Clean Water Makes You Dirty: Water Supply and Sanitation Behavior in Metro Cebu, the Philippines*

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Abstract

Water supply improvements are a frequent policy response to endemic diarrhea in developing countries. However, these interventions may unintentionally cause community sanitation worsen. Such a response could occur because improved water supplies desensitize the community to the consequences of poor sanitation. Since sanitary behaviors have large externalities, the health impact of this endogenous response may overwhelm the direct benefit of clean water. This paper shows how the expansion of municipal piped water in Metro Cebu, the Philippines has exacerbated public defecation, garbage disposal, and diarrhea. I rely on instrumental variables and household fixed effects to rule out non-causal explanations for these results, and find that a neighborhood's complete adoption of piped water increases the likelihood of observing excrement or garbage by 15-30 percent. Such a change increases diarrhea incidence by at least 3 cases per household per year. Based on these findings, I develop a model in which sanitation is a privately-provided local public good. Empirical tests support this framework, highlighting the importance of community dynamics for sanitation and health.

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1 Introduction

Diarrheal diseases kill millions of people in developing countries each year, more than either malaria or tuberculosis (WHO 2002). Inadequate sanitation is the root cause of diarrhea, since infected waste is a critical aspect of the fecal-oral transmission of these diseases. Poorly-contained waste is a direct hazard to anyone coming into contact with it. It also seeps through the soil to contaminate local groundwater sources. Because they lack natural immunity, children are particularly vulnerable to diarrhea, and most deaths occur among children younger than two.

Common interventions to combat diarrhea include improvements in water supply, latrine construction, and education campaigns touting the benefits of sanitation and hygiene. Researchers have studied the relative effectiveness of these interventions (Esrey et al. 1991, Fewtrell et al. 2005), but have payed little attention to the underlying incentives and behaviors that perpetuate the problem. These studies typically suppose that exogenous interventions determine water supply and sanitary infrastructure and that the household's awareness of disease risks is the primary determinant of its behavior. Lacking a notion that sanitary practices may be endogenous to water supply, policymakers have emphasized improvements in drinking water as an anti-diarrheal intervention. A thematic document from the recent 4th World Water Forum (2006, p. 82) opines, "*Water supply and sanitation* . . . are words that often appear together in speeches and pronouncements. Sanitation . . . somehow disappear[s] during the planning, policy-making, budgeting, and implementation phases, while the lion's share of effort and resources are allocated to water supply." Such an emphasis on water supply may be counterproductive if communities trade off water supply investments with less rigorous sanitation.

While the costs of clean behavior are private, the benefits are public. Without government provision of waste disposal, households manage their own waste by constructing and maintaining latrines, and by adhering to sanitary protocols. However, the household's actions impact the entire community. Public defecation increases the risk of transmission to anyone who might contact the waste, either directly or through the water supply. In this context, social norms are likely to evolve to promote sanitation. These rules of behavior further the provision of a public good by overcoming the short-term incentive to free-ride off of others' behavior. A social norm of cleanliness implies some mutual inconvenience, and the sustainability of this regime depends on how much the community values sanitation.

Piped water may reduce the benefit of sanitation in two ways. With poor sanitation, waste enters the groundwater through the soil, polluting the locally-drawn water supply. In contrast, the quality of piped water is invariant to local pollution because this source is extracted outside the neighborhood. This partially protects the recipient from waste in the local environment and makes unsanitary conditions less hazardous. Moreover, piped water boosts recipients' health directly because it generally contains less contamination than alternative sources. If sanitation and clean water are substitutes as health inputs, a recipient of piped water derives less benefit from incremental sanitation. Through either mechanism, piped water desensitizes recipients to sanitary conditions, shrinking the benefit that the recipients derive from the public good. Cleanliness becomes unsustainable as an equilibrium when a critical mass of the community is sufficiently desensitized. This mechanism may generate the counterintuitive result that piped water actually exacerbates diarrheal disease.

This paper examines the effect of piped water on sanitation and health in Metro Cebu, the Philippines. As the government has expanded piped water service in recent decades, sanitary conditions have deteriorated, and areas with the greatest access exhibit the most severe contamination and diarrhea incidence. OLS regressions show that these correlations are strong and statistically significant, but do not establish causality. To find a causal effect of piped water on sanitation and health, I sequentially employ household fixed effects and instrumental variables, which are subject to divergent sources of bias. These specifications find that piped water has a comparable effect, pointing to a causal rather than spurious relationship. Depending on the specification, a neighborhood's complete adoption of piped water increases the likelihood of observing excrement or garbage by 15-30 percent. Such a change increases diarrhea incidence by at least 3 cases per household per year.

A model in which sanitation is a local public good explains these findings and offers additional predictions. Without government provision, households must decide whether to clean up their waste, and thereby contribute to the local sanitary regime. Multiple equilibria are possible, with high and low levels of sanitation, depending upon the community's ability to cooperate. Cleanliness is costly, and the household only participates if the benefits from the clean equilibrium outweigh the inconvenience of participating. With greater piped water prevalence, fewer households are invested in the clean regime, and the prospect for cooperation declines. In this framework, the particular equilibrium in the community dictates household behavior, and the household's own water source is irrelevant for its sanitation. Given these dynamics, piped water has two countervailing effects on health. It improves the health of its recipients by exposing them to fewer waterborne pathogens. However, piped water reduces everyone's health by exacerbating unsanitary conditions. The technology's overall health impact depends upon the relative magnitudes of these effects.

Empirical tests support this framework, highlighting the distinction between the household's own water supply and community-wide prevalence of piped water. Regressions that distinguish between these variables show that prevalence of piped water is an important determinant of household sanitation, but household's own water source has a precisely-estimated zero effect. In diarrhea regressions, households with piped water have less diarrhea, but greater prevalence of piped water exacerbates disease. The importance of piped water prevalence suggests that the enforcement of community norms is an important determinant of sanitation, and hence diarrhea.

2 Motivation

Anti-diarrheal interventions are a frequent target for development assistance, particularly given the recent efforts around the Millennium Development Goals. Calling water supply and sanitation one of the Big Five development interventions, Sachs (2005, p. 236) has urged the international donor community to think, "round the clock about one question: *how can the Big Five interventions be scaled up in [poor rural areas].*" (emphasis in original) He urges that "Sooner rather than later, these investments would repay themselves not only in lives saved, children educated, and communities preserved, but also in direct commercial returns." The desire to take massive action against these problems is noble. However, these investments are unlikely to succeed if policymakers misunderstand how recipients may respond to such interventions.

Confusion in the public health literature about the effectiveness of water supply interventions may point to unmeasured behavioral interference with these experiments. Public health studies (summarized in Fewtrell et al. 2005) sometimes conclude that water supply improvements reduce infant diarrhea, but sometimes find the opposite (Esrey et al. 1988, Ryder et al. 1985). Other papers show that the health gains of piped water are contingent upon wealth (Jalan and Ravallion 2003) and the existence of sanitary facilities (Esrey 1996). The confusion in the literature is consistent with a behavioral response that interferes with intended effect of the intervention.

Historical evidence supports the idea that sanitary practices are endogenous to the prevailing disease environment. In the late 19th and early 20th centuries, the United States developed a strong tradition of cleanliness, which was useful in combating epidemics of yellow fever and cholera (Hoy 1995, ch. 2-3). However, behaviors changed in mid-century, coincident with the development of penicillin and the first vaccines. Hoy comments, "Yet even as personal cleanliness was recognized as a quintessentially American value, public places became dirtier [after World War II]. According to Edna Ferber, the well-traveled novelist, New York City was "the most disgustingly filthy" city in the world in the mid-1950s, and litter and rubbish had already begun to turn "ribbons of green countryside along the highways into casual dumps."" (p. 173) In Hoy's view, these changes came about because recent technological advances reduced the role of cleanliness as a major influence on health. Sanitation requires time and effort, and people conserve on these inputs when the payoffs are low.

While previous authors have not (to my knowledge) studied the endogeneity of sanitation behavior to water supply, other contexts feature a behavioral response that offsets a technological improvement.[1] Gains in automobile fuel efficiency reduce the per-mile cost of travel, and drivers compensate by traveling more (Small and Van Dender 2005, Greene, Kahn and Gibson 1999). An inconclusive debate has explored whether automotive safety improvements like seat belts and airbags exacerbate reckless driving by reducing the severity of a potential accident (e.g. Cohen and Einav 2003, Keeler 1994, Peterson, Hoffer and Millner 1995). In the communicable disease context, recent advances in antiretroviral (ARV) therapy for HIV/AIDS have changed the risk calculus of high-risk individuals such as gay men (Andriote 1999, ch. 10; Dunlap 1996). These drugs dramatically reduce viral loads in the body, cutting the biological risk of transmission while allowing infected people to lead nearly normal lives. An uptick in risky behavior among gay men has followed this decline in the perceived riskiness of unprotected sex, according to several studies (Crepaz et al. 2004, Ostrow et al. 2002, Remien et al. 2005). A recent paper by Lakdawalla, Sood and Goldman (2006) uses interstate variation in Medicaid eligibility as an instrument for HIV treatment and finds that expansions in treatment increase risky behavior and HIV infection. Like improved water supplies, these drugs are a technological advance that reduces the risk of disease transmission but may provoke a behavioral response.

