Water Practice & Technology Vol 16 No 1
doi: 10.2166/wpt.2020.097

Decentralization policies and clean water practitioners: using hollow fiber membrane water filters to reduce the prevalence of GI-related symptoms and diagnoses in rural Honduras

Colin Swearingen*, Rachel Schubert and Elizabeth Marcelli

Political Science, John Carroll University, University Heights, OH 44118, USA

*Corresponding author. E-mail: cswearingen@jcu.edu

Abstract

Illnesses caused by dirty water are still prevalent in developing countries, resulting in significant health problems. This study explores how hollow fiber membrane point-of-use filters can reduce the prevalence of gastrointestinal (GI)-related symptoms and diagnoses. We summarize the current approach and policies regarding clean water in Honduras, which is marked by decentralization, and note the resulting challenges for clean water provision. To highlight how this works in practice, we combine medical brigade diagnosis data with survey data to explore the effect of point-of-use water filters on the prevalence of GI-related symptoms and diagnoses in rural south-central Honduras. Using OLS and penalized logistic regression, we find that hollow fiber membrane filters are effective in reducing GI-related diseases. Specifically, they reduce the number of GI-related symptoms by 0.30, and specifically those patients complaining of stomach aches (39 percent), diarrhea (39 percent), and vomiting (70 percent). We also find that they reduce the likelihood of a patient receiving an infectious disease/parasitic diagnosis (48 percent in all patients and 87 percent in children under the age of 13 years). These results have significant implications on those working with non-profit and non-governmental organizations to bring clean water to those living in developing nations.

Key words: drinking water quality, GI symptoms, membrane filter, on-site water treatment, public health, water treatment

Highlights

- Hollow fiber membrane filters reduced the number of GI-related symptoms in patients by 0.30 ($p < 0.05$).
- The filters reduced the likelihood of complaining of stomach aches (39 percent), diarrhea (39 percent), and vomiting (70 percent, all results $p < 0.05$).
- They also reduced the likelihood of being diagnosed with an infectious or parasitic disease (48 percent for all patients and 87 percent for children, $p < 0.05$).

INTRODUCTION

Article 145 of the Honduran Constitution states that 'the right to health protection is recognized, the duty of all to participate in the promotion and preservation of personal and community health.' However, Honduras's health system is marked by weak governance, poor system management capacity, and rigid human resource administration, which all make it difficult to increase access to clean water (Carmenate-Milián *et al.* 2017). Further compounding the matter, roughly 20 percent of rural Hondurans earn less than US$1.90 per day (World Bank 2018). This status as a low- or middle-income country (LMIC) has serious ramifications on its public health situation, including how it

Water Practice & Technology Vol 16 No 1
doi: 10.2166/wpt.2020.097

implements public policies related to clean water. The World Health Organization (WHO) observed in 2009 that lack of clean water and improved sanitation were responsible for the deaths of 1,200 Hondurans per year (WHO 2009). Children under 5 years old are particularly susceptible to diarrhea and rotavirus, which from 2000 to 2004 was responsible for 222,000 clinic visits, 4,390 hospitalizations, and 162 in-hospital deaths within this age group (Girón *et al.* 2006).

Clean water is critically important to public health, where water related diseases are 'arguably the most manageable set of health problems affecting humans using existing technologies' (Deal *et al.* 2010, 15). Yet, these diseases are preventable and should be considered a major health priority (Prüss *et al.* 2002; Deal *et al.* 2010). Solving the issue of heavily contaminated water in developing countries is crucial in reducing gastrointestinal (GI) diseases in individuals of all ages. Moving forward, unless we are specifically referencing another author's findings or an ICD-10 classification, we refer to such diseases as GI-related.

The need for water filter distribution in Honduras, as well as in other developing countries, does not arise out of nothing. Relevant government policies play a key role in how water practitioners and various organizations operate. In our context, the Honduran health system emphasizes decentralization, which establishes national frameworks for service provision and delegates implementation to local governments. In 2003, the National Council for Drinking Water and Sanitation (CONASA) developed the Framework Law and Regulation of the Drinking Water and Sanitation Sector as part of the overall Strategic Plan for the Modernization of the Drinking Water Sector and Sanitation (PEMAPS) (RAS-HON *et al.* 2007). The law decentralized the country's water and sanitation sector (WSS) and set the national priorities and standards for these sectors (CONASA 2016). Effectively, the municipalities were given responsibility to manage their own water. One result of this decentralization is that 'local governments find it difficult to effectively balance the conflicting needs for affordability, expanded coverage to poorer communities, and the sector's need for financial viability' ('Decentralizing Water and Sanitation Services: The Honduras Experience' n.d.). Basically, the national government is failing to provide enough funding to the municipalities to manage their own water systems. This lack of funding means it will take a significant amount of time for the municipalities to build new water and sanitation systems as well as repair/maintain existing systems (Sano 2009).

Even though the Framework Law outlined its goal to decentralize the WSS, and to give management authority to the municipalities, there is not much evidence that the rural communities are receiving much support from either the municipality or the national government. Because of this, it can be seen that neither the municipalities, nor the rural communities, have the financial support, human knowledge, and resources that they need to support and build these water systems. It is difficult to say whether there is a benefit of decentralizing the WSS, considering the continuous lack of access to clean water and sanitation, specifically in rural Honduran communities (Sano 2009). Although help from international organizations is beneficial, it is a challenge to receive support from them on a regular basis, which makes water systems difficult to manage and repair as well.

The gap between the government's goals regarding clean water and reality is borne out in the statistics. According to the UN Water Global Analysis and Assessment of Sanitation and Drinking Water (GLAAS) data, in 2015, 91% of the total population had access to 'improved' water, 99% and 84% in urban and rural areas, respectively. The reality of these statistics is that over 700,000 people lack access to improved water sources (WHO 2017). Because of this, rural Hondurans heavily rely on external financing from governmental and non-governmental organizations to support decentralization and institutional framework and related utilities.

