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Water, sanitation, and diarrhea incidence among children: evidence from Guatemala

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Abstract

Using household survey data for Guatemala, this paper investigates the role of water and sanitation infrastructure on diarrhea incidence in children. Hierarchical logit models of diarrhea incidence are estimated to account for potential regional heterogeneity of water and sanitation effects. Results indicate that the incidence probability of diarrhea is on average 20% lower in homes connected to a sewerage system. The effect of in-home access to tap water is weaker at 11% and subject to regional heterogeneity. Findings also indicate that consumption of bottled water reduces the incidence probability of diarrhea by 20–22%. In-home water treatments have no effect on incidence of diarrhea. Policy implications are discussed.

Keywords: Diarrheal incidence; Guatemala; Morbidity; Sanitation; Tap water; Treatment

1. Introduction

Diarrheal diseases caused primarily by unsafe water supply and inadequate sanitation are the second leading cause of child mortality in developing countries, responsible for approximately 1.87 million deaths among children under 5 years of age annually (Prüss-Üstün *et al.*, 2004; Boschi-Pinto *et al.*, 2008). In Guatemala, for instance, diarrheal diseases accounted for 7% of deaths and 8% of disability-adjusted life years among children under 5 years of age in 2012 (World Health Organization (WHO) Global Burden of Disease, 2012). The prevalence of diarrhea is alarming in Guatemala with approximately 30% of Guatemalan children suffering from diarrhea, about 35% in rural areas and 25% in urban centers (Gragnolati & Marini, 2003; World Bank, 2009). Under these circumstances, it is policy relevant to identify interventions that are more effective in reducing the prevalence of diarrhea among children in Guatemala, a developing country with one of the highest infant mortality rates in Latin America at 26.5 per 1,000 live births in 2012, below Haiti, Guyana and Bolivia only (Gragnolati & Marini, 2003; World Bank Indicators, 2012).

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Given that diarrheal diseases are often associated with quality and availability of water, investments in potable water infrastructure are expected to reduce the prevalence of diarrhea and, in turn, child mortality (Keusch *et al.*, 2006). Similarly, child health is expected to improve from investing in sanitation infrastructure given that a majority of pathogenic agents causing diarrhea in children are transmitted through contaminated water via the fecal-oral route (Esrey *et al.*, 1991; Cairncross & Valdmanis, 2006; Keusch *et al.*, 2006). In Guatemala, the provision of tap water and sanitation services are still far from universal, particularly in rural areas (WHO-United Nations Children's Fund (UNICEF), 2014; Vásquez, 2014), and consequently investments in water and sanitation infrastructure seem appropriate to reduce diarrhea incidence. Comparing the effectiveness of water and sanitation may help prioritize public investments in infrastructure, especially in a country with limited resources and where child mortality is still a primary concern such as Guatemala.

This article compares the effectiveness of water access and sanitation services in Guatemala using hierarchical logit models that account for potential regional heterogeneity of water and sanitation effects. Our inclusion of sanitation services in the analysis contributes to a meager number of studies on sanitation and its impact on diarrheal diseases, relative to other water infrastructure studies (Fewtrell *et al.*, 2005; Waddington *et al.*, 2009). Our results suggest that sanitation services are effective in reducing the incidence probability of diarrhea by approximately 20%, while the effect of access to piped water in the home is weaker and heterogeneous across regions in Guatemala. Results also suggest that consumption of bottled water is associated with a reduction in the incidence probability of diarrhea of 20–22%. In contrast, in-home water treatments (i.e. boiling and treating water with chlorine) seem to be ineffective in reducing diarrhea incidence.

2. Methodology

The data used in this study come from the 2006 Living Standards Measurement Survey referred to as Encuesta Nacional de Condiciones de Vida 2006 (ENCOVI). Owing to its sampling design, ENCOVI is representative at the national level. ENCOVI followed a two-stage strategy to select representative samples of households in 44 sampling areas: rural and urban areas in 22 departments. The first stage consisted of a stratified sampling procedure implemented in each sampling area to classify primary sampling units (PSUs) according to unsatisfied basic needs indicators. PSUs in urban areas were classified in five strata (very low, low, medium, medium high, and high), and rural PSUs were classified in four strata (low, medium, medium high, and high). In the second stage, two secondary sampling units consisting of clusters of an average of six households were selected. A total of 13,686 households were interviewed, providing information on diarrhea incidence for 11,176 children aged 5 years or younger. Specifically, sampled households reported whether children had suffered a diarrheal episode in the last month. Sampled households also provided information on access to water and sanitation infrastructure, as well as information about their water practices.

Given the binary response of households regarding prevalence of diarrhea among their children in the last month (i.e. Yes or No), depicted by the indicator DIARRHEA (see its definition in Table 1), logit models for diarrhea incidence may seem suitable to investigate health effects of water and sanitation infrastructure. However, it is likely that considerable geographical heterogeneity exists in terms of service characteristics and related health policies and programs. Water governance approaches vary between rural and urban areas, with rural households receiving tap water primarily from

Table 1. Variables definition and descriptive statistics ($n = 11{,}176$).