Externalities are crucial in mediating the impact of compensatory behavior. When the behavior is strictly private, standard models predict that the technological gain will outweigh the compensatory loss. In the example of automotive fuel economy, traveling additional distance imposes relatively small externalities (chiefly in terms of traffic congestion) on other motorists. The aforementioned studies calculate the elasticity of fuel consumption with respect to fuel efficiency to be around -0.8: the behavioral response only offsets twenty percent of the technology's direct effect. When the compensatory behavior exhibits large

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[1] The economics literature examining sanitation or other health behaviors in developing countries is sparse. Miguel and Kremer's (2004b) evaluation of a deworming program in Kenya finds significant positive externalities from deworming on school attendance. In another paper, Miguel and Kremer (2004a) find that individuals whose social networks include many dewormed people are less likely to seek deworming treatment themselves, but the authors attribute this finding to social learning rather than treatment externalities. Alberini and coauthors (1996) examine the role of hygiene and water supply in diarrhea outcomes, and find that piped water significantly decreases hand washing. Treating the creation of municipal water works as exogenous, Cutler and Miller (2005) find that piped water adoption resulted in major reductions in mortality in US cities, though Melosi (2000, ch. 8-9) documents multiple sewerage and garbage investments that occurred concurrently.

externalities, individual responses are compounded within the community, and the aggregate response may more than offset the technology's direct effect. This scenario describes the case of ARV drugs for HIV, in which the externalities from risky sex are substantial. While ARV drugs reduce the biological risk of transmission, rates of HIV infection for gay men have risen in recent years (CDC 2004, Hall et al. 2003). Considering the parallels between piped water and ARV technologies, water supply improvements may also carry unintended consequences.

3 Context and Data

Like many cities in developing countries, Metro Cebu is dirty, congested, and poor. Situated on a small island in the Visayas region of the Philippines, Cebu had 1.6 million inhabitants in the 2000 census. The metro area abuts the eastern coast of the island, and includes adjoining Mactan Island and other small islands nearby. Though the population is concentrated in the urban center, Metro Cebu is defined to include outlying areas that are sparsely populated. The *barangay* (neighborhood) is the primary political subdivision, and these areas aggregate into municipalities. Metro Cebu encompasses 296 barangays and 10 municipalities. A democratically-elected "captain" leads each barangay and receives municipal funds to maintain public areas and provide basic medical care.

The Metro Cebu Water District (MCWD) provides chlorinated piped water to around 40 percent of area households. It sources from 110 production wells, which are high-volume deep wells located mostly in upland areas. The MCWD stores the water at a handful of reservoirs around the city and charges subscribers the equivalent of $86 for installation, a monthly fee of $2.70 for a 1/2 inch connection, and $0.30 per cubic meter. Fees are graduated to subsidize poor households, and the MCWD provides communal taps in disadvantaged areas through a "community well" program. In much of Metro Cebu, the water table is just a few meters below ground, and many households can extract their own water through boreholes, dugwells, or artesian springs. Water from these sources has no monetary cost, but is generally less convenient and microbiologically inferior to the piped supply (Moe et al. 1991). Strictly speaking, these private wells are illegal, but the government does not enforce the ban because the MCWD lacks the capacity to meet the implied increase in demand. Seawater intrusion renders local groundwater unpotable in areas near the coast, and local residents must seek water from the MCWD or a private vendor.

The Department of Public Services (DPS) handles sanitation in Cebu, focusing exclusively on trash collection. With 63 garbage trucks, the agency collects and deposits around 500 tons of waste per day in a centralized landfill located 8 kilometers south of the city center. The level of service in a barangay depends upon the ease of access. While the DPS collects around 90 percent of trash overall, it only collects 77 percent in poor and distant barangays (Sileshi 2001). The municipal governments fund this agency through property taxes and license fees, and barangay governments may supplement this service as needed. No centralized agency handles human waste in Metro Cebu, and residents must maintain their own toilets or latrines. Rich households are likely to have flush toilets connected to septic systems, while poor households may share a public latrine, or use a nearby field or stream. The MCWD's mandate technically includes human waste management, but the agency has neglected this role in favor of piped water provision.

The primary data source for this paper is the Cebu Longitudinal Health and Nutrition Survey (CLHNS), a household panel survey of roughly 3000 families spanning 22 years. The survey focuses on 33 randomly-chosen barangays in Cebu and follows all households who gave birth in the year beginning in June of 1983. Of the 33 barangays, 17 are designated as "urban," representing 74 percent of the sample population. The survey includes 12 bimonthly interviews in 1983-85 that deal with the nutrition and health of the mother and infant. Five subsequent follow-up interviews from 1991 to 2005 focus on age-relevant health issues. Since the survey selects households based on fertility in 1983-84, it oversamples poor families, who are more fertile. To understand the role of this selection, Adair et al. (1997) compare mothers of CLHNS children to women in the 1980 Philippines census. They find that the survey is not representative of all Filipina women, but does represent ever-married women with at least once child in the early 1980s. Because the survey tracks the same cohort for two decades, respondents are disproportionately young in early rounds and disproportionately old in late rounds.

From the baseline survey and five follow-up rounds, I construct separate datasets to analyze sanitation and diarrhea outcomes. During interviews, surveyors judged on a scale of 1 to 4 the amount of excrement and the amount of garbage immediately around the respondent's house.[2] I collapse each measure by combining categories 1 with 2 and 3 with 4, a simplification that follows naturally from the wording of the categories. Defecation data are available in all six panel rounds, while garbage data are available in all but the first round. Construction of the diarrhea measure is complicated because, while there are panel data on diarrhea from 1983-85, water supply is fairly constant over this interval. At each of the initial twelve bimonthly interviews, the survey records whether the sample child, the sample mother, or others in the household experienced diarrhea in the previous

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[2] The categories for the defecation variable are: 1-heavy defecation in area, 2-some defecation in area, 3-very little excreta visible, 4-no excreta visible. The categories for the garbage variable are: 1-lots of uncollected garbage, 2-some uncollected garbage, 3-very little garbage, 4-no garbage visible.

week. I prefer the combination of these measures (whether *anyone* in the household had diarrhea), though regressions focusing solely on the sample child give similar results. Since there is little variation in water supply over this two-year period, I collapse these data into a cross-section of counts by summing morbidity outcomes across the twelve rounds.

Variables measuring several household characteristics illuminate patterns in the data and control for observed heterogeneity in subsequent regressions. Households with more education or wealth may exhibit a stronger preference for sanitation relative to other goods and face less restrictive budget constraints. The household's education is defined as the maximum individual attainment within the household. The age of the household head is a proxy for wealth, and I construct this measure using the survey's designation of the household head. Since dogs, pigs, and roosters are common among Cebu households, an indicator for the presence of animals controls for the waste that they produce. Indicators for whether the household has a flush toilet or no toilet measure the household's access to sanitary facilities. The household's age and gender composition may matter, since young children are less restrained in creating mess and gender roles may affect the assignment of chores. Based on the household roster, I calculate the percent of the household that falls within four age bins: 4 and under, 5 to 10, 11 to 15, and older than 15, and also the percent that is male. The family's home construction is another wealth indicator. According to the survey, a respondent's housing may either be light, using only nipa or similar materials; medium, based on a wood or cement foundation with nipa walls or roof; or strong, with a wood or cement foundation and walls, and a galvanized iron roof.

Cross-sectionally, areas with greater availability of piped water have worse sanitation and health outcomes. Figures 1A to 1C plot piped water prevalence against sanitation and diarrhea. These figures show barangay means, which are calculated across all available survey rounds. There is a noisy but distinctly negative relationship between piped water and sanitation, in terms of both "no defecation" and "no garbage." The plot of diarrhea against piped water prevalence shows substantial variability in incidence among barangays without piped water, with values ranging from 0.7 to 2.8 cases per household. However, all barangays with non-zero piped water prevalence have incidence exceeding 1.6. A decomposition into high- and low-prevalence areas shows the pattern of other household characteristics in these areas. Table 1 shows the mean and standard deviation of piped water, sanitation and related household characteristics, and Columns 1 and 2 split the sample by the average of piped water prevalence (0.31). High-prevalence areas are dirtier, either in terms of "no defecation" or "no garbage," even though other characteristics favor increased sanitation and health. On average, households in these areas have two additional years of education and are 26 percent less likely to keep animals. They have better access to sanitary facilities, are composed of fewer young children, and live in more robust housing.