With the financial guidance from international organizations like the World Bank, the WHO, and the International Monetary Fund, many different groups around the world conduct medical brigades/mission trips in rural Honduras (see Martiniuk *et al.* 2012a, 2012b; Dainton *et al.* 2016).

Water Practice & Technology Vol 16 No 1
doi: 10.2166/wpt.2020.097

Organizations like *Shoulder to Shoulder*, *Global Brigades*, *Sociedad Amigos de los Niños*, and others try to fill the gaps in the Honduran health care system, including providing access to improved water sources. Some of these organizations and groups focus on building community-wide water systems (for instance, see https://www.waterbrigades.org/), while others focus on point-of-use water filters (for instance, see https://www.purewaterfortheworld.org/where-we-work/honduras/). To do so, they often coordinate with *juntas de agua y sanamiento* (JAS), which were established by the Framework Law to maintain and operate water systems in the rural areas. Within a few years of enactment of the Framework Law, nearly 5,000 of these community groups were created throughout (RAS-HON *et al.* 2007).

With non-profit and non-governmental organizations filling in the gaps created by government policy, the question becomes how practitioners can work to improve public health in developing countries. The public health literature makes it clear that point-of-use water filters can be a successful strategy to increase access to clean water (see Esrey *et al.* 1991; Clasen *et al.* 2007a, 2007b). Contaminated water can lead to various diseases and problems affecting an individual's GI system. Point-of-use water treatment can directly target communities that are most affected by various GI diseases and could play a role in rapidly decreasing the amount of fecal indicator bacteria (Rosa *et al.* 2014) and water borne diseases in individuals (Mintz *et al.* 2001; Lantagne *et al.* 2008). They can also be effective in reducing diarrhea (Arquiette *et al.* 2014), especially in those under the age of five (Clasen & Boisson 2006; Arnold & Colford 2007; Fink Günther & Hill 2011; Halder *et al.* 2013; Wolf *et al.* 2014). Such successes would be meaningful in a country like Honduras, where children under the age of five are expected to experience 18.6 episodes of diarrhea each year (Halder *et al.* 2013). In particular, point-of-use chlorine water treatment could reduce child diarrhea by almost 30%, in combination with safe storage, education, and sanitation practices (Arnold & Colford 2007; Sobsey *et al.* 2008). Finally, a study conducted in 12 Honduran villages concluded that the prevalence of parasites decreased in subjects in communities where a multistage or sand filter and chlorination water treatment system existed (26.4% tested positive), compared to subjects from communities where such systems had yet to be installed (35.9% tested positive) (Deal *et al.* 2010).

Another important component factoring into the success of point-of-use filters is that they are generally efficient, easily accessible, and cost effective in developing countries (Arnold & Colford 2007; Clasen *et al.* 2007a, 2007b; Halder *et al.* 2013). They are also flexible in terms of the materials used, including bleach, flocculants, adsorption, filtration, boiling, or solar disinfection (Zwane & Kremer n.d.; Sobsey *et al.* 2008). In studying the effectiveness of point-of-use chlorine water treatments in developing countries, Arnold & Colford (2007) found that chlorine treatments reduced diarrheal episodes in children in the majority of the studies that were systematically reviewed, demonstrating that there is a positive effect between chlorine water treatments and a reduction in diarrheal diseases (see also Sobsey *et al.* 2008). A number of studies report similar findings for ceramic filters (Clasen *et al.* 2004, 2005).

Hollow fiber membrane water filters pose some benefits over chlorine treatments or other point-of-use filters. Not only are they effective at removing bacteria such as *Escherichia coli* (Murray *et al.* 2017) as other treatments do, they also are effective in reducing turbidity, suspended solids, and direct particle counts (Jacangelo *et al.* 1989). Furthermore, they can have better water flow than other types of point-of-use filters, particularly ceramic pot filters (see Salvinelli & Elmore 2015).The study breaks new ground by examining the efficacy of a hollow fiber membrane filter in reducing self-reported GI symptoms, as well as infectious and parasitic disease diagnoses in rural villages in south-central Honduras. Furthermore, the reality of external organizations helping to provide clean water to rural Hondurans means that practitioners need to be generally aware of the policies and structures of the Honduran water system. Thus, we explore the importance of partnering with village health councils and community leaders in leading to the long-term benefits of point-of-use filters.

Water Practice & Technology Vol 16 No 1
doi: 10.2166/wpt.2020.097

METHODS

Patients attended one-day brigades across ten unique villages in the years 2016, 2018, and 2019. Brigade locations were determined by *Sociedad Amigos de los Niños* (*SAN*) and the researchers based upon their perceived health care needs and access to suitable transportation. Any resident of the community or a nearby community was welcomed to attend the brigade. When patients arrived at the brigade, they were given a sheet of paper, which was completed as they progressed through the brigade stations. These intake sheets included information on each patient's vitals, past medical history, and medical diagnoses. After visiting with a doctor, patients went to the pharmacy, where they receive their prescribed medications. While waiting in line at the pharmacy, patients were asked to complete a health survey and provided with informed consent information. This survey, administered in Spanish, asks about key household health factors, including access to improved sanitation and water filter usage. In this case, improved sanitation is defined by the WHO as sanitation that 'hygienically separates human excreta from human contact' and includes pour-flush latrines, ventilated pit latrines, and pit latrines with a slab. We note that this definition does not include hand washing or other personal hygiene (WHO n.d.).

Both the intake sheets and health survey (approval numbers 2012-089, 2016-082, and 2018-065) were approved by our institution's IRB, as there is no formal method for obtaining ethics approval from Honduran officials. As such, this study adheres to the guidelines put forth by the U.S. Department of Health and Human Services Office for Human Research Protections. All patient information was anonymized and only aggregate-level data were generated in order to protect confidentiality.