Variable	Description	Mean	S.D.
DIARRHEA	If the child had diarrhea in the last month (1 = Yes, 0 = Otherwise)	0.316	0.465
TAPWATER	If the house is connected to water system (1 = Yes, 0 = Otherwise)	0.698	0.459
SANIT	If the house is connected to wastewater system (1 = Yes, 0 = Otherwise)	0.274	0.446
TREATED	If the household treats water at home (1 = Yes, 0 = Otherwise)	0.510	0.500
BOIL	If the household boils water at home (1 = Yes, 0 = Otherwise)	0.378	0.485
CHLORINE	If the household treats water with chlorine at home (1 = Yes, 0 = Otherwise)	0.122	0.327
FILTER	If the household filters water at home (1 = Yes, 0 = Otherwise)	0.009	0.096
BOTTLED	If the household consumes bottled water (1 = Yes, 0 = Otherwise)	0.141	0.348
FEMALE	Sex of the child (1 = Female, 0 = Male)	0.492	0.500
AGE	Age of the child (in years)	2.614	1.718
HHSIZE	Household size	6.596	2.724
RURAL	If the child lives in a rural area (1 = Yes, 0 = Otherwise)	0.671	0.470
SPANISH	Primary language spoken at home (1 = Spanish, 0 = Otherwise)	0.712	0.453
EXTPOOR[a]	If the household is extremely poor (1 = Yes, 0 = Otherwise)	0.231	0.421
POOR[a]	If the household is poor (1 = Yes, 0 = Otherwise)	0.429	0.494

[a]The national poverty lines are based on annual consumption of household. The extreme poverty line is established at 3,206 quetzals (US$ 414), and the non-extreme poverty line is at 6,574 quetzals (US$ 848).

community based water organizations, and urban households being served mainly by municipalities (Vásquez, 2014). Coverage, quality, and reliability of tap water and sanitation infrastructure may also differ between urban and rural areas and across the 22 departments within Guatemala. These regional differences may cause heterogeneity in the effects of water and sanitation infrastructure on diarrhea incidence among children.

Hierarchical logit models are suitable to investigate tap water and sanitation effects on diarrhea incidence in the presence of regional heterogeneity. Given the sampling strategy applied in ENCOVI, we implement two-level logit estimation with unstructured covariance between random effects. At the first level, the indicator DIARRHEA_{ij} takes the value of one if child i in sampling area j experienced diarrhea in the month prior to the survey implementation. Otherwise DIARRHEA_{ij} takes the value of zero. In the second level, we account for regional heterogeneity by allowing coefficients of a subset of covariates to vary across the 44 sampling areas. The two-level logit models are specified as follows:

$$\text{logit}\,(p_{ij}) = X_{ij}\beta + Z_{ij}u_j + e_{ij} \tag{1}$$

where $p_{ij} = \Pr(\text{DIARRHEA}_{ij} = 1)$, X is the vector of factors associated with diarrhea incidence, Z is a subset of factors assumed to have heterogeneous effects across sampling areas, and e is the error term that follows a logistic distribution. β is a conformable vector of relevant coefficients to be estimated. Those coefficients depict fixed effects of corresponding factors on diarrhea incidence. u_j is a set of random effects that depict regional heterogeneity across sampling areas.

Table 1 presents the definitions of factors included in vector X. These factors include the binary indicators TAPWATER and SANIT that take the value of one if the child has access to water and sanitation infrastructure, and zero otherwise. Water availability, even if it is of poor quality, may reduce contamination of food, utensils, and hands. Hand washing after handling children's feces and before food preparation is associated with reduced incidence of diarrhea (Curtis *et al.*, 2000; Curtis & Cairncross, 2003; Luby *et al.*, 2004a). Consequently, diarrhea is expected to be less prevalent in households with access to tap water than in households who have to gather water from sources outside the home (Cairncross & Valdmanis, 2006). Sanitation infrastructure is also expected to reduce diarrhea prevalence because it interrupts the fecal–oral route through which children are exposed to pathogenic agents causing diarrhea by preventing fecal contamination of water bodies (see Haller *et al.*, 2007). Given regional differentials in service governance, system reliability and water treatment, TAPWATER and SANIT are also included in vector Z to investigate potential heterogeneity of infrastructure effects on diarrhea incidence across sampling areas.

The binary indicators TREATED, BOIL, CHLORINE, FILTER, and BOTTLED are also included to control for the primary drinking water source of the household. The incidence of diarrhea among children is expected to decrease with in-home water treatments, as pathogenic agents associated with diarrhea can be killed by boiling, chlorinating, and filtering water (Quick *et al.*, 1999; Reller *et al.*, 2003; Clasen *et al.*, 2007). Also, under the assumption that bottled water has been properly treated before its distribution, consuming bottled water may help reduce the incidence of diarrhea. In addition, socio-demographic variables are included to control for the heterogeneity of children and their households (FEMALE, AGE, HHSIZE, RURAL, SPANISH, EXTPOOR, and POOR). The effects of those variables remain to be empirically estimated.