Trends over time illustrate a similar relationship between piped water and sanitation. Columns 3 and 4 of Table 1 show how water supply, sanitation, and related characteristics change from the first to the last survey rounds. The proportion of households with piped water expands by 18 percentage points from 1983 to 2005, while the proportion of households with "no defecation" declines by 8 points.[3] Moreover, trends in other variables do not explain these declines. Education, which is positively correlated with sanitation, increases by 2.5 years over this interval, while the share of households keeping animals falls by 7 points. By 2005, sample households have fewer young children, better housing, and better access to sanitary facilities. Except for the proportion of respondents in strong housing, all of these differences are statistically significant.[4]

4 Sanitation, Health, and Piped Water Prevalence

In this section, I estimate the effect of barangay-wide piped water prevalence on sanitation and health. Piped water may affect behavior directly by changing the household's water supply technology, or indirectly through norms and externalities. The reduced-form effect of prevalence represents the combined influence of these factors. Since potential instruments only vary by barangay, this specification has the advantage that it can be estimated with instrumental variables. I estimate the following equations:

$$s_{ijt} = \alpha_0 + \alpha_1 \overline{w}_{jt} + X'_{ijt}\alpha_2 + \epsilon_{ijt} \tag{1}$$

$$d_{ij} = \beta_0 + \beta_1 \overline{w}_j + X'_{ij}\beta_2 + u_{ij} \tag{2}$$

where i indexes the household, j indexes the barangay, and t indexes the survey round. s and d are sanitation and diarrhea outcomes, respectively. The proportion of households that use MCWD piped water, $\overline{w}$, is calculated in sample including the index household. X is a vector of household characteristics to control for observable heterogeneity across households. In the simplest specification, I only control for age and education, which proxy for household health preferences and budget constraints. Other specifications include a more elaborate set of characteristics, including the household's size, age and gender composition, and whether it keeps animals. Like education and age, these are determinants of sanitation

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[3] The "no garbage" outcome does not exist in 1983. From 1991 to 1998, "no garbage" declined from 0.35 to 0.15, before rebounding to 0.45 by 2005.

[4] Attrition is high in the CLHNS, and could potentially drive some of these trends. However, summary statistics for non-attriters (not reported) reveal the same patterns in water supply, sanitation, and household characteristics. I discuss attrition further in Section 4.2.

and health that may be correlated with water supply. I estimate equation (1) using OLS, fixed effects, and instrumental variables. Without time-series data for diarrhea, fixed effects regressions are not available to estimate equation (2). In all regressions, I cluster the standard errors within the barangay, allowing for an arbitrary correlation between error terms for neighboring households, either contemporaneously or over time. Standard errors are also robust to heteroskedasticity.

Several potential sources of bias confound the OLS estimates of α_1 and β_1. Cross-sectional heterogeneity in household and neighborhood characteristics is likely to be correlated with sanitation, health, and water supply. For example, urban areas are more likely to receive piped water, and are also more congested, contributing to poor sanitation and health. As the city's population has grown from 1.0 million in 1980 to 1.6 million in 2000, areas with piped water have seen greater increases in population density, which has exacerbated unsanitary conditions. Diverging secular trends in sanitation and water supply could also spuriously indicate a causal effect.[5]

Reverse causality raises other identification issues, as sanitary conditions may affect the prevalence of piped water. Planners may target water supply improvements to areas with poor sanitary or health conditions, inducing a spurious correlation. Planners could also target *changes* in sanitary or health conditions by delivering piped water to areas that are deteriorating along these dimensions. At the household level, water supply and sanitation are joint decisions, and sanitary or health conditions may affect the water supply decision. A sanitation or health shock could, in principle, either persuade or dissuade a household from adopting piped water. In one natural story, households seek better health by adopting piped water in response to a negative shock. However, households could also adopt piped water after a positive shock reveals the benefits of avoiding infection.

Measurement error in piped water prevalence introduces additional bias. $\overline{w}$ is percent of sample households who receive piped water. However, participants in the CLHNS are a small share of any barangay's population, and this sample average only approximates the true prevalence of piped water in the barangay. This sampling variation creates classical measurement error in $\overline{w}$. In addition, the survey tracks a non-random subset of the barangay's population. Respondents, who all gave birth in 1983-84, are disproportionately young in early survey years and disproportionately old in later years. Insofar as their water supply choices are not representative of the wider community, $\overline{w}$ also contains non-classical

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[5] Residential sorting may introduce bias if households locate throughout the city based on their sanitation preferences. Residential sorting biases in favor of the findings in this section if inherently cleaner households avoid areas with piped water. This is unlikely based on the differences between high and low prevalence areas in Table 1. Residents in high-prevalence areas are better educated, wealthier, and more likely to be clean based on other observable characteristics.

measurement error, which exerts an unknown bias.

Given these concerns, I approach identification by exploiting two independent sources of variation. Both cross-sectional and time-series variation identify the effects of water supply on sanitation in OLS regressions. Regressions with household fixed effects absorb all cross-sectional variation that is time constant, estimating the effect of water supply from changes over time in piped water prevalence and sanitation within a household. This approach removes bias due to fixed geographic or other household heterogeneity. However, fixed effects do not address endogeneity due to sanitation shocks or water supply targeting to poor areas. I address these concerns through instrumental variables regressions. These regressions, which rely on time-constant instruments, identify the effect of piped water using an exogenous component of the cross-sectional variation. The instruments, discussed further below, are based on geological differences between barangays that are arguably uncorrelated with sanitation-related unobservables. Results using OLS, fixed effects, and instrumental variables are similar, indicating that the bias in these regressions is not severe and that the estimates represent a causal effect.

4.1 OLS and Fixed Effects

OLS regressions, which appear in Table 2, quantify the correlations in Figure 1 between water supply and sanitation and health. Columns 1 and 4 present the most parsimonious regressions of sanitation ("no defecation" and "no garbage" respectively) on piped water prevalence, with controls for age and education. Columns 2 and 5 replicate these regressions, but also control for a more expansive set of household characteristics (age and gender composition, household size, and animal ownership). In the linear probability framework, the coefficient represents the effect of a barangay's complete adoption of piped water on the likelihood of observing the outcome. Parsimonious specifications (Columns 1 and 4) show coefficients on water supply of -0.24 for "no defecation" and -0.15 for "no garbage." In Columns 2 and 5, additional controls do not change the effect of piped water, even though these controls are jointly significant. An increase in prevalence of one standard deviation (0.33) is associated with a 7 point increase in the likelihood of defecation and a 5 point increase in the likelihood of garbage.

On their own, OLS regressions in Table 2 are identified in part from diverging trends in water supply and sanitation. It is possible to include year or municipality-year controls, and identify the effect piped water off of deviations from these trends. Coefficients do not measurably change in these regressions when year controls are added, and become slightly stronger with the addition of municipality-year controls (results not reported).[6] Population density is the most likely sanitation shock that may spuriously generate an effect of piped water. Population growth, which has been concentrated in urban areas, may reduce sanitation by straining sanitary facilities. Rounds 2-6 of the survey feature a household-specific measure of density: the number of houses within 50 meters of the respondent. Including this variable in the OLS regressions of Table 2 reduces the piped water coefficient by 20-30 percent but does not affect its significance.

Regressions that incorporate household fixed effects can control for time-invariant differences across households. Columns 3 and 6 of Table 2 expand upon prior specifications by including household fixed effects. For the "no defecation" outcome, these results are similar to OLS, with a coefficient estimate of -0.22. For "no garbage," the effect is positive and insignificant. The lack of "no garbage" data from the first round may explain this result: with less data, the regression loses statistical power, and point estimates may change if the effect of water supply is non-uniform over time. To diagnose this problem, I exclude the first round from the "no defecation" fixed effects regressions. Without the first round, regressions for "no defecation" see a similar attenuation and loss of significance under fixed effects. The coefficient on piped water prevalence is -0.080, with a standard error of 0.083. The large change in the coefficient relative to the standard error suggests that the effect of piped water is stronger in the first round than in later rounds, so that excluding these observations weakens the effect. The failure to find an effect in Column 6 notwithstanding, fixed effects results indicate that inherent differences between households do not drive the correlation between water supply and sanitation.[7]

The effect of piped water prevalence on diarrhea appears in Columns 7 and 8 of Table 2. The diarrhea outcome, which is only available in the first round of the panel, counts the number of instances on twelve intervals in which anyone in the household develops diarrhea. When only age and education are included as controls, the coefficient estimate is 0.7, meaning that a standard deviation (0.27) increase in piped water prevalence increases morbidity by 0.19 cases per household. Since the survey question inquires about the previous

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[6] Barangay-year controls cannot be used because they are collinear with $\overline{w}_{jt}$, which varies by barangay.

