in the household may result in post-treatment contamination
- Clasen *et al*. 2008 reported a mean 97% reduction in thermotolerant coliform (TTC) in a 12 week study of 50 households in Vietnam, so these results are consistent with at least one other study
- No significant difference in reported diarrhea between those who boil and those who do not

A majority of households in Vietnam boil or otherwise treat some or all drinking water[15], although there are two caveats: (i), often, boiled water is used to make tea or may only be used by certain members of the household, and (ii), it may not be stored or handled properly and therefore may be subject to recontamination after treatment. In this study, approximately 90% of households had stored, boiled water at the time of visit, and boiling water reduced microbes from 99% - 99.9% on average (figures 5 and 6 show the distribution of $\log_{10}$ reduction of *E. coli* and TC, which is a function of the untreated water quality as well as the efficacy of boiling). This is an important step in ensuring the safety of drinking water, although due to the high microbial counts in untreated water, households in this study may yet have been exposed to unsafe drinking water even after boiling. Tables 4 and 5 summarize key statistics on boiling. No clear association was detected between boiling of drinking water and reported diarrheal disease when controlling for study group and covariates.

In addition to boiling, two other water treatment practices were observed in a minority of households: use of ceramic filtration and allowing collected water to “settle” to reduce turbidity (table 5).

[15] Clasen et al. 2008 reported that 90.1% of Vietnamese households regularly practiced boiling some drinking water. Clasen, T.F., Thao, D.H., Boisson, S., and Shipin, O. 2008. Microbiological effectiveness and cost of boiling to disinfect drinking water in rural Vietnam. *Environmental Science and Technology* 42(12): 4255-4260.

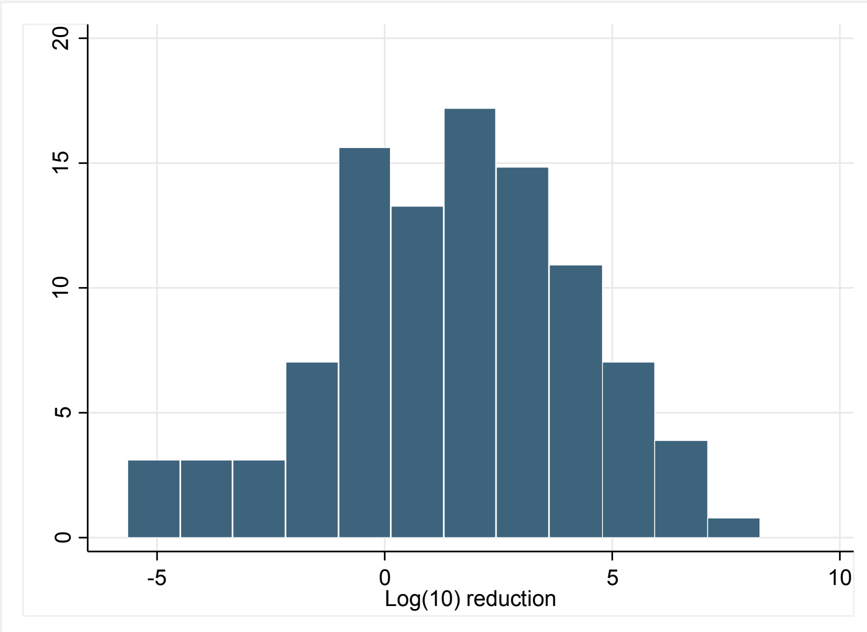


Figure 5. Household water treatment by boiling: $log_{10}$ reduction histogram for all paired samples, *E. coli*.

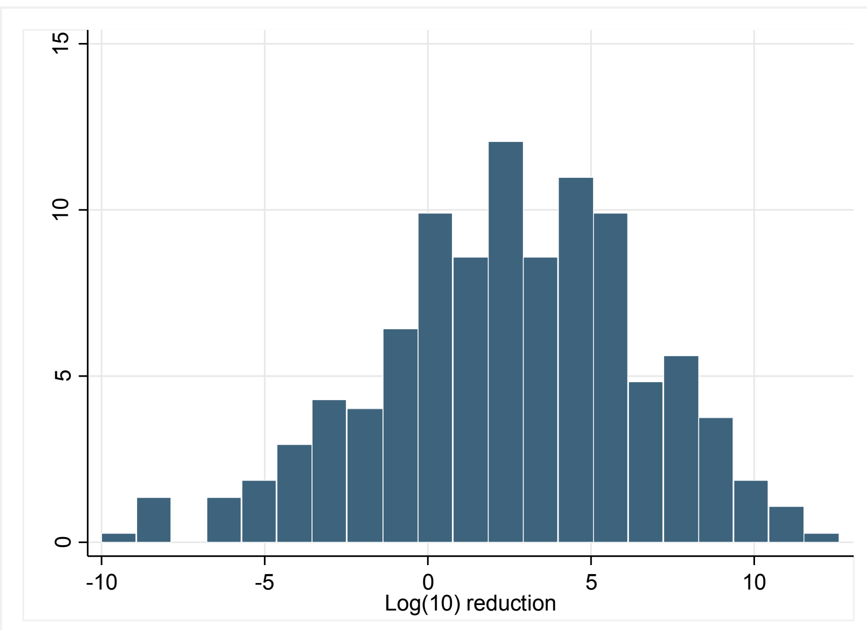


Figure 6. Household water treatment by boiling: $log_{10}$ reduction histogram for all paired samples, total coliform (TC).