3. Survey and estimation results

The descriptive statistics presented in Table 1 provide an average profile of sampled children. Approximately 49% of sampled children were females. On average, children were 2.61 years of age, living in households of more than six members. More than 67% of sampled children lived in rural areas. A significant percentage of sampled children lived in poverty (almost 43%) or extreme poverty (more than 23%). More than 71% of sampled children lived in a home whose primary language was Spanish. Table 1 also shows that the provision of water and sanitation services is far from universal. Less than 70% of sampled children lived in a household with access to piped water, and only 27.4% had access to sanitation services. Approximately 35% of children lived in households who reported primarily drinking water without treating it at home, approximately half of the sample reported treating water at home for drinking purposes, and just over 14% of children lived in households who reported primarily drinking bottled water. Boiling water was the most popular in-home treatment, followed by treating water with chlorine.

Under those circumstances, it is not surprising to observe a national diarrhea incidence rate of almost 32% (see Table 1). Figure 1 shows considerable variation in diarrhea incidence across sampling areas, with higher incidence rates in rural areas compared to urban areas. The lowest incidence rate (15%) is observed in urban areas of two departments in the east of the country, Jutiapa and Zacapa. A majority of the 22 departments have a diarrhea incidence of 20–30% in their urban areas, and only five departments have an urban incidence rate above 30%. In contrast, in rural areas, a vast majority of the departments show a diarrhea incidence between 30 and 40%, five departments have an incidence of 25–30%, and three departments reach an incidence rate of more than 40%. The lowest rural incidence rate is observed in the department of Guatemala (where the capital city is located) at 25%, and the highest rate is at 46% in the southern department of Suchitepéquez.