[7] Around 40 percent of households move and 40 percent attrit over the 22 years of the CLHNS. To gauge the impact of relocation and attrition, I reproduce the results of Tables 1-3 (not reported), comparing movers to non-movers and attriters to non-attriters. Movers are defined as households who ever relocate across barangays or partition during the survey, and attriters are households who do not report exactly one observation per round. Movers and non-movers have comparable age and household composition, but non-movers are 0.35 years better educated, slightly dirtier, and have worse health. Attriters are slightly younger and one year less educated than non-attriters. Sanitation estimates are up to 50 percent larger and diarrhea estimates are double for movers than for non-movers. Estimates for sanitation are 50 percent larger for attriters while the effect on diarrhea is 40-100 percent larger for non-attriters. However, the results for these groups are qualitatively similar.

week, but two months elapse between survey intervals, scaling this effect up by 4.35 (the ratio of one month to one week) gives the annualized effect on morbidity, which is at least 0.83 cases per household.[8] Municipality controls, which absorb some geographic heterogeneity, do not change OLS estimates for diarrhea (not reported).

4.2 Instrumental Variables

Unobserved time-varying factors may generate a spurious effect of water supply in OLS and fixed effects regressions. To address these concerns, I estimate specifications (1) and (2) using instrumental variables. Cebu's geology naturally limits where groundwater may be extracted, and the instruments capture the technical feasibility of obtaining piped water or alternative sources. "Kharstic" limestone is the main geological formation underlying the city. This limestone is a good conductor of groundwater, and is Cebu's main source of drinking water. Near the coast, a layer of alluvial silt and clay, produced by erosion in the mountains, overlays the limestone. In these areas, seawater intrusion threatens to make groundwater unpotable. Further inland, the terrain becomes mountainous, and a volcanic formation displaces the limestone. The volcanic rock conducts groundwater poorly, so extraction is not feasible in the mountains. The following instruments reflect technical realities of groundwater extraction. The first two represent the ability of the municipal agency to deliver piped water to an area, while the last instrument measures the feasibility of extracting water privately and forgoing piped water service.

- *Distance to the Limestone-Alluvial Boundary:* The MCWD has exploited the geological boundary between alluvium and limestone for extraction, since this area is insulated from both saline intrusion and the volcanic zone. Figure 2 is a map of Cebu that shows the main geological formations in the area and plots the locations of the MCWD's 110 production wells. These wells are nearly all located along the boundary between the alluvial and limestone formations. Transporting water over land is costly, so barangays far from extraction zones are less likely to receive piped water, all else equal. To capture this variation in the cost of water delivery, I calculate the minimum distance from each sample barangay to the limestone-alluvial boundary as a proxy for the distance to an MCWD production well. Households that are close to this geological feature are more ready recipients of MCWD piped water, which the agency must only transport a short distance.[9]

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[8] On each interval, the diarrhea outcome measures whether *anyone* in the household becomes sick in the previous week. To the extent that household members develop diarrhea at the same time, this measure undercounts the disease incidence.

[9] I construct this measure by averaging the distance to the boundary over the area of the barangay. It is possible to weight the average by population density, based on the location of roads within the barangay.

- *40-Meter Elevation Threshold:* The limestone-alluvial boundary lies at approximately 40 meters above sea level, as do most MCWD wells. Upon extraction, it is much easier to transport water downhill, working with gravity, while moving water uphill is technically challenging and costly. Therefore, barangays located above nearby extraction points are less likely to receive MCWD piped water. Since the elevation of most wells is 35-40 meters, this instrument is an indicator for whether the barangay is located above 40 meters, on average. Figure 3 shows how this threshold divides Metro Cebu and shows the locations of the sample barangays. Most of the populated areas lie below this threshold, however a handful of barangays are uphill from extraction zones, making it much harder to serve these areas.[10]

- *Groundwater Salinity:* In areas near the coast, seawater infiltrates the aquifer, making locally-drawn groundwater unpotable. Residents must seek water from either the MCWD or a private vendor, and the MCWD has met this demand in many communities, even though these areas are relatively far from its source wells. On on a map of Cebu, Figure 4 shows the salinity gradient for groundwater extracted at the water table in 1985. This estimate is based on MCWD maps of the 50 parts per million (ppm) contour line. I derive the gradient in Figure 4 by additionally assuming that the salinity is 300 ppm (the salinity of brackish water) at the coast, and that the salinity reaches its natural level at three times the distance inland that is required to reach the 50 ppm contour line (Bowen 1986, Ch. 10).[11] The figure shows that several sample barangays near the coast or on adjacent Mactan Island have groundwater salinity in excess of 200 ppm, a noticeably salty level. For barangays further inland, salinity levels are less than 50 ppm and private wells are a viable alternative water source. To limit the influence of urban development on this instrument, I use only 1985 values of salinity. Since the 1980s, excessive extraction has played a larger role in Cebu's saline intrusion problem, but estimates from 1985 reflect natural salinity to

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However, the correlation between the weighted and unweighted measures is around 0.99, so this alternative adds little value.

[10] The 40 meter elevation threshold may incidentally capture intrinsic differences between rural and urban populations. As a robustness check, I control for the barangay's elevation, relying only on the discontinuity at 40 meters to identify water supply variation. With this additional control, the 40 meter threshold remains significant in the first stage (t statistic: 3.85), while 2nd stage estimates are smaller but comparable to the benchmark IV regressions.

[11] These assumptions, while necessarily arbitrary, are unrestrictive. If anything, salinity at the coast exceeds 300 ppm, however any excess salinity does not incrementally reduce the water's potability. Since the difference between 50 ppm and the natural level of 35 ppm is small, the assumed distance at which the aquifer is unintruded has an insignificant effect on the salinity map. Under these assumptions, Figure 4 fits approximately with anecdotal notions of the location of the 250 ppm contour line, which the MCWD also tracks.

a greater degree.[12]

First stage results based on these instruments appear in Table 3. Each additional kilometer between a barangay and the boundary reduces prevalence by 2 to 4 percentage points, an effect that is significant at 5 percent in the sanitation sample and at 10 percent in the diarrhea sample. Elevation has a strong effect on the availability of piped water: the prevalence is 17 to 27 percent lower (depending upon the sample) in high elevation areas. As expected, areas with higher salinity have greater piped water prevalence, conditional on the other instruments. An increase in salinity of one standard deviation (65 ppm) increases the prevalence of piped water by 13 percentage points in the sanitation sample, and by 5 points in the diarrhea sample, although the latter effect is insignificant. The instruments are jointly significant in predicting piped water prevalence, but perform better in the larger sanitation panel than in the diarrhea cross-section. For sanitation, the F statistic on the instruments is between 8 and 9, showing strong predictive power. The instruments are weaker in the diarrhea sample, with an F statistic close to 4.

Second-stage estimates based on these instruments appear in Table 4. For sanitation regressions in Columns 1-4, piped water prevalence has a negative and significant effect that matches the magnitude of OLS and fixed effects estimates. The coefficient ranges from -0.26 to -0.29, depending on the specification, meaning that an increase in prevalence of one standard deviation (0.34) increases the likelihood of observing defecation or garbage by 9 percentage points. These regression perform similarly in specifications that include year effects to control for generalized time trends (results not reported).

Results for diarrhea appear in Columns 5 and 6, and the coefficient on piped water ranges from 1.6 to 1.7. Weak instruments may explain why the effect is over twice the size of the OLS estimate. Although a comparison of the coefficient and standard error indicates statistical significance, the bias due to weak instruments in both statistics makes this inference questionable (Dufour 2003). The Anderson-Rubin statistic is an indicator of the significance of $\overline{w}$ that is robust to the bias introduced by weak instruments (Anderson and Rubin 1949). Although this technique does not render a coefficient or standard error, the effect of piped water on diarrhea is non-zero at under 5 percent significance.