Our sample encompasses individuals of all ages. We analyze the patient data in two groups: all patients ($n = 1,040$) and those under the age of 13 whose parents answered the survey questions ($n = 408$). Our explanatory variables focus on clean water, which we operationalize three different ways. The first is whether the patient used any point-of-use water filter, whether purchased by someone in the household or donated by an outside organization. The second is whether the patient's water was chlorinated. This generally takes place where a community's water is stored, such as in large concrete water tanks.

The final measure is whether the patient was using a previously provided hollow fiber membrane point-of-use water filter provided by our team (Figure 1). These filters are attached to a 5-gallon bucket (which was provided to patients) via a tube. Using gravity, the water flows through the tube before running through a 0.1-micron absolute filter, which removes 99.99 percent of bacteria, protozoa, and microorganisms. The filtered water meets US EPA drinking water standards related to removing protozoa and bacteria. It does not filter viruses, nor is it guaranteed to be effective in removing chemicals. One filter can provide up to 150 gallons of clean water each day if properly maintained. Maintaining the filter requires taking a syringe of clean water and backflushing the filter until all dirt/debris is removed (Filter of Hope n.d.). Individuals using these filters were trained by fellow Hondurans on how to use and maintain their filters. We also left additional supplies, such as tubing and syringes, with community leaders.

Each clean water measure is operationalized where 0 = the patient did not use this method to clean their water and 1 = the patient did use this method to clean their water. In each model, we included the general point-of-use filter and chlorinated water variables. We then ran the same model replacing those variables with the hollow fiber membrane point-of-use filter (with training) variable. In Tables 1–3, where we report the coefficient and statistical significance for the hollow fiber membrane point-of-use filter (with training), the *n*-size is smaller than the full model because these filters were distributed in 2018–2019.

We use three dependent variables: the total number of GI-related symptoms documented for each patient and a dichotomous measure for each of these six symptoms (where 0 = patient did not have

Water Practice & Technology Vol 16 No 1
doi: 10.2166/wpt.2020.097

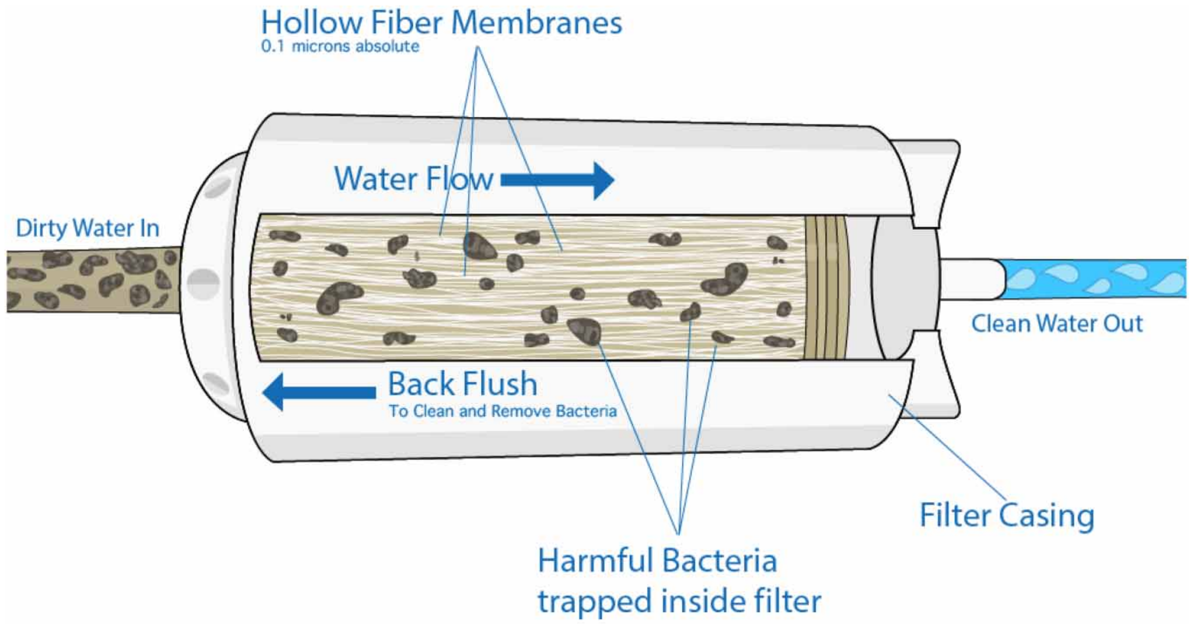

Figure 1 | Diagram of the hollow fiber membrane water filter.

Table 1 | Descriptive statistics for continuous variables

	All patients					
Variable	**Minimum**	**Maximum**	**Median**	**Mean**	**S.D.**	**n**
GI symptoms	0	6	1	0.83	1.07	3,212
Age (years)	0.08	102	16	24.95	21.93	3,203
Recent doctor visit (months)	0	864	4	10.39	46.41	2,846
	Children under 13					
Variable	**Minimum**	**Maximum**	**Median**	**Mean**	**S.D.**	**n**
GI symptoms	0	6	1	0.88	1.11	1,388
Age (years)	0.08	12	6	6.36	3.56	1,388
Recent doctor visit (months)	0	144	4	7.14	15.58	1,224
	Children 5 & under					
Variable	**Minimum**	**Maximum**	**Median**	**Mean**	**S.D.**	**n**
GI symptoms	0	6	0	0.86	1.13	596
Age (years)	0.08	5	3	2.83	1.50	596
Recent doctor visit (months)	0.03	84	3	4.97	7.98	528

that symptom and 1 = patient did have that symptom). The six symptoms include a stomachache, diarrhea, vomiting, parasites, no appetite, and nausea. The last dependent variable is whether or not the patient was diagnosed with an infectious disease (ID) or parasite by the examining physician. This ID/parasitic classification is based on the ICD-10 standard and is operationalized as 0 = the patient was not diagnosed with an ID/parasitic disease and 1 = the patient was diagnosed with an ID/parasitic disease. Because the first dependent variable is continuous, we use OLS regression for its analyses. For the dichotomous dependent variables, we use a penalized logistic regression due to the presence of perfectly separated observations (see Firth 1993). All analyses were conducted in R 3.6.0 using the *Rcmdr* and *brglm2* packages.