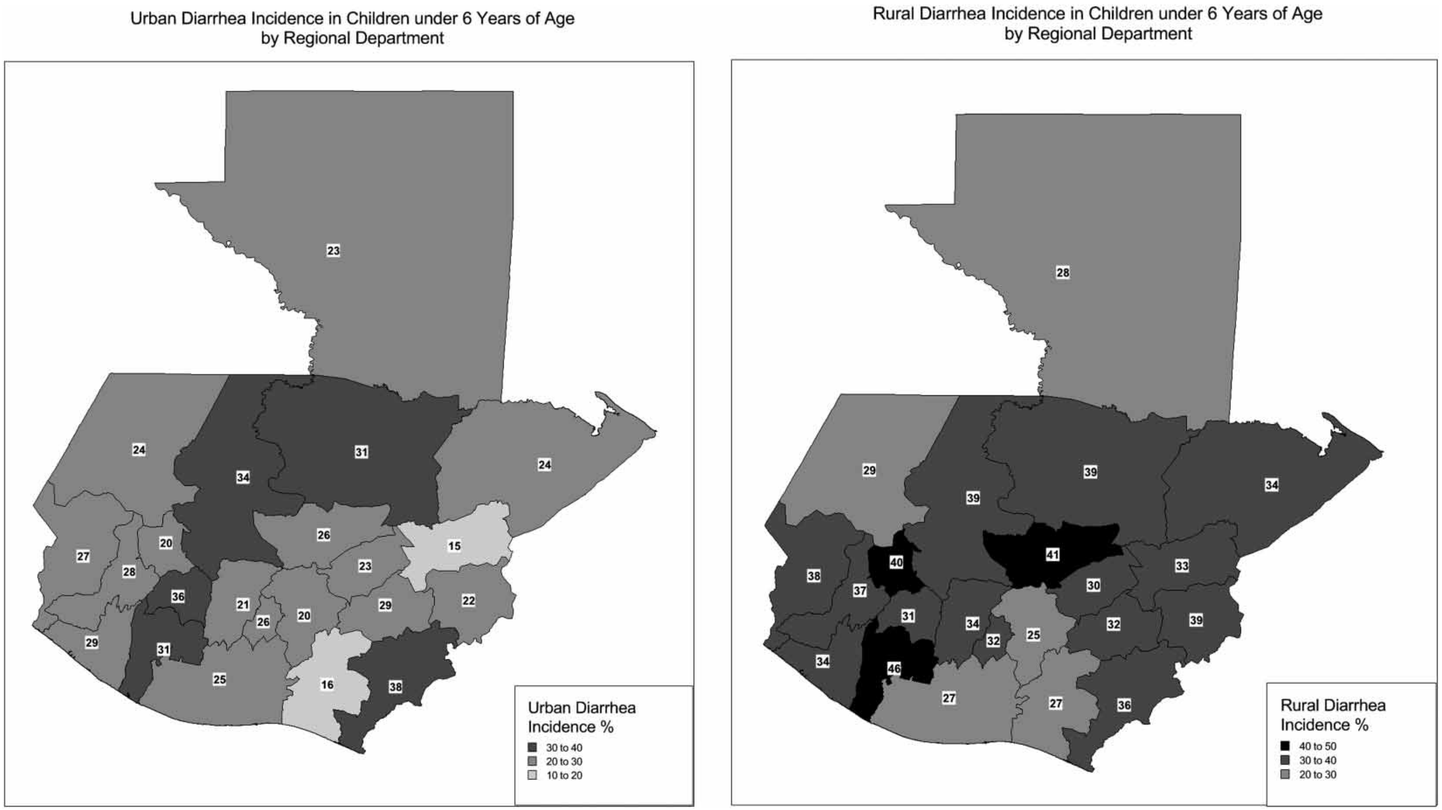

Fig. 1. Diarrhea incidence in children under 6 years of age by sampling areas (*Source:* ENCOVI).

Figure 2 presents tap water coverage indicators by sampling area. There are notable differentials in tap water coverage among sampling areas, with rural areas in clear disadvantage relative to urban areas. Most departments show a coverage rate of more than 90% in urban areas. Five departments have an urban coverage of 80–90%, and only four departments have a rate below 80%. The departments of San Marcos and Quiché show the lowest coverage in urban areas at 76%. Tap water coverage is lower in rural areas, with only one department, Sololá, above 90%. There are eight departments with a rural coverage rate of 70–80%, eight departments with a rural coverage rate of 50–70%, and five departments where less than 50% of rural households have access to tap water. The department of Alta Verapaz shows the lowest rural coverage rate at 31%. In addition to heterogeneity in coverage, prior studies have indicated that service governance, system reliability and water quality also differ across regions (Galindo & Molina, 2007; Vásquez, 2014). That heterogeneity may affect the effectiveness of water infrastructure in reducing diarrhea incidence among children.

The coverage of sanitation is alarming, particularly in rural areas, as demonstrated in Figure 3. In urban areas, four departments show a sanitation coverage rate of more than 80%, nine departments have a coverage rate of 60–80%, and eight departments are at a coverage rate of 30–60%. The department of Petén has the lowest urban coverage rate at 15%. On the other hand, the rural sanitation coverage rate is lower than 20% in 18 out of the 22 departments. The scenario is not much better in the departments of Suchitepéquez and Chimaltenango where sanitation services are provided to 24% and 20% of rural households, respectively. Sacatepéquez is the only department where sanitation is provided to more than 50% of rural households, followed by the department of Guatemala that has a coverage rate of 45%.

Table 2 provides a comparison of diarrhea incidence between households with water and sanitation infrastructure and households who do not have access to those services. The diarrhea incidence among children without access to tap water is 36.2%. The incidence decreases by 6.6% for children with access to tap water. Within urban areas, the difference in diarrhea incidence for households with and without tap water is statistically insignificant, while it is significant for rural households at 4.2%. The difference between children with and without sanitation services is greater (10.4%) than that for access to tap water. The difference in diarrhea incidence for households with and without sanitation infrastructure is also statistically significant in both urban and rural areas (7.8% and 5.6% respectively). Given that approximately 90% of households in urban areas have tap water, but far fewer have sanitation coverage, it can be argued that the marginal returns of extending sanitation exceed those of extending tap water access in urban areas. Marginal returns to extending either service are potentially high in rural areas that have low coverage of both services.

Table 3 presents six models estimated to investigate the effects of water and sanitation infrastructure on the prevalence of diarrhea among children aged 5 years or younger. In Models 1, 3, and 5, in-home water treatments are represented by a single binary indicator (i.e. TREATED). In Models 2, 4, and 6, in-home water treatments are disaggregated in three indicators (i.e. BOIL, CHLORINE, and FILTER) to explore potential differentials in the effectiveness of corresponding treatments. Models 1 and 2 follow a logit specification under the assumption that there is no regional heterogeneity that can affect estimated coefficients. In Models 3 and 4, we allow for random effects in the intercept across the 44 sampling areas. In Models 5 and 6, we further allow for random effects in TAPWATER and SANIT. Likelihood ratio tests indicate that hierarchical models outperform logit model specifications (see Table 3). Likelihood ratio tests also favor Model 5 over Model 3 ($\chi^2 = 19.35$, $p = 0.0017$), and Model 6 over Model 4 ($\chi^2 = 18.39$, $p = 0.0025$), suggesting that water and sanitation infrastructure have random effects on diarrhea incidence due to regional heterogeneity. Estimated coefficients are