While the instruments plausibly exploit exogenous variation in the availability of piped water and alternative sources, they may also capture unwanted variation in sanitation. For instance, areas near the city center have high salinity and low elevation, leading the

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[12] Excessive groundwater extraction may exacerbate saline intrusion, but only high-volume extractors such as breweries or the MCWD are large enough to influence salinity directly. These operations, which typically draw water a few kilometers inland, primarily affect the salinity down-gradient in areas near the coast. A barangay's water consumption from private wells does not significantly affect the underlying salinity, so it is unlikely that salinity influences sanitation behavior directly.

instruments to predict high piped water prevalence. If these areas are also inherently dirtier for unrelated reasons, IV regressions will spuriously attribute this effect to the water supply. With more instruments than endogenous variables, tests of overidentifying restrictions can evaluate whether the instruments are correlated with the second-stage error term. Table 4 reports the Hansen J statistic from a joint test of overidentifying restrictions. With p values greater than 0.6 in every case, the tests fail to reject the null hypothesis that the instruments are exogenous.[13]

For a second check, I compare the effect of piped water in IV regressions that exclude and include controls for household characteristics. The identifying assumption under IV is that predicted water supply is uncorrelated with sanitation-related unobservables such as preferences for sanitation and location-specific sanitary infrastructure. These unobservables are likely to be correlated with observable household characteristics. If the effect of piped water is insensitive to the inclusion of observable household characteristics, it is unlikely to hinge upon the correlation with other unobservables. By this standard, IV results perform well. Comparing specifications with and without these controls in Table 4, coefficients for piped water vary by only around 7 percent, despite the joint significance of household characteristics in these regressions.

If the effect of piped water on sanitation is causal, regressions of unrelated outcomes on water supply should not show a negative relationship. As a final falsification exercise, I investigate the effect of piped water prevalence on two measures of educational attainment: school enrollment and grade for age. Both education and sanitation are forms of human capital investment, and households that value sanitation and health are also likely to value education. Yet schooling is an appropriate variable for falsification tests because a standard model does not predict a first-order effect of piped water prevalence on this outcome. A negative relationship between schooling and piped water prevalence suggests that the effect of water supply on sanitation is spurious; conversely, a finding of no effect on schooling is consistent with the framework in this paper.

Enrollment and grade for age are proxies for whether the household's children are currently attending school. School enrollment, which is available in rounds 3-6, is an indicator of whether each child in the household roster is enrolled in school. Grade for age is a noisier measure of school attendance, but is available in round 1, in addition to rounds 3-6. To con-

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[13] I sequentially exclude one instrument from the first stage to check the sensitivity of the IV results to the instrument set. Exclusion of the elevation threshold instrument depresses the coefficient in sanitation regressions by around 15 percent (not affecting significance) while exclusion of either other instrument has a negligible effect. Tests of overidentifying restrictions and first-stage f tests are comparable to before. Omitting the elevation threshold instrument reduces the effect on diarrhea to around 1.0 (losing significance) while omission of either other instrument increases the coefficient to around 2.0.

struct grade for age, I divide the child's grade attainment by his or her age. Since children begin formal schooling at age 6, I normalize age by subtracting 5 from the denominator. A child who begins schooling at age 6 and remains enrolled will report a grade for age of 1 in every year, but children who start late or drop out have lower values. For each household, I construct the average of both variables across all school-aged children (ages 6 to 16).

Regressions of enrollment and grade for age on water supply generally find no effect, as illustrated in Table 5. The table displays OLS, fixed effects, and IV results in which the specifications are consistent with earlier regressions. For enrollment in Columns 1 through 3, OLS and IV estimates are between -0.05 and -0.02 and are statistically insignificant. According to these estimates, an increase in water supply of one standard deviation reduces the percent of a household's children who are enrolled by less than two points. The fixed effect estimate in Column 2 is large, imprecisely estimated, and has the opposite sign of the OLS and IV estimates. With grade for age, regressions in Columns 4-6 find a small but positive effect of water supply. This effect is nearly zero in most specifications, but is statistically significant under household fixed effects. Even a significant positive effect on education, if taken at face value, is inconsistent with earlier findings that piped water *worsens* sanitation. Other household characteristics behave as expected in these regressions, and both outcomes are increasing in the household's education, but are decreasing in household size. Overall, I find almost no effect of water supply on these educational outcomes, suggesting that the effects of water supply on sanitation are not a spurious artifact of the data.[14]

5 Sanitation as a Local Public Good

Results in the previous section indicate that greater piped water prevalence reduces sanitation and health. This section shows formally how these results may arise when sanitation has large positive externalities. For ease of exposition, I explore the limiting case of positive externalities by approaching sanitation as a local public good. This model generates several testable predictions that distinguish between the household's own water source and piped water prevalence. I also extend the model to incorporate *soil thickness*, which similarly desensitizes the community to unsanitary conditions.

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[14] By construction, regression samples for these outcomes only include households with school-aged children. This requirement creates attrition in later years of the panel, when respondents' children are older than 16. To ensure that the changes in sample composition do not drive the findings in Table 5, I repeat the regressions of Tables 2-4 using only the observations for which these educational variables are present. In these regressions, OLS and IV estimates are qualitatively similar, while fixed effects results are similar in the grade for age sample, but are insignificant in the enrollment sample.

5.1 Model Setup

Households, indexed by i, reside in communities of population n and make discrete sanitation choices, $s_{it} \in \{0, 1\}$ in each period t. While the t subscripts convey the game's infinite repetition, the model is static, and time-constant parameters determine the community's outcome. Sanitation choices aggregate into community-wide sanitation, $\overline{s}_t = \frac{1}{n} \sum s_{it} \in [0, 1]$, and households incur a private cost c when $s_{it} = 1$, reflecting the expenditure of time and effort.[15] I introduce heterogeneity through $\gamma_i^w \geq 0$, the household's sensitivity to dirtiness, and $\phi^w \geq 0$, a health endowment. Both parameters depend upon the household's water source, $w \in \{p, a\}$, which is either "piped" or "alternative." The household's sanitation choice determines its one-shot payoff:

$$\begin{aligned} u(s_{it} = 1) &= \gamma_i^w(\overline{s}_t - 1) + \phi^w - c \qquad (3) \\ u(s_{it} = 0) &= \gamma_i^w(\overline{s}_t - 1) + \phi^w \end{aligned}$$

In this specification, utility can be decomposed into "health," $h_{it}^w = \gamma_i^w(\overline{s}_t - 1) + \phi^w$, and "inconvenience," c. Sanitation is a public good because only $\overline{s}_t$ is a health input, while s_{it} is not. Assuming that $\gamma_i^w/n < c$, expression (3) shows how the household only does worse by being clean itself. This incentive to free ride leads to a unique Nash equilibrium of non-provision ($\overline{s}_t = 0$) in the one-shot game.

With infinite repetition of the game, the community can enforce a cooperative equilibrium by threatening to punish households who exhibit poor sanitation. Now, households must weigh the streams of payoffs from "cooperating" ($s_{it} = 1$) and "defecting" ($s_{it} = 0$), given the community's punishment regime. For analytical tractability, I assume that players follow "grim strategies," punishing a defection by jointly defecting in the subsequent period and in perpetuity thereafter.[16] With discount rate δ and given previous cooperation,

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[15] Differences in c by water source bear some consideration. In the most likely scenario, $c^p < c^a$, since a ready source of water is necessary to flush a toilet and clean up. This gap, if sufficiently large, could override the decreased sensitivity of piped households, so that increasing prevalence improves sanitation. Since heterogeneity of this nature weighs against the model's findings, the empirical results suggest that differences in c are minimal.

[16] The model's conclusions are equivalent under tit-for-tat strategies, where players punish a defection by jointly defecting for one round. Under this regime, the threshold is $\gamma_i^w > c(2n + 2\delta)/(1 + \delta + n)$, which is greater than c as long as $n > 1$. Tit-for-tat has the theoretical infelicity that equilibria other that $\overline{s}_t = 0$ and $\overline{s}_t = 1$ may also be subgame perfect, interfering with the computations in (6), (9), and (10).

players face the following discounted payoff streams:

$$\begin{aligned} u(s_{it}=1) &= \phi^w \frac{1+\delta}{\delta} - c\frac{1+\delta}{\delta} \\ u(s_{it}=0) &= \phi^w \frac{1+\delta}{\delta} - \gamma_i^w \frac{n+\delta}{n\delta} \end{aligned} \tag{4}$$

In this expression, $u(s_{it}=1)$ is the discounted utility the household receives from cooperating from period t to ∞. $u(s_{it}=0)$ is the discounted utility the household earns by defecting in period t and receiving the punishment of $\overline{s}=0$ from period $t+1$ to ∞. Households maximize utility by cooperating if and only if $\gamma_i^w > c(n+\delta n)/(n+\delta) \equiv \tau$. Since grim strategies imply unanimous and perpetual punishment for any defection, complete cooperation ($\overline{s}_t = 1$) and non-cooperation ($\overline{s}_t = 0$) are the only subgame perfect Nash equilibria. Households choose their sanitation in unison.[17]

A straightforward generalization allows for non-unanimous sanitation behavior. Suppose the community detects and punishes a defector with exogenous probability, $\alpha \in (0,1)$. Now a household only cooperates if $\gamma_i^w > c(n\delta + n\alpha)/(\delta + n\alpha)$, which equals the original threshold when $\alpha = 1$. For sufficiently low values of α, a subset of the community can cheat on the cooperative equilibrium without being detected, thereby preserving the cooperative equilibrium. Another way to allow non-unanimous sanitation behavior is to suppose that some players do not participate in the game. If the community recognizes that certain households are always dirty, remaining households may still pursue cooperation among themselves. The game proceeds as before among this subset of households, who still make unanimous sanitation choices.