Water Practice & Technology Vol 16 No 1
doi: 10.2166/wpt.2020.097

Table 2 | Frequencies for dichotomous variables

Variable	Percent		
	All patients	Children under 13	Children 5 & under
Stomach ache			
Yes	38.67	34.58	23.99
No	61.33	65.42	76.01
Diarrhea			
Yes	8.25	11.02	16.78
No	91.75	88.98	83.22
Vomiting			
Yes	6.88	9.15	10.91
No	93.12	90.85	89.09
Parasites			
Yes	10.8	11.38	10.23
No	89.2	88.62	89.77
No appetite			
Yes	12.83	17.44	20.3
No	87.17	82.56	79.7
Nausea			
Yes	5.11	3.96	3.52
No	94.89	96.04	96.48
Improved sanitation			
Yes	40.13	40.04	38.63
No	59.87	59.96	61.37
Chlorinated water supply			
Yes	46.88	48.78	46.85
No	53.12	51.22	53.15
Point-of-use filter (general)			
Yes	22.23	21.02	21.62
No	77.77	78.98	78.38
Point-of-use filter (training)[a]			
Yes	31.57	31.69	25.93
No	68.43	68.31	74.07
Sex			
Male	33.74	48.95	55.57
Female	66.26	51.05	44.43
Potable water			
Yes	58.78	58.10	
No	41.22	41.90	

[a]Point-of-use filter (training) is a subset of patients. For all patients, $n = 662$, whereas for point-of-use filter (general), $n = 1,201$.

We include numerous control variables in our models, two of which are continuous: age (measured in years) and the number of months since the patient last saw a doctor or medical professional. The rest of the controls are dichotomous and include whether the patient's home has potable water (0 = no, 1 – yes), and the patient's sex, where 0 = male or 1 = female. We also control for whether or not the patient has direct access to improved sanitation. This variable is operationalized dichotomously, where 0 = the patient did not have access to improved sanitation and 1 = the patient did have access

Water Practice & Technology Vol 16 No 1
doi: 10.2166/wpt.2020.097

Table 3 | Factors explaining the number of GI symptoms in patients

Variables	All patients	Under 13 years old	5 years old & under
Household health factors			
Point-of-use filter (general)	0.01	0.10	−0.22
Hollow fiber membrane filter (with training)	**−0.30**	−0.32	−0.31
Chlorinated water	−0.09	0.04	0.12
Potable water	0.10	**0.22**	0.15
Improved sanitation	−0.07	*− 0.17*	*− 0.28*
Individual controls			
Recent doctor visit	**0.00**	0.00	0.02
Age	−0.00	0.00	*0.08*
Sex	*0.12*	−0.00	−0.00
Villages			
El Pedregal	0.01	−0.36	0.21
El Suyatillo	**− 0.71**	**− 1.22**	−0.66
El Tenidero	−0.29	−0.61	−0.01
La Lima	−0.26	−0.12	0.70
Lomas Limpias	**− 0.54**	**− 0.97**	−0.48
Nuevo Paraiso	**− 0.59**	–	–
Ocobas	**− 0.49**	**− 0.83**	−0.30
Terrero Blanco	−0.05	−0.45	0.51
Valle Arriba	−0.02	*− 0.51*	0.08
Other			
Intercept	**0.99**	**1.34**	0.67
F-Statistic	**5.49**	**2.46**	**2.20**
N	1,056	423	195
Adjusted R-square	0.06	0.05	0.09

Dependent variable is the number of GI symptoms mentioned for each patient. Coefficients in bold indicate statistical significance at $p < 0.05$ or greater. Coefficients in italics indicate statistical significance at the $p < 0.10$ level. One-tailed test where hypothesized.

to improved sanitation. We also included whether the patient has access to chlorinated water (0 = no, 1 = yes). Finally, we control for the brigade location; Corral Falso is used as the reference category, thus its coefficient is captured in the intercept.

RESULTS AND DISCUSSION

Among all patients, the median number of reported GI symptoms was 1, with a mean reporting of 0.83, a maximum reporting of 6 and a minimum reporting of 0 (see Table 1). The median age of the patients seen is 16 years and the mean is 24.95 years, with the maximum age of 102 and a minimum age of 0.08 years. In all patients, the median number of months in between doctor visits is 16 and the mean is 10.39. In children under the age of 13, the median number of GI symptoms is 1 and the mean is 0.88, where the maximum number of reported symptoms is 6 and the minimum is 0. The median age of children under the age of 13 is 6, with a mean of 6.36, a maximum age of 12, and a minimum age of 0.08. The median number of months in between doctor visits for children under 13 is 4, with a mean of 7.14, a maximum of 144, and a minimum of 0. Lastly, in children 5 and under, the median number of GI symptoms is 0, with a mean of 0.86, a maximum of 6, and a minimum of 0. The median age is 3, with a mean of 2.83, a maximum of 5, and a minimum of

0.08. In children that are 5 and under, the median number of months between doctor visits is 3, with a mean of 4.97, a maximum of 84, and a minimum of 0.03.

In terms of frequencies related to our dependent, explanatory, and control variables, 38.67% had reported a stomach ache GI symptom, in comparison to 34.58% of children under the age of 13 and 23.99% of children 5 and under (see Table 2). Children that are 5 and under have the highest percentages for the GI symptoms of diarrhea and vomiting in comparison to children under 13 and all patients, where 16.78% had reported a diarrhea GI symptom, and 10.91% had reported a vomiting symptom. Just over 40% of all patients use improved sanitation measures, including 40.04% of children under 13, and 38.63% of children 5 and under. We also note that the filter with training variable is a subset of patients, which is why there are higher percentages in all of the age group categories in the training variable, in comparison to the general variable. For example, in all patients, 31.57% indicate they use the hollow fiber membrane point-of-use filter and received training, in comparison to only 22.23% of individuals who use a general point-of-use filter. Lastly, 58.78% of all patients used a potable water source, including 58.10% of children under the age of 13.