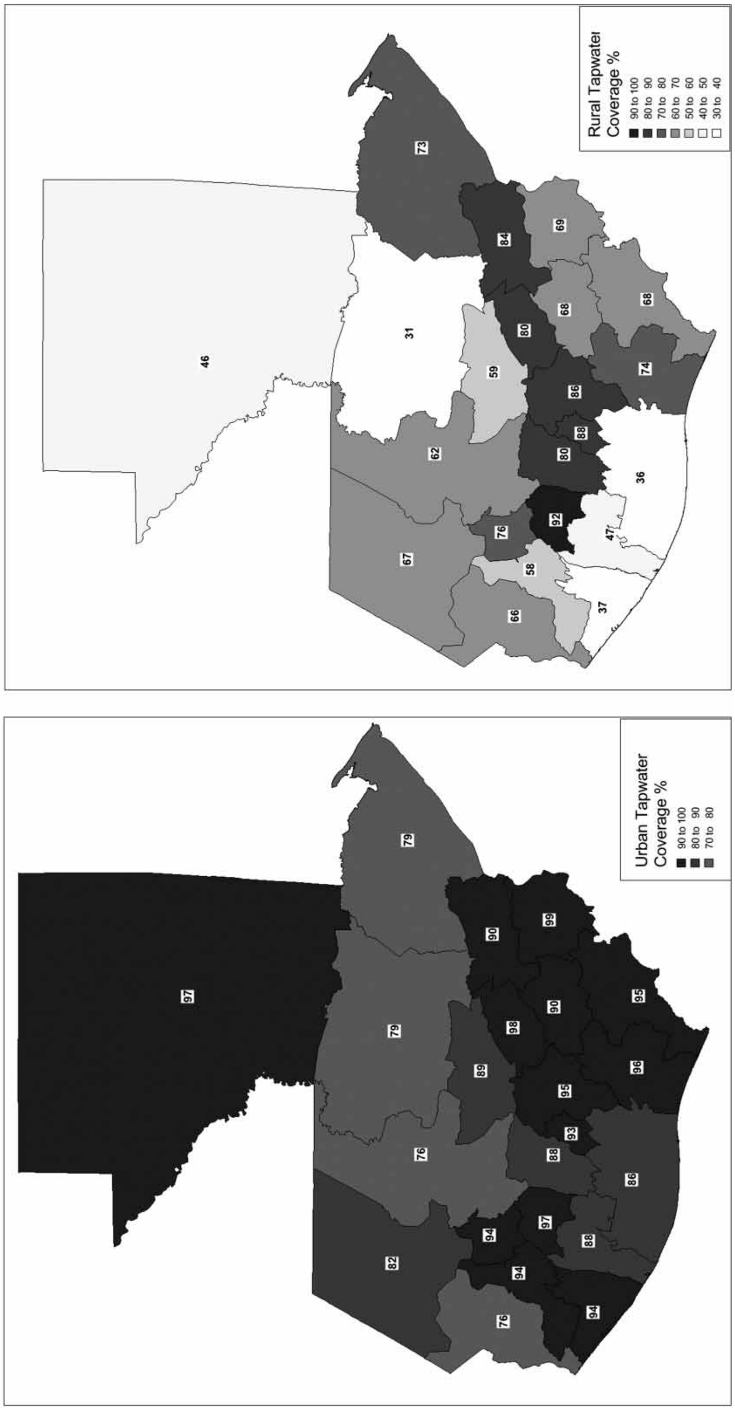

Fig. 2. Tap water coverage by sampling areas (*Source:* ENCOVI).