Cooperation can break down even if everyone prefers the clean equilibrium. Whenever $\gamma_i^w > c$, the household receives a higher one-shot payoff from the joint cooperation than from joint defection. However, households only cooperate when $\gamma_i^w > c(n+\delta n)/(n+\delta)$, which is greater than c as long as $n > 1$. For values of γ_i^w that are between c and $c(n+\delta n)/(n+\delta)$, the household chooses to defect even though it prefers the one-shot payoff from the cooperative regime. Intuitively, households in this position choose to free-ride off of others' contributions

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[17] Perfect complementarity between s_i and $\overline{s}$ in health production delivers the same predictions for sanitation and health as the Prisoner's Dilemma. Suppose $\overline{s} = \min(s_1, ..., s_n)$, following the familiar Leontif production function. Households play a one-shot game with equilibria of either $\overline{s} = 0$ or $\overline{s} = 1$, and any individual can destroy the cooperative equilibrium by not contributing (Cornes and Sandler 1996, pp. 185-190). A household opts out of the cooperative equilibrium if the costs of this regime exceed the benefits, and the health production technology assures that sanitation decisions are unanimous in equilibrium. The nonnecessity of a repeated game apparatus makes this framework attractive. However, the assumption that sanitary inputs are perfect complements is unrealistic, since households within the same community are exposed to disparate sources of pollution. This model is also less theoretically satisfying because it implicitly requires at least one household to prefer the dirty equilibrium for sanitation to decline.

to $\overline{s}_t$, creating a wedge between the desirability and sustainability of the cooperative regime.

5.2 The Impact of Piped Water

Piped water conveys a direct health benefit through exposure to fewer pathogens, but also desensitizes the household to unsanitary conditions. To formalize these ideas, let $\phi^p > \phi^a$, so that piped households have a larger health endowment than non-piped households. Furthermore, define the cumulative distribution function of γ_i^w, $F^w(\gamma)$, and let $F^p(\gamma) \geq F^a(\gamma)$. By this assumption, γ^a first order stochastically dominates (FOSD) γ^p, meaning that households have heterogeneous sensitivities to dirtiness, but those with piped water tend to be less sensitive.

For cooperation to be sustainable, every household must be above the threshold. The probability that a community obtains the good equilibrium is the product of the individual probabilities that γ_i^w is greater than τ: $pr(\overline{s}_t = 1) = \prod_i (1 - F^w(\tau))$. The prevalence of piped water matters critically, since piped households are more likely to defect. When proportion q of the community has piped water, the probability of cooperation is given by:

$$pr(\overline{s}_t = 1) = (1 - F^p(\tau))^{nq}(1 - F^a(\tau))^{n(1-q)} \tag{5}$$

Differentiating this expression with respect to q shows that the probability of a cooperative equilibrium declines as more households adopt piped water. The sign of this derivative follows from the FOSD assumption.

$$\frac{\partial pr(\overline{s}_t = 1)}{\partial q} = pr(\overline{s}_t = 1) \times n\bigg(ln(1 - F^p(\tau)) - ln(1 - F^a(\tau))\bigg) \leq 0 \tag{6}$$

Since sanitation behavior is unanimous within the community, the household's own water source is irrelevant for its sanitation. The assumption of certain and unanimous punishment and the exclusion of s_i from the health production function jointly deliver this prediction. When the model is relaxed to allow for some cheating on the otherwise-cooperative equilibrium, piped households become more likely to cheat than non-piped households.[18] Intuitively, the household's own water source does not affect its sanitation to the extent that the *community's* equilibrium in sanitation dictates household behavior. By allowing some households to cheat, this extension reduces the community's role in household sanitation.

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[18] Adapting the model to include a non-unitary probability of defection, α, creates a role for a household's own water supply to affect its sanitation. Here, a household cooperates when $\gamma_i^w > c(n\delta + n\alpha)/(\delta + n\alpha)$, but defections do not necessarily lead to the bad equilibrium. To the extent that piped households are more likely to defect but these defections go unnoticed, households piped households will tend to be dirtier than non-piped households.

In contrast to this setup, the household's own water source, rather than piped water prevalence, influences behavior in a model without sanitation externalities. To illustrate, suppose the household's health only depends on its own water supply and sanitation: $h_i = h(w_i, s_i)$. A household with income y_i maximizes utility over health and all other goods (g_i), facing the budget constraint that $ps_i + g_i = y_i$. By definition, sanitation is a purely private good under this scenario. Implicitly differentiating the household's first order condition shows the equilibrium relationship between water supply and sanitation:

$$\frac{\partial s_i}{\partial w_i} = -\frac{\partial^2 h(s_i, w_i)}{\partial s_i \partial w_i} / \frac{\partial^2 h(s_i, w_i)}{\partial s_i^2} < 0 \tag{7}$$

This derivative is negative if sanitation and clean water are substitutes and health is concave in sanitation. Piped water prevalence does not affect household sanitation in this framework, as it might if either $\overline{w}$ or $\overline{s}$ entered the household's objective function.[19]

When sanitation is a public good, piped water can easily undermine health by causing a good equilibrium to collapse. This sanitation decline counteracts the benefit that piped households receive from cleaner water. To model these effects, define health as the sum of the utility derived from sanitation and the endowment : $h_{it}^w = \gamma_i^w(\overline{s}_t - 1) + \phi^w$, which is equivalent to overall utility except for inconvenience, c. The sanitation term disappears in the clean equilibrium, and health equals the endowment, ϕ^w. However, households with large values of γ_i^w suffer differentially as sanitation deteriorates.

Since the model generates effects of water supply on sanitation that are probabilistic, the expectation of health across the possible equilibria incorporates the health effects of a sanitation change. The assumption that players follow grim strategies streamlines the analysis since only two subgame perfect Nash equilibria exist: $\overline{s}_t = 0$ and $\overline{s}_t = 1$. Taking the expectation of health across these two outcomes gives the following simplified expression:

$$E(h_{it}^w) = \phi^w - pr(\overline{s}_t = 0)\gamma_i^w \tag{8}$$

Piped households have better expected health for two reasons. These households have larger health endowments, reflecting the greater purity of the piped water supply. Piped households also suffer less in the event of a bad equilibrium because they are relatively insensitive to the dirty environment. Differencing expected health by water source shows

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[19] $\overline{w}$ may affect s_i if piped water prevalence enters the utility or health function directly, but this an implausible assumption. Instead, complementarity between s_i and $\overline{s}$ can deliver this relationship, either through the health or utility function. The public good model presented here is an example of complementarity in utility: s_i and $\overline{s}$ are strategic complements since the payoff to taking action $s_{it} = 1$ is highest when others are also taking this action (Bulow et al. 1985).

this inequality explicitly.

$$E(h^p_{it} - h^a_{it}) = (\phi^p - \phi^a) + pr(\overline{s}_t = 0) \times E(\gamma^a_i - \gamma^p_i) > 0 \tag{9}$$

Conditional upon the household's own water source, greater piped water prevalence causes the household's health to worsen by undermining sanitation. The derivative of expression (8) with respect to q isolates the "sanitation effect" of greater prevalence.

$$\frac{\partial E(h^w_{it})}{\partial q} = \frac{\partial pr(\overline{s}_t = 1)}{\partial q} \times \gamma^w_i \leq 0 \tag{10}$$

The household's sensitivity, γ^w_i, appears in this derivative, implying a differentially severe consequence of piped water prevalence for non-piped households, for whom γ^w_i is larger. Expressions (9) and (10) highlight the countervailing health effects of the piped water technology. If the sanitation effect overwhelms piped water's direct benefit, water supply improvements will exacerbate diarrheal disease.