Moving on to testing the effects of clean water and improved sanitation on a patient's total number of GI symptoms (Table 3), we see that using hollow fiber membrane point-of-use filters in addition to training were associated with a reduction in total GI symptoms. Specifically, those patients using these filters were expected to have 0.3 fewer GI symptoms than those who were not using them. Patient location is a key factor in understanding GI symptoms. The villages analyzed for this study belong to one of two Honduran departments and are all within a 90-minute bus ride from our host site. Beyond the similarities of geographic proximity and socioeconomic level, they differ in many ways: political and social organization, elevation, and proximity to health facilities and non-farm jobs. That these communities face slightly different public health problems should not be surprising. Patients from El Suyatillo, Lomas Limpias, Nuevo Paraiso, and Ocobas typically experience fewer GI symptoms compared to the reference village (Corral Falso). Combining location with hollow fiber membrane water filters and training can make a substantive difference in GI symptoms. For instance, patients in El Suyatillo, who received water filters and training three months before our 2019 brigade, were expected to have one fewer GI symptom than patients in the reference village (0.71 fewer symptoms associated with being from El Suyatillo plus 0.30 fewer symptoms associated with using a hollow fiber membrane water filter and training).

Next, we examined total GI symptoms within two groups of children. Among patients under 13 years old, the results are fairly similar. Although the clean water variables were not statistically significant, location matters. Patients in El Suyatillo, Lomas Limpias, and Ocobas were experienced fewer GI symptoms as did those with potable water. Among those 5 years old and younger, the results change. Here, none of the variables was statistically significant, although access to improved sanitation was significant at the $p < 0.1$ level.

This latter finding is particularly curious as potable water is expected to be safe to drink. In some ways, this could be similar to chlorine not reducing the number of GI-related symptoms. There are a few explanations for this. First, decentralization means that communities have the authority to establish *juntas de agua*. Yet, these water councils will vary in effectiveness. In some communities we visited, the water council was very organized; in others, the council was disorganized. The variation in organization could have significant effects on a community's public health, especially as it related to clean water. Second, some communities had trouble procuring chlorine for their water systems. Without chlorine, residents simply have access to potable water but they must find another way to purify it. Third, water infrastructure is problematic in nearly every community we visited. In most cases, water flows from a tank located in or near the community to households through a series of tubes. It is common to find small holes or perforations in these tubes, which can allow for contamination between the tank and households and thus diminishes the quality of water throughout the community.

Water Practice & Technology Vol 16 No 1
doi: 10.2166/wpt.2020.097

The models are more robust when explaining the presence of specific GI symptoms. Tables 3–5 use penalized logistic regression models to explain dichotomous dependent variables. The numbers in the cells represent odds ratios and bolded numbers indicate statistical significance. Each of the models has a significant model chi-square with one exception ('No appetite' in Table 5).

The specific symptoms for all patients are examined in Table 4. Based on the literature reviewed above, we expected access to clean water to reduce GI symptoms. The clean water results were mixed. Chlorinated water does not reach a statistically significant threshold in any of the models, although it comes close ($p < 0.10$) in half of them. General point-of-use filters were not associated with reducing GI symptoms at all. In fact, patients with these filters were almost twice as likely to complain of having parasites than those without them. Part of this could be due to when these filters were first used. In one village, Flor Azul, residents were supplied with a ceramic point-of-use filter in 2016, three years before we distributed the hollow fiber membrane filters. Over the intervening period, it is possible that the effectiveness of these filters was reduced due to poor handling, maintenance, or training. Yet, the results were markedly different for patients using hollow fiber membrane filters and had received training. Such patients were 0.61 times as likely to complain of stomach aches and diarrhea; complaints of vomiting were reduced by 70 percent. This indicates that providing thorough training along with a hollow fiber membrane point-of-use water filter is more successful in reducing GI symptoms than relying on chlorinated water or the other point-of-use filters being used in these villages.

Table 4 | Effect of improved sanitation and clean water on gastrointestinal symptoms, all patients

Variables	Stomach-ache	Diarrhea	Vomiting	Parasites	No appetite	Nausea
Household Health Factors						
Point-of-use filter (general)	1.04	0.64	0.62	**1.80**	0.72	*0.62*
Hollow fiber membrane filter (with training)	**0.61**	**0.61**	**0.30**	0.70	0.76	1.20
Chlorinated water	1.12	0.98	*0.66*	*0.70*	0.79	*0.66*
Potable water	1.14	1.07	1.48	1.30	0.97	1.34
Improved sanitation	1.02	0.74	0.90	0.92	**0.66**	1.15
Individual controls						
Recent doctor visit	**1.01**	1.00	1.00	1.00	1.00	1.00
Age	1.00	**0.98**	**0.98**	1.00	**0.98**	**1.02**
Sex	*1.32*	0.83	1.01	1.36	1.08	**2.72**
Villages						
El Pedregal	0.80	5.88	0.56	1.09	1.55	0.28
El Suyatillo	**0.28**	0.75	0.14	0.12	0.25	0.23
El Tenidero	0.55	4.67	0.76	0.27	0.63	1.73
La Lima	**0.39**	*15.83*	1.88	2.69	1.25	1.79
Lomas Limpias	**0.30**	1.63	**0.18**	**0.21**	**0.18**	1.25
Nuevo Paraiso	**0.18**	5.70	0.30	0.92	0.57	0.36
Ocobas	**0.31**	2.92	0.28	*0.06*	0.43	0.53
Terrero Blanco	**0.44**	8.34	0.81	1.21	1.04	1.17
Valle Arriba	**0.48**	5.32	1.06	1.63	1.02	0.94
Other						
Intercept	1.02	**0.03**	**0.17**	**0.08**	*0.39*	**0.02**
Model chi-square	**43.63**	**57.72**	**44.93**	**78.98**	**60.24**	**38.11**
n	1,056	1,056	1,056	1,056	423	1,056

Dependent variables are dichotomous, where 0 = child did not have a particular symptom and 1 = child had the symptom.
Odds ratios presented in the cells. Bolded odds ratios indicate statistical significance at $p < 0.05$ or higher, one-tailed test where hypothesized. Italicized cells indicate statistical significance at $p < 0.10$.