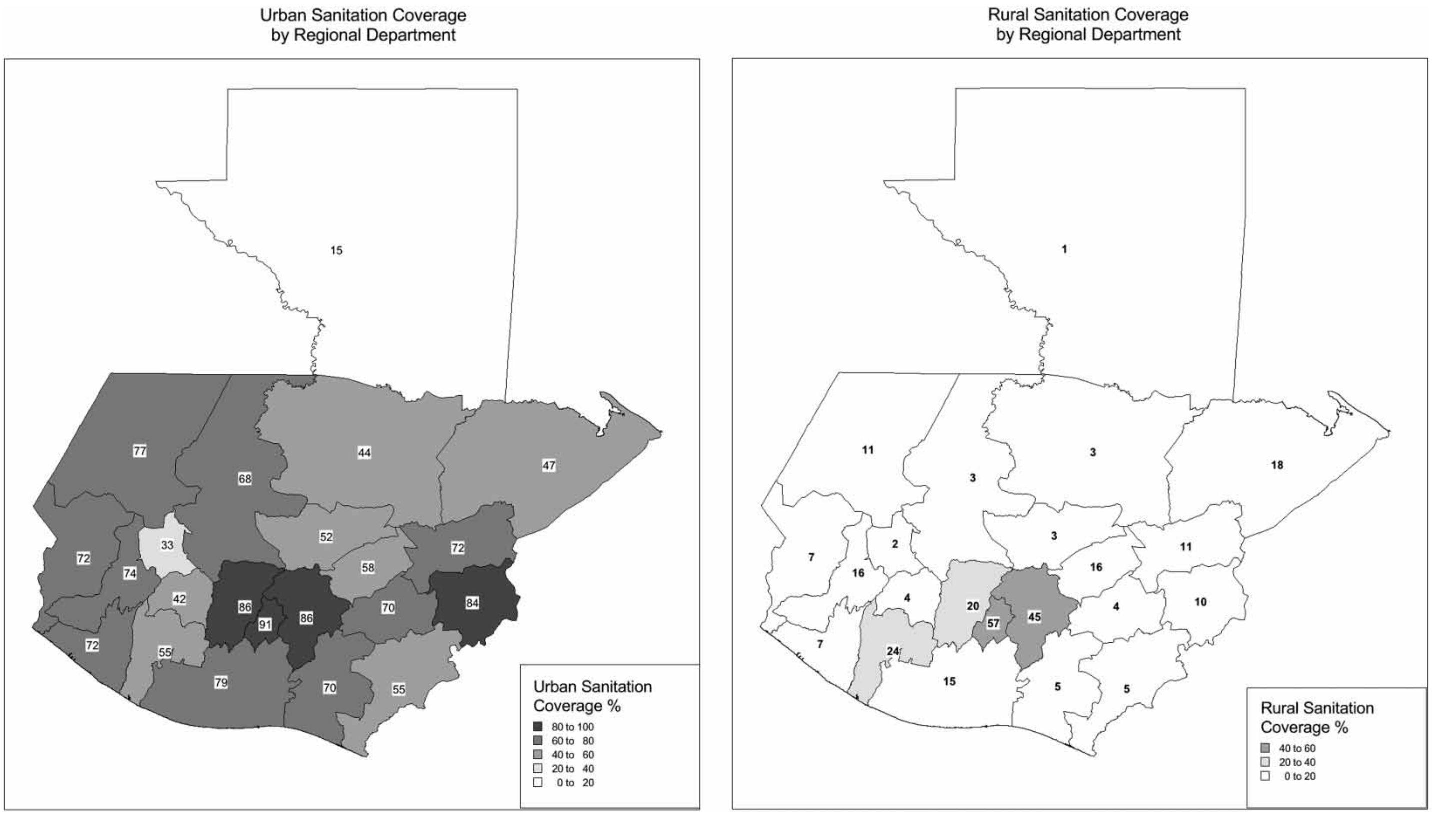

Fig. 3. Sanitation coverage by sampling areas (*Source:* ENCOVI).

Table 2. Diarrhea incidence by infrastructure.

	National incidence (%)	Rural incidence (%)	Urban incidence (%)
Without tap water	36.2	37.2	28.4
With tap water	29.6	33.0	24.8
Change in incidence	−6.6***	−4.2***	−3.6
Without sanitation	34.4	35.2	30.3
With sanitation	24.0	29.6	22.5
Change in incidence	−10.4***	−5.6***	−7.8***

***Implies significance at 1% level.

presented as odds ratios. These results show a considerable degree of robustness across model specifications, except for the variable TAPWATER.

Estimated coefficients in Models 1–4 show that water infrastructure is effective in reducing the likelihood of diarrhea incidence by about 11%. However, once we allow for heterogeneity of tap water infrastructure across sampling areas (Models 5 and 6), the estimated coefficients that depict the fixed effects of TAPWATER become insignificant, and the random effects are statistically significant. These results suggest that the significance of tap water in affecting diarrhea incidence depends on the area in question. This is consistent with the comparison shown in Table 2, where the difference in diarrhea incidence for households with and without tap water is not statistically significant in urban areas, where coverage is already high but water quality may nonetheless vary.

Results on sanitation infrastructure are more robust. The effects of sanitation infrastructure surpass the effects of water infrastructure, reducing the incidence probability of diarrhea by approximately 20%, doubling the impact of water infrastructure. This is consistent with the findings of Esrey (1996) and Esrey *et al.* (1991) who argue that sanitation infrastructure is more effective than water provision in fighting diarrheal diseases. Keusch *et al.* (2006) also report that sanitation supply results in nearly twice the median reduction in diarrhea incidence as an investment in water quality alone or in water quantity and water quality together. The statistics in Table 2 confirm this effect of sanitation on diarrhea incidence. It is worth noting that estimated random effects of sanitation infrastructure are statistically significant suggesting that sanitation effects on diarrhea incidence may vary across sampling areas, although the fixed effects remain significant for an estimated reduction in diarrhea incidence of approximately 20%.

Estimated coefficients on TREATED are statistically insignificant suggesting that in-home water treatments are ineffective in reducing the incidence of diarrhea among children (see Table 3). Similar results are observed for specific treatments such as boiling and chlorinating water. These results are surprising given that previous randomized studies have found that point-of-use water treatment can reduce diarrhea incidence by some 20–30% (Quick *et al.*, 1999; Reller *et al.*, 2003). Water filters seem to be effective given that the incidence probability of diarrhea is 52–54% lower for those filtering water at home, although this result is viewed with caution given that less than 1% of households in the sample fall into this category. Similarly, the incidence probability of diarrhea is 20% lower in households who consume bottled water relative to households who drink untreated water. This suggests that the quality of bottled water is acceptable for drinking purposes.