5.3 Soil Thickness: Another Dimension of Sensitivity

The model's underlying premise is that the community's exposure to local pollution determines its support for the sanitation regime. For families that drink from local groundwater, the soil is a natural shield against unsanitary conditions. Within the soil, predatory organisms and sunlight and moisture fluctuations create a hostile environment that effectively filters out pathogens (Pedley et al. 2004). The soil's "thickness"–the distance from the surface to underlying bedrock–affects its ability to attenuate pollution. Thick soil naturally protects underlying groundwater from contamination, insulating the community from ambient pollution in the same manner as piped water. Therefore soil thickness may also affect the community's willingness to pursue sanitation.

The direct benefits of thick soil only extend to non-piped households, whose water supply is subject to contamination through the ground. Since it reduces the contamination in the groundwater, thick soil increases the health endowment of non-piped households. It also desensitizes these households by making their water quality less dependent on the level of surface pollution. To incorporate these features into the model, let the sensitivity and endowments of non-piped households, ϕ_a and γ^a_i, depend on soil thickness, ρ, and assume that $\partial\phi^a/\partial\rho > 0$ and that $\partial\gamma^a_i/\partial\rho < 0$. Soil thickness does not affect the endowments or sensitivity of piped households, so that ϕ^w and γ^w_i do not depend on ρ.

This extension leaves intact the essential structure of the model. Households make dichotomous sanitation decisions, facing an infinitely repeated Prisoner's Dilemma, and choose to cooperate if and only if $\gamma_i^w(\rho) > c(n+\delta n)/(n+\delta) \equiv \tau$. Now the soil thickness, along with the household's water source, determines whether the household is above or below the threshold, τ. Since γ_i^a is decreasing in ρ, the CDF of γ_i^a is increasing in ρ: $\partial F^a(\gamma,\rho)/\partial\rho > 0$. To reach the good equilibrium, every household in the community must be above the threshold, so the likelihood of the good equilibrium is the product of the individual probabilities that $\gamma_i^w(\rho) > \tau$. This expression matches (5), except for the modification making F^a a function of ρ. Differentiating with respect to ρ shows that the prospect for a clean equilibrium falls with greater soil thickness.

$$\frac{\partial pr(\overline{s}_t = 1)}{\partial\rho} = -pr(\overline{s}_t = 1) \times \frac{n(1-q)}{1-F^a(\tau,\rho)} \times \frac{\partial F^a(\tau,\rho)}{\partial\rho} < 0 \tag{11}$$

Non-piped households, who are less sensitive to their environment with thick soil, drive this decline in sanitation. By desensitizing a subset of the community, thick soil functions like piped water in undermining the cooperative equilibrium.

Soil thickness also mirrors piped water in its effects on health. Thick soil provides a direct health benefit to non-piped households by insulating the local groundwater from pollution. By exacerbating unsanitary conditions, thick soil also worsens health across the community. While non-piped households are subject to both effects, piped households only experience the negative "sanitation effect." To generate these prediction formally, I modify the expression for expected health (8) to incorporate the role of soil thickness. This expression is unchanged for piped households, who only experience ρ through the likelihood of the clean equilibrium. For non-piped households, ρ also enters through the endowment, ϕ^a, and the sensitivity parameter, γ_i^a: $E(h_{it}^a) = \phi^a(\rho) - pr(\overline{s}_t = 0)\gamma_i^a(\rho)$. The derivative of expected health with respect to ρ shows the impact of soil thickness on health for each group.

$$\frac{\partial E(h_{it}^p)}{\partial\rho} = \underbrace{\frac{\partial pr(\overline{s}_t = 1)}{\partial\rho}}_{-} \times \gamma_i^p < 0 \tag{12}$$

$$\frac{\partial E(h_{it}^a)}{\partial\rho} = \underbrace{\frac{\partial pr(\overline{s}_t = 1)}{\partial\rho} \times \gamma_i^a}_{-} + \underbrace{\frac{\partial\phi^a}{\partial\rho} - pr(\overline{s}_t = 0) \times \frac{\partial\gamma_i^a}{\partial\rho}}_{+} \gtrless 0 \tag{13}$$

For piped households, equation (12) shows that thick soil is unambiguously harmful. Thick soil reduces sanitation in the community, worsening health among these households. Equation (13) shows the health effect for non-piped households. The first term is the negative effect of soil thickness on health through diminished sanitation. The second and third terms capture the direct benefits of thick soil through larger health endowments and reduced sensitivity to pollution. Since these benefits counteract the losses from poor sanitation, the overall effect of soil thickness for non-piped households cannot be signed. If these effects have similar magnitudes, the net effect is approximately zero.

6 Empirical Tests

By incorporating a strategic framework, the model creates a role for community dynamics in household sanitation behavior. The sustainability of a cooperative equilibrium depends on the community's sensitivity to dirtiness, and the particular equilibrium is the primary determinant of household sanitation. By desensitizing the community, piped water undermines the clean equilibrium and causes communities to become dirtier. The technology may paradoxically exacerbate diarrheal disease if this "sanitation effect" overwhelms the health benefit of a cleaner water supply. By extension, soil thickness also insulates and desensitizes the community, similarly influencing sanitation and health.

6.1 Effects of Piped Water

Previous regressions in Section 4 show that greater piped water prevalence reduces sanitation and exacerbates diarrhea. Since these regressions do not control for the household's own water source, they implicitly combine individual and neighborhood-wide effects of water supply. However, the model draws clear distinctions between the household's own water source and the prevalence of piped water. Piped water prevalence undermines the cooperative equilibrium, reducing sanitation, while the household's own water source does not matter for its sanitation. Piped water for the individual household and piped water prevalence also have countervailing health effects. Since piped water is relatively uncontaminated, it boosts the health of its recipients; however, piped water prevalence reduces health by undermining the sanitation regime. I test these predictions by regressing sanitation and diarrhea on the household's own water supply as well as piped water prevalence in the following specifications:

$$s_{ijt} = \alpha_0 + \alpha_1 w_{ijt} + \alpha_2 \overline{w}_{jt} + X'_{ijt}\alpha_3 + \epsilon_{ijt} \tag{14}$$

$$d_{ij} = \beta_0 + \beta_1 w_{ij} + \beta_2 \overline{w}_j + X'_{ij}\beta_3 + u_{ij} \tag{15}$$

Here, w_i is an indicator that the household receives MCWD piped water, while $\overline{w}$ is the percent of the barangay's sample households who have piped water, and X is a vector of household characteristics matching earlier specifications. Consistent with the model's definition of piped water prevalence, the index household is included in the calculation of $\overline{w}$. I estimate these equations using OLS and household fixed effects; IV is not available because independent instruments for w_i and $\overline{w}$ do not exist. However, the similarity among earlier OLS, fixed effects, and IV estimates (Tables 2-4) minimizes the concern about bias in these regressions. The model's predictions are that $\alpha_1 = 0$ and that $\alpha_2 < 0$, while $\beta_1 < 0$ and $\beta_2 > 0$.

Regressions of sanitation on the household's own water supply and piped water prevalence appear in Table 6. These results cover both the "no defecation" (Columns 1-3) and "no garbage" (Columns 4-6) outcomes. For each outcome, the table shows a parsimonious OLS specification (controlling only for the household's age and education), a specification controlling for a larger set of household characteristics, and a specification that also includes household fixed effects. The coefficient estimates for w_i in Columns 1-6 test the model's prediction that the household's own water source is irrelevant. For the "no defecation" outcome, these regression find an effect of w_i that is precisely estimated as zero under both OLS and fixed effects. The 95 percent confidence interval for this coefficient is $-0.02 - 0.05$, which is a small effect relative to $\overline{w}$. For "no garbage," OLS regressions also find a precise zero effect of w_i, while the fixed effect regressions find a small but significantly negative effect. The uniformity of behavior across piped and non-piped sources indicates that community dynamics, rather than household substitution of health inputs, relates water supply to sanitation.

The regressions in Columns 1-6 also test whether piped water prevalence affects sanitation, conditional upon the household's own water supply. The simple OLS specifications in Columns 1 and 4 show a significant effect of piped water prevalence of -0.26 for "no defecation" and -0.15 for "no garbage." These magnitudes closely match estimates of the combined effect of w_i and $\overline{w}$ in Table 2 (Columns 1 and 4). Columns 2 and 5 include controls for additional household characteristics. Despite their joint significance, these controls do not appreciably change the estimates for $\overline{w}$. Adding household fixed effects to the "no defecation" regression (Column 3) gives a similar coefficient estimate of -0.21. However, fixed effects regressions for the "no garbage" outcome find a positive but insignificant effect. As discussed in Section 4.1, the lack of data for this outcome in the first survey round is the likely reason for this inconsistency with other results. Overall, the results in Table 6 show that piped water prevalence has a strong effect on household sanitation behavior, even after controlling for the household's own water source.