Water Practice & Technology Vol 16 No 1
doi: 10.2166/wpt.2020.097

Table 5 | Effect of improved sanitation and clean water on gastrointestinal symptoms, children under 13 years old

Variables	Stomachache	Diarrhea	Vomiting	Parasites	No appetite	Nausea
Household health factors						
Point-of-use filter (general)	1.31	1.43	0.59	**2.59**	0.99	**0.07**
Hollow fiber membrane filter (with training)	0.61	0.61	0.90	0.37	0.73	1.28
Chlorinated water	1.41	1.25	0.88	0.80	0.99	0.48
Potable water	1.35	1.34	*1.86*	**2.14**	1.13	1.14
Improved sanitation	1.23	*0.59*	**0.46**	0.73	**0.43**	**7.62**
Individual controls						
Recent doctor visit	1.01	1.01	**1.02**	1.00	0.99	1.00
Age	**1.13**	**0.79**	**0.90**	1.01	0.97	1.01
Sex	0.94	0.71	0.90	0.98	1.20	**3.46**
Villages						
El Pedregal	**0.22**	2.44	0.20	0.70	2.32	0.14
El Suyatillo	**0.13**	0.38	0.07	0.07	0.32	3.86
El Tenidero	0.20	3.10	0.73	0.22	0.95	0.84
La Lima	**0.15**	5.59	1.23	1.12	2.41	1.35
Lomas Limpias	**0.12**	0.72	**0.07**	**0.12**	0.24	2.29
Ocobas	**0.11**	2.03	0.19	*0.05*	0.70	0.43
Terrero Blanco	**0.11**	5.66	0.51	0.43	1.05	0.54
Valle Arriba	**0.19**	1.99	0.47	0.48	0.79	0.35
Other						
Intercept	0.9	0.18	0.48	**0.17**	0.44	**0.01**
Model chi-square	**37.08**	**42.26**	**33.30**	**29.10**	23.09	**26.61**
n	423	423	423	423	423	423

Dependent variables are dichotomous, where 0 = child did not have a particular symptom and 1 = child had the symptom.
Odds ratios presented in the cells. Bolded odds ratios indicate statistical significance at $p < 0.05$ or higher, one-tailed test where hypothesized. Italicized cells indicate statistical significance at $p < 0.10$.

As with the total number of GI symptoms, location made a difference in a patient's proclivity to have a particular symptom, for similar reasons as stated above. Those in El Suyatillo were less likely to have stomach aches, as were those in La Lima, Lomas Limpias, Nuevo Paraiso, Ocobas, Terrero Blanco, and Valle Arriba. Patients in Lomas Limpias were also less likely to complain of vomiting, parasites, and a lack of appetite. In terms of individual-level controls, older patients were less likely to have diarrhea, vomiting, and a loss of appetite, but more likely to have nausea. Lastly, women were over twice as likely to complain of nausea than men. Improved sanitation was statistically significant only in the 'No appetite' model, where patients with access to improved sanitation were 0.66 times as likely to complain of this symptom than those without access.

In examining children under the age of 13 (Table 3), improved sanitation reduces some GI symptoms. Children with access to improved sanitation were 0.46 times as likely to complain of vomiting, 0.43 times as likely to lose their appetite, and 41% less likely to experience diarrhea ($p < 0.10$ for this last finding). However, improved sanitation was also associated with an increased likelihood of nausea. The results were also mixed for clean water access. Having a point-of-use filter was associated with a decrease in nausea (93% less likely to have that symptom). Yet a general point-of-use filter also led to being more likely to complain of parasites. Finally, hollow fiber membrane point-of-use filters with training led to no statistically discernible change in GI symptoms.

Among children under 13 years old, location played a smaller role in explaining specific GI symptoms than it did among all patients. Patients in many villages were less likely to complain of having a stomach ache compared to the reference village, but beyond that, only patients in Lomas Limpias

Water Practice & Technology Vol 16 No 1
doi: 10.2166/wpt.2020.097

were less likely to experience vomiting and parasites. Age played a significant role for some symptoms, as older children were more likely to have stomach aches but less likely to complain of diarrhea and vomiting. Finally, girls were more than three times as likely as boys to list nausea as a symptom.

In addition to collecting information about symptoms at our medical brigades, each patient is examined by a doctor, who indicates which, if any, diagnoses are present. Patients can receive multiple diagnoses, although some are given a clean bill of health. Table 6 provides the results of our model for whether or not a patient was diagnosed with an ID/parasitic disease. Both models (all patients, children under the age of 13) have a statistically significant model chi-square. Importantly for our analysis, there is strong evidence that hollow fiber membrane water filters decrease the chances of an individual being diagnosed with an ID/Parasitic disease. Patients who received our training with their point-of-use water filter saw their odds of an ID/parasitic diagnosis drop by 48 (all patients) and 87% (children).