Socio-demographic characteristics of children and their households also affect the probability of experiencing episodes of diarrhea. Estimated coefficients on FEMALE suggest that females are less

Table 3. Logit models of diarrhea incidence in children under 6 years of age (odds ratios).

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Fixed effects						
TAPWATER	0.88	0.88	0.89	0.89	0.91	0.91
	(0.04)***	(0.04)***	(0.04)**	(0.04)**	(0.07)	(0.07)
SANIT	0.79	0.80	0.79	0.79	0.79	0.80
	(0.05)***	(0.05)***	(0.05)***	(0.05)***	(0.06)***	(0.06)***
TREATED	1.02	–	1.02	–	1.02	–
	(0.05)		(0.05)		(0.05)	
BOIL	–	1.02	–	1.01	–	1.02
		(0.05)		(0.05)		(0.05)
CHLORINE	–	1.06	–	1.07	–	1.05
		(0.07)		(0.07)		(0.07)
FILTER	–	0.46	–	0.48	–	0.48
		(0.13)***		(0.13)***		(0.13)***
BOTTLED	0.78	0.77	0.80	0.79	0.80	0.79
	(0.06)***	(0.06)***	(0.06)***	(0.06)***	(0.06)***	(0.06)***
FEMALE	0.93	0.93	0.93	0.92	0.92	0.92
	(0.04)*	(0.04)*	(0.04)*	(0.04)*	(0.04)*	(0.04)**
AGE	0.90	0.90	0.90	0.90	0.90	0.90
	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
HHSIZE	0.98	0.98	0.98	0.98	0.98	0.98
	(0.01)**	(0.01)**	(0.01)**	(0.01)**	(0.01)**	(0.01)**
RURAL	1.25	1.24	1.23	1.24	1.26	1.26
	(0.07)***	(0.07)***	(0.10)***	(0.10)***	(0.11)***	(0.11)***
SPANISH	0.82	0.82	0.81	0.81	0.79	0.79
	(0.04)***	(0.04)***	(0.05)***	(0.05)***	(0.05)***	(0.05)***
EXTPOOR	0.98	0.98	0.97	0.96	0.97	0.96
	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)
POOR	1.04	1.03	1.03	1.02	1.03	1.02
	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)
CONSTANT	0.81	0.82	0.83	0.84	0.82	0.83
	(0.09)*	(0.09)*	(0.10)	(0.10)	(0.10)	(0.10)
Random Effects						
TAPWATER	–	–	–	–	0.10	0.10
					(0.05)**	(0.05)**
SANIT	–	–	–	–	0.06	0.06
					(0.05)**	(0.05)**
CONSTANT	–	–	0.03	0.03	0.03	0.03
			(0.01)**	(0.01)**	(0.02)**	(0.02)**
Observations	11,176	11,163	11,176	11,163	11,176	11,163
AIC	13,698	13,678	13,671	13,651	13,661	13,642
BIC	13,786	13,780	13,766	13,761	13,793	13,789
LRT (χ^2)	–	–	29.65***	28.62***	48.99***	47.01***

***, **, and * imply significance at 1%, 5%, and 10% levels, respectively; numbers in parentheses are corresponding standard errors.

likely to suffer from diarrhea than are males, with a 7% lower probability of incidence, presumably because boys tend to have greater environmental exposure (see Melo *et al.* (2008) for a study of urban slums in Salvador, Brazil). Also, the incidence of diarrhea decreases with age at a rate of 10%

per year. There is wide consensus that children under the age of two have the highest incidence of diarrhea due to underdeveloped immune systems, early weaning, which exposes young children to contaminated foods, and incomplete immunizations. Weaning foods tend to be more contaminated than drinking water throughout developing countries (Lanata, 2003). In addition, estimated coefficients on HHSIZE are significant (at the 10% level) implying that prevalence of diarrhea is lower in larger households, although the change per household member, at 2%, is small relative to other factors. It can be presumed that children benefit from having more members in their household and more experienced parents in terms of care and hygiene.

Results also indicate that prevalence of diarrhea is approximately 25% greater in rural areas than in urban areas. Medical services are more readily available in urban areas, which may reduce transmission of infectious diseases, including diarrhea, by providing treatment for infected children and educating parents in how to prevent future infection. In addition, incidence of diarrhea decreases by 17–21% in households whose primary language is Spanish. Given that Spanish is the business language in Guatemala, health and hygiene messages may be published mainly in Spanish. The effectiveness of such campaigns may explain the lower prevalence of diarrhea in Spanish-speaking households relative to households who primarily speak an indigenous language[1]. Indigenous populations tend to receive less formal education in Guatemala (Edwards, 2002; McEwan & Trowbridge, 2007), and children of more educated mothers are less prone to diarrhea infection (Fuentes *et al.*, 2006). Finally, estimated coefficients on poverty indicators (i.e. POOR and EXTPOOR) are insignificant, which suggests that there are no differences in terms of diarrhea incidence between poor and non-poor children.