Health impact

*Summary of health impact analysis*

- *The measure used was the risk ratio for diarrheal disease in last 7 days, controlling for clustering within households and within individuals over time*
- The group with access to piped water and improved sanitation reported significantly less (a mean 33% less) diarrhea than the control group: **RR = 0.77 (95% CI 0.62-0.95)**
- The group with access to piped water only reported significantly less diarrhea than the control group: **RR = 0.53 (95% CI 0.31-0.90)**
- No statistically significant difference was detected in comparing diarrheal disease between piped water with piped water + sanitation groups: RR = 1.1 (95% CI 0.64-1.8)
    - But the study was not sized to sort out this difference; more data would need to be collected to assess the relative health benefits of both improved water and sanitation over improvements in one or the other
- Bolded estimates (above) are statistically significant at the α = 0.05 level, indicated by the 95% CI excluding the null value of 1.0.
- There were no measured confounders based on the *a priori* 10% change in estimate of effect criterion when used in a backward-elimination model

Our analysis indicates that there was a clear health impact for households who were both connected to the piped water supply systems and had access to a pour-flush latrine over unconnected, control households, despite the fact that access to "improved" water and some form of sanitation was available to many control households. The group connected to the piped water systems (but without the EMW-sponsored pour-flush latrine) reported 33% less diarrheal disease (RR = 0.77 (95% CI 0.62 – 0.95)), and the group with access to piped water only reported 47% less diarrhea than the control group: RR = 0.53 (95% CI 0.31-0.90). No difference was detected between the two "intervention" groups (detection limit: 30%), probably because the study was not sized to detect this (probably smaller) difference. Also, this study was not sized to detect diarrheal disease differences between those under 5 years of age, a high-risk group for serious diarrhea-related outcomes. Statistical power generally was limited in this study since the prevalence of diarrheal disease in this population was already relatively low. Table 8 provides unadjusted estimates of longitudinal prevalence by study group and strata. In the backward elimination procedure for covariates to include in the GEE model, no significant adjustments were necessary based on *a priori* criteria.

Additionally, using water quality as the independent variable and controlling for study group, we assessed the relationship between categorical water quality data and diarrheal disease. No relationship was detected (table 9).

Although we did collect data on dysentery (diarrheal disease with blood), no cases were reported during this study.

| Diarrheal disease mean longitudinal prevalence, GEE | **Piped water** | **Piped water + improved sanitation** | **Control** |
|---|---|---|---|
| All people | **0.019** | **0.021** | **0.035** |
| Under 5s | 0.040 | 0.063 | 0.050 |
| Male | 0.016 | 0.018 | 0.032 |
| Female | 0.019 | 0.023 | 0.042 |
| Boiled water on hand | 0.013 | 0.026 | 0.044 |
| All samples <1 cfu/100ml *E. coli* | 0.015 | 0.027 | 0.042 |
| All samples <10 cfu/100ml *E. coli* | 0.015 | 0.026 | 0.040 |

Table 8. Unadjusted estimates of longitudinal estimates by study group and key strata.

| | **"Safe"** <1 *E. coli*/100ml | **Low risk** 1-10 *E. coli*/100ml | **Medium risk** 11-100 *E. coli*/100ml | **High risk** 101+ *E. coli*/100ml |
|---|---|---|---|---|
| Untreated water (stored or tap) | 1.0 (referent) | 0.85 (95%CI 0.48-1.5) | 1.1 (95% CI 0.89-1.4) | 1.0 (95% CI 0.87-1.2) |
| Treated water (stored) | 1.0 (referent) | 0.57 (95% CI 0.26-1.3) | 0.88 (95% CI 0.56-1.4) | 1.1 (95% CI 0.86-1.5) |

Table 9. Correlation between risk categories as indicated by *E. coli* counts in drinking water and diarrheal disease. No association was detected: stratum-specific estimates do not exclude the "no effect" value of 1.0.

**Conclusions**

This program has rapidly expanded access to improved quality drinking water, improved access to water (quantity, for all uses), and improved sanitation among poor populations of rural Vietnam. Results of this study suggest that these activities do have a measurable and significant impact on the health and quality of life of participating households. Specifically, households connected to piped water supply systems benefit from improved water quality, greater water quantity, and lower cost water. Individuals in connected households were also found to have a reduced risk of diarrheal disease over the study period when compared with unconnected households.

The health and other impacts of the EMW sanitation program were less clear from this study, since sanitation (including pour-flush sanitation) was widespread in these communities (even among controls). A subsequent analysis of qualitative data related to investment decision-making is forthcoming and may shed light on the relative advantages presented by EMW's sanitation program.

This study also suggests that maintaining drinking water quality is small supply systems is a challenge. Although systems resulted in improved water quality over other available sources, microbial counts in water samples were elevated. A number of other, related challenges were identified and described in this report.

**Recommendations for next steps: water quality**

Safeguarding water quality can result in greater health gains associated with small water systems. Possible next steps to address problems associated with water quality might be:

- A Water Safety Plan (WSP) approach to protecting water quality in piped systems

- Exploration of household water treatment options, including filtration technologies. Household water treatment (HWT) is already widely used by this population. One solution to explore would be the bundling of HWT with water connections or providing options to invest in decentralized water treatment. Because maximum water tariffs are externally mandated, fees for water quality products

- Increased monitoring by CPC and addition of water quality criteria to service agreements with operators