Table 6 | Factors explaining ID/parasitic diagnoses

Variables	All patients	Under 13 years old
Household health factors		
Point-of-use filter (general)	*1.51*	1.51
Hollow fiber membrane filter (with training)	**0.52**	**0.13**
Chlorinated water	*0.76*	*0.58*
Potable water	0.82	0.82
Improved sanitation	*0.74*	**0.53**
Individual controls		
Recent doctor visit	1.00	1.01
Age	**1.01**	*0.92*
Sex	1.22	1.09
Villages		
El Pedregal	4.27	1.62
El Suyatillo	**7.55**	2.36
El Tenidero	0.58	0.77
La Lima	**11.04**	*11.72*
Lomas Limpias	3.53	2.20
Ocobas	*4.72*	2.14
Terrero Blanco	**7.78**	3.82
Valle Arriba	2.36	2.36
Other		
Intercept	**0.04**	0.11
Model chi-square	**69.67**	**34.30**
N	1,056	423

Dependent variable is dichotomous, where 0 = child was not given an ID/parasitic diagnosis and 1 = child was given an ID/parasitic diagnosis. Odds ratios presented in the cells. Bolded odds ratios indicate statistical significance at $p < 0.05$ or higher, one-tailed test where hypothesized. Italicized cells indicate statistical significance at $p < 0.10$.

Improved sanitation also played a significant role in reducing ID/parasitic diagnoses. Specifically, patients with improved sanitation are 0.74 (all adults, $p < 0.10$) and 0.53 (children) times as likely to have such a disease as those without access. Similarly to the previous models, age and location were important to understanding the dependent variable. Older patients were slightly more likely to receive an ID/parasitic diagnosis than younger ones. Patients in El Suyatillo (7.55 times), La Lima (11.04

Water Practice & Technology Vol 16 No 1
doi: 10.2166/wpt.2020.097

times), and Terrero Blanco (7.78 times) were significantly more likely to get such a diagnosis than others.

CONCLUSIONS

The purpose of this study was to assess the efficacy of hollow fiber membrane water filters. According to our results and discussion, these filters, in conjunction with training, are effective in reducing GI symptoms. They are particularly effective in reducing complaints of stomach aches compared to not having the filter (39% less likely), diarrhea (39% less likely) and vomiting (70% less likely). They are also effective in reducing the likelihood of an ID/parasitic diagnosis among all patients (48% less likely) and especially so for children under 13 years old (87% less likely). This has significant ramifications for practitioners, namely, that they invest time in training village water councils, community leaders, and those receiving filters.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

REFERENCES

Arnold, B. F. & Colford, J. M. 2007 Treating water with chlorine at point-of-use to improve water quality and reduce child diarrhea in developing countries: a systematic review and meta-analysis. *The American Journal of Tropical Medicine and Hygiene* **76**(2), 354–364.

Arquiette, J., Stevens, M. P., Rabb, J. M., Sanogo, K., Mason, P. & Bearman, G. M. L. 2014 Clinical and microbiologic efficacy of a water filter program in a rural Honduran community. *Advances in Public Health* **2014**. https://doi.org/10.1155/2014/734254.

Carmenate-Milián, L., Herrera-Ramos, A., Ramos-Cáceres, D., Lagos-Ordoñez, K., Lagos-Ordoñez, T. & Somoza-Valladares, C. 2017 Situation of the health system in Honduras and the new proposed health model. *Archives of Medicine* **9**(4), 1.

Clasen, T. & Boisson, S. 2006 Household-based ceramic water filters for the treatment of drinking water in disaster response: an assessment of a pilot programme in the Dominican Republic. *Water Practice and Technology* **1**(2). https://doi.org/10.2166/wpt.2006031.

Clasen, T. F., Brown, J., Collin, S., Suntura, O. & Cairncross, S. 2004 Reducing diarrhea through the use of household-based ceramic water filters: a randomized, controlled trial in rural Bolivia. *The American Journal of Tropical Medicine and Hygiene* **70**(6), 651–657. https://doi.org/10.4269/ajtmh.2004.70.651.

Clasen, T., Parra, G. G., Boisson, S. & Collin, S. 2005 Household-based ceramic water filters for the prevention of diarrhea: a randomized, controlled trial of a pilot program in Colombia. *The American Journal of Tropical Medicine and Hygiene* **73**(4), 790–795. https://doi.org/10.4269/ajtmh.2005.73.790.

Clasen, T., Haller, L., Walker, D., Bartram, J. & Cairncross, S. 2007a Cost-effectiveness of water quality interventions for preventing diarrhoeal disease in developing countries. *Journal of Water and Health* **5**(4), 599–608. https://doi.org/10.2166/wh.2007.010.

Clasen, T., Schmidt, W.-P., Rabie, T., Roberts, I. & Cairncross, S. 2007b Interventions to improve water quality for preventing diarrhoea: systematic review and meta-analysis. *BMJ* **334**(7597), 782. https://doi.org/10.1136/bmj.39118.489931.BE.

CONASA 2016 *Segundo Informe de Monitoreo de Los Avances de País En Agua Potable y Saneamiento – Mapas II*. Available from: http://conasa.hn/wp-content/uploads/2017/09/MAPAS-II-Honduras-small-version.pdf.

Dainton, C., Chu, C. H., Lin, H. & Loh, L. 2016 Clinical guidelines for western clinicians engaged in primary care medical service trips in Latin America and the Caribbean: an integrative literature review. *Tropical Medicine & International Health* **21**(4), 470–478.

Deal, J. L., Nazar, S., Delaney, R., Sorum, M., Leatherman, T., Gijsbert van Vliet, N. F., Greene, G. & Wolf, P. 2010 'A multidimensional measure of diarrheal disease load changes resulting from access to improved water sources in Honduras. *Practicing Anthropology* **32**(1), 15–20.

'Decentralizing Water and Sanitation Services: The Honduras Experience' n.d. Text/HTML. World Bank. Available from: https://projects.worldbank.org/en/results/2017/10/30/decentralizing-water-and-sanitation-services-the-honduras-experience (accessed 1 June 2020).

Water Practice & Technology Vol 16 No 1
doi: 10.2166/wpt.2020.097

Esrey, S. A., Potash, J. B., Roberts, L. & Shiff, C. 1991 Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis, and trachoma. *Bulletin of the World Health Organization* **69**(5), 609–621.