4. Conclusions

This paper investigated effects of water and sanitation infrastructure on the incidence probability of diarrhea among children in Guatemala using nationally representative survey data. Sanitation infrastructure is most effective, reducing diarrhea incidence by about 20%. The effect of water infrastructure is approximately 11% but this result is not robust when accounting for regional heterogeneity in water infrastructure. Surprisingly, findings suggest that boiling and chlorinating water at home have no effect on diarrhea incidence. Bottled water consumption is associated with a 20–22% reduction in the probability incidence of diarrhea, similar to the effectiveness of sanitation infrastructure. While providing bottled water is an expensive alternative to infrastructure (Ferrier, 2001), this may be an effective short-term policy in the event of an emergency.

At first glance, it could be presumed that in-home treatments are ineffective because water is already clean. This, however, seems not to be the case in Guatemala (see Galindo & Molina, 2007; Vásquez, 2014). A more plausible explanation is that in-home treatments are not being adequately implemented. That could be the case for treating water with chlorine, but it is less likely to explain the ineffectiveness of water boiling given that most pathogenic agents die by 60° C, before the boiling temperature of 100° C is reached (Sabir & Farooqi, 2008). Earlier studies indicate that diarrhea incidence is also associated with water storage practices (Quick *et al.*, 2002; Brick *et al.*, 2004; Wright *et al.*, 2004; Clasen, 2009; Rosa

[1] Approximately 43% of the population in Guatemala is indigenous belonging to over 20 Mayan language groups (Gragnolati & Marini, 2003).

et al., 2010; Lacey et al., 2011; Gunther & Schipper, 2012). Rangel et al. (2003) found much greater reduction in diarrhea incidence in rural Guatemala when in-home water treatment was combined with improved water storage vessels. Water treatments may appear ineffective when households store treated water in wide-mouthed devices, as those devices facilitate recontamination of water after boiling it or treating it with chlorine. This may also partially explain why bottled water is effective in reducing diarrhea incidence; recontamination of bottled water is less likely given the shape (i.e. narrow mouth) of containers. Similarly, diarrhea incidence is lower in households that filter their drinking water, which is likely to occur directly prior to consumption, thus reducing the opportunity for recontamination. Treatment of water immediately prior to consumption has been found to be effective in reducing diarrhea incidence in previous studies (Fewtrell et al., 2005; Waddington et al., 2009). Unfortunately, the data used in this study do not include information about in-home water storage, which prevented us from testing the interaction of water treatments and storage. This could be a logical extension of this study.

Findings indicate that access to piped water in the home is generally associated with lower diarrhea incidence, but that these effects differ by area. Previous studies find discernible health improvements from access to water in the home (Cairncross & Valdmanis, 2006; Waddington et al., 2009). Having access to tap water facilitates adequate hand washing and hygienic food preparation practices (Curtis et al., 1995), which are essential for reducing transmission of pathogens that cause diarrheal infection (Curtis & Cairncross, 2003; Luby et al., 2004a, b). This is especially true for water-washed diseases, but also for waterborne diseases, which, once introduced into the home through contaminated water, may propagate in the absence of proper hygiene (Cairncross & Valdmanis, 2006; Zwane & Kremer, 2007). Having piped water also reduces the need for storage, a potential source of contamination (Fewtrell et al., 2005). However, there is evidence of tap water contamination throughout Guatemala (Galindo & Molina, 2007). Our results indicate that heterogeneity in water infrastructure across departments in Guatemala affects its significance on alleviating diarrhea, and further research is needed to assess the quality of tap water. Whether water infrastructure is universal within an area or the quality of the tap water delivered may affect the potential for health improvements. This suggests that health improvements may be achieved by improving access and quality in underserved areas. Results for bottled water suggest that diarrhea incidence would decrease if households were provided with piped water of improved quality.

Our result that improved disposal of wastewater is more effective than access to piped water in reducing diarrhea prevalence is consistent with the findings of Gunther & Fink (2010) based on worldwide data. Most of the pathogenic agents causing diarrhea affect children via the fecal–oral route (Cairncross & Valdmanis, 2006). Sanitation infrastructure diminishes fecal–oral transmission by preventing fecal contamination of local water sources. Water access for hygiene purposes is important in reducing disease transmission within the home, but providing water that is not adequately treated for fecal contamination, which seems to be the case in Guatemala, may weaken the attenuating effect of water access on diarrhea incidence. Thus, given the low coverage of sanitation infrastructure and its effectiveness in reducing diarrhea incidence, investing in sanitation infrastructure may be more effective than providing tap water in the context of this study.

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