Filter of Hope. n.d. Clean water filter. Available from: https://filterofhope.org/why-filters/ (accessed 8 June 2020).

Fink, G., Günther, I. & Hill, K. 2011 The effect of water and sanitation on child health: evidence from the demographic and health surveys 1986–2007. *International Journal of Epidemiology* **40**(5), 1196–1204. https://doi.org/10.1093/ije/dyr102.

Firth, D. 1993 Bias reduction of maximum likelihood errors. *Biometrika* **80**(1), 27–38.

Girón, S., Orlando, J., Molina, I. B., Turcios-Ruiz, R. M., Quiroz Mejia, C. E., Amendola, L. M., de Oliveira, L. H., Andrus, J. K., Stupp, P. W., Bresee, J. S. & Glass, R. I. 2006 Burden of diarrhea among children in Honduras, 2000–2004: estimates of the role of rotavirus. *Revista Panamericana de Salud Pública* **20**, 377–384.

Halder, G. E., Bearman, G., Sanogo, K. & Stevens, M. P. 2013 Water sanitation, access, use and self-reported diarrheal disease in rural Honduras. *Rural and Remote Health* **13**(2), 2413.

Jacangelo, J. G., Marco Aieta, E., Cams, K. E., Cummings, E. W. & Mallevialle, J. 1989 Assessing hollow-fiber ultrafiltration for particulate removal. *Journal AWWA* **81**(11), 68–75. https://doi.org/10.1002/j.1551-8833.1989.tb03309.x.

Lantagne, D. S., Blount, B. C., Cardinali, F. & Quick, R. 2008 Disinfection by-product formation and mitigation strategies in point-of-use chlorination of turbid and non-turbid waters in Western Kenya. *Journal of Water and Health* **6**(1), 67–82. https://doi.org/10.2166/wh.2007.013.

Martiniuk, A. L. C., Adunuri, N., Negin, J., Tracey, P., Fontecha, C. & Caldwell, P. 2012a Primary care provision by volunteer medical brigades in Honduras: a health record review of more than 2,500 patients over three years. *International Journal of Health Services: Planning, Administration, Evaluation* **42**(4), 739–753. https://doi.org/10.2190/HS.42.4.i.

Martiniuk, A. L. C., Manouchehrian, M., Negin, J. A. & Zwi, A. B. 2012b Brain gains: a literature review of medical missions to low and middle-income countries. *BMC Health Services Research* **12**(May), 134. https://doi.org/10.1186/1472-6963-12-134.

Mintz, E., Bartram, J., Lochery, P. & Wegelin, M. 2001 Not just a drop in the bucket: expanding access to point-of-use water treatment systems. *American Journal of Public Health* **91**(10), 1565–1570. https://doi.org/10.2105/ajph.91.10.1565.

Murray, A. L., Stewart, B., Hopper, C., Tobin, E., Rivera, J., Mut-Tracy, H., Stewart, P., Tobin, C., Goeb, M., Meub, C. & Lantagne, D. S. 2017 Laboratory efficacy and field effectiveness of hollow fiber membrane microfilters used for household water treatment in Honduras. *Journal of Water, Sanitation and Hygiene for Development* **7**(1), 74–84. https://doi.org/10.2166/washdev.2017.156.

Prüss, A., Kay, D., Fewtrell, L. & Bartram, J. 2002 Estimating the burden of disease from water, sanitation, and hygiene at a global level. *Environmental Health Perspectives* **110**(5), 537–542.

RAS-HON, SANAA, CONASA, and WSP 2007.

Rosa, G., Majorin, F., Boisson, S., Barstow, C., Johnson, M., Kirby, M., Ngabo, F., Thomas, E. & Clasen, T. 2014 Assessing the impact of water filters and improved cook stoves on drinking water quality and household air pollution: a randomised controlled trial in Rwanda. *PLOS ONE* **9**(3), e91011. https://doi.org/10.1371/journal.pone.0091011.

Salvinelli, C. & Elmore, A. C. 2015 Assessment of the impact of water parameters on the flow rate of ceramic pot filters in a long-Term experiment. *Water Supply* **15**(6), 1425–1432. https://doi.org/10.2166/ws.2015.107.

Sano, Y. 2009 '*Water Management Decentralization in Rural Honduras*.' Oregon State University, Corvallis, OR.

Sobsey, M. D., Stauber, C. E., Casanova, L. M., Brown, J. M. & Elliott, M. A. 2008 Point of use household drinking water filtration: a practical, effective solution for providing sustained access to safe drinking water in the developing world. *Environmental Science & Technology* **42**(12), 4261–4267. https://doi.org/10.1021/es702746n.

WHO 2009 *Honduras*. World Health Organization. Available from: https://www.who.int/quantifying_ehimpacts/national/countryprofile/honduras.pdf.

WHO 2017 *Honduras*. UN.

WHO n.d. Key terms. Accessed June 1, 2020. http://www.who.int/water_sanitation_health/monitoring/jmp2012/key_terms/en/.

Wolf, J., Prüss-Ustün, A., Cumming, O., Bartram, J., Bonjour, S., Cairncross, S., Clasen, T., Colford Jr, J. M., Curtis, V., De France, J., Fewtrell, L., Freeman, M., Gordon, B., Hunter, P. L., Jeandron, A., Johnston, R., Mausezahl, D., Mathers, C., Neira, M. & Higgins, J. P. T. 2014 Systematic review: assessing the impact of drinking water and sanitation on diarrhoeal disease in low- and middle-income settings: systematic review and meta-regression. *Tropical Medicine & International Health* **19**(8), 928–942. https://doi.org/10.1111/tmi.12331.

World Bank. 2018 Overview. Available from: https://www.worldbank.org/en/country/honduras/overview.

Zwane, A. P. & Kremer, M., n.d. *What Works in Fighting Diarrheal Diseases in Developing Countries? A Critical Review*. p. 48.