The interaction of w_i and $\overline{w}$ provides an additional test of the model. If piped water prevalence affects sanitation by changing the equilibrium provision of the public good, it should uniformly affect the sanitation of piped and non-piped households. I test this prediction by including an interaction between w_i and $\overline{w}$ in regressions comparable to those in Table 6 (not reported). For the "no defecation" outcome, the interaction term is small and insignificant. This result is consistent with the model, demonstrating a uniform effect of $\overline{w}$ that is equivalent for piped and non-piped households. For "no garbage," the interaction term is negative and significant, while the level of $\overline{w}$ (representing the effect of prevalence for non-piped households) is close to zero. This result is not consistent with the model's predictions and indicates more complicated relationship between piped water and the "no garbage" outcome.

Regressions showing the health effects of w_i and $\overline{w}$ appear in Columns 7 and 8 of Table 6. Column 7 only controls for the household's education and age, while Column 8 controls for additional household characteristics. Conditional upon piped water prevalence, households with piped water experience 0.18 fewer cases of diarrhea within the sample time frame. This difference is statistically significant at 10 percent in the simple specification and at 5 percent when additional controls are included. The finding is consistent with the model's assumption that piped households are less sensitive to sanitary conditions. If water quality and sanitation are substitutes in the health production function and sanitation has a concave effect on health, then a health improvement due to water quality reduces the marginal utility of sanitation. These empirical results, which show a health benefit of piped water, validate the plausibility of this mechanism.

Conditional upon this health improvement for piped households, piped water prevalence significantly increases diarrhea incidence. Point estimates range from 0.84 to 0.87, indicating that an increase in prevalence of one standard deviation (0.27) leads to 0.23 additional diarrhea cases for each sample household. These coefficients, which represent the effect of $\overline{w}$ conditional upon w_i, are 25 percent larger than the estimates that combine w_i and $\overline{w}$ in Table 2 (Columns 7 and 8).[20] Thus the sanitation effect of piped water prevalence offsets the technology's direct health benefit. Whether a household adopting piped water is ultimately better off depends on the proportion of its neighbors that also obtain piped water.

Diarrhea regressions featuring the interaction of w_i and $\overline{w}$ test the model's prediction that piped water prevalence differentially harms non-piped households. This prediction is clear from expression (10), in which the derivative of expected health with respect to q is universally negative, but is scaled by γ_i^w. Regressions following Columns 7 and 8 of

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[20] To account for the difference between sampling intervals (two months) and the time frame of the diarrhea survey question (one week), I scale these coefficients by 4.35 to obtain an annual effect. Based on this extrapolation, households with piped water experience around 0.78 fewer cases of diarrhea per year, conditional upon piped water prevalence and the included controls. An increase in prevalence of one standard deviation leads to 1.0 additional case of morbidity per year on average.

Table 6 that include an interaction term (not reported) show that the coefficient on $\overline{w}$ is around 0.49 for piped households and 1.01 for non-piped households, but this difference is not statistically significant (p value: 0.3). This result suggestively supports the prediction that declining sanitation differentially hurts non-piped households.

6.2 Effects of Soil Thickness

Like piped water, soil thickness affects the community's exposure to unsanitary conditions. Thick soil attenuates surface pathogens before they reach the water table, insulating the local groundwater from contamination. Through this channel, it improves the health of non-piped households and reduces their sensitivity to poor sanitation, thereby undermining support for the cooperative sanitation regime. Soil thickness is analogous to piped water since it technologically improves health while triggering an adverse behavioral response. The net health impact of soil thickness depends on which of these effects is stronger.

The CLHNS measures soil thickness through a categorical variable recorded in the first survey round. The possible responses, which are generally homogeneous within a barangay, are (1) less than 0.3 meters, (2) 0.3 to 1 meters, (3) 1 to 3 meters, and (4) greater than 3 meters. Since subsequent estimates are similar for categories (1) and (2), I combine these groups and regress on three soil thickness categories. I define soil thickness as the modal value within each barangay to make this variable available in later rounds. Appendix Table 1 summarizes the characteristics of households in each soil thickness category. Areas with thick and thin soil are similar in terms of age composition and wealth. However, respondents with thick soil have 1.5 additional years of education and have better access to sanitary facilities. This group is also 20 percent less likely to keep animals. Piped water prevalence is positive correlated with soil thickness: 14 percent of thin-soil households (Column 1) have piped water, compared to over half of thick-soil households (Column 3).

In this section, I consider how soil thickness affects water quality, sanitation, and diarrhea. The CLHNS includes a water quality module (described below), and these data show how thick soil insulates non-piped water from contamination. Based on this mechanism, the model predicts worse sanitation for both piped and non-piped households in areas with thick soil. For piped households, this sanitation decline exacerbates diarrhea; but for non-piped households, thick soil's protective properties offset this decline. The following specifications examine the effects of soil thickness separately for piped and non-piped households.

$$s_{ijt} = \alpha_0 + \alpha_1 \rho_j + X'_{ijt}\alpha_2 + \epsilon_{ijt} \tag{16}$$

$$y_{ij} = \beta_0 + \beta_1 \rho_j + X'_{ij}\beta_2 + u_{ij} \tag{17}$$

where $y_{ij} \in \{e_{ij}, d_{ij}\}$. Here, e_{ij} is an indicator of water quality, and s_{ijt} and d_{ij} are sanitation and diarrhea, respectively. Soil thickness, ρ_j, is categorical, and effects are measured relative to the thinnest-soil group, which is excluded. X is a vector of household characteristics that is consistent with earlier regressions, and all specifications control for the age of the household head and the maximal education within the household.

To validate the hypothesis that thick soil insulates non-piped households from contamination, I investigate the relationship between soil thickness and microbiological quality of respondents' drinking water. As part of the baseline CLHNS, surveyors measured the levels of several indicators of contamination in sample households' water sources: fecal coliforms, *E. coli*, enterococci, and fecal streptococci, counting the number of bacterial colonies per 100 ml of water. Using these data, Moe et al. (1991) find that while the *E. coli* indicator most reliably tracks diarrheal morbidity, concentrations of less than 100 colonies per 100 ml lead to minimal health risk. Based on this finding, I use an indicator for whether the household's sample contains fewer than 100 colonies per 100 ml as a water quality outcome.[21] Like data on diarrhea, *E. coli* data are available in a cross-section corresponding to the first round of the panel.

Regressions of water quality on soil thickness appear in Table 7. The table splits the sample into piped and non-piped households and shows regressions with and without household characteristics. For non-piped households (Columns 1 and 2), thick soil leads to less contamination. Households with the thickest soil (greater than 3 meters) are 28 percent less likely to have contaminated water than those in the thinnest group. These estimates are robust to controlling for household characteristics, even though these controls are jointly significant. Regressions of water quality on soil thickness for piped households (Columns 3 and 4) are a falsification test for the non-piped results, since the quality of piped water is theoretically invariant to soil thickness. As expected, these regressions show no significant effect of soil thickness on the quality of piped water, a result that is consistent with the claim that pathogenic attenuation drives the non-piped results.[22] Table 7 also indirectly supports the model's assumption that piped water desensitizes its recipients to unsanitary conditions. By showing that the quality of piped water is invariant to soil thickness, these results suggest that non-piped water is also insensitive to the level of surface contamination, which is modulated by soil thickness.

With thick soil protecting non-piped water from contamination, communities may have

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[21] Soil thickness is also significant in regressions using a linear water quality outcome, but coefficients in these regressions are difficult to interpret since the effects of contamination on health are non-linear.

[22] To make this interpretation, I implicitly assume that surface pollution is uncorrelated with soil thickness. However, the model predicts and Table 8 confirms that areas with thick soil are dirtier. Omitting sanitation as an independent variable leads these regressions to *understate* the ability of thick soil to attenuate pathogens.

an incentive to disregard sanitation. Based on expression (11), thick soil should lead to worse sanitation since non-piped households within the neighborhood are insensitive to unsanitary conditions. Table 8 tests this prediction by regressing sanitation on soil thickness. Distinguishing between piped and non-piped households, Columns 1 and 2 show the effects of soil thickness on "no defecation," while Columns 3 and 4 show its effects on "no garbage." Households in the thickest soil category are 10-13 percent more likely than those in the thinnest category to exhibit defecation and garbage. Coefficients are significant at under 10 percent in these regressions, and are significant at under 5 percent in regressions combining piped and non-piped households (not reported). The results for "no defecation" conform well to the model's predictions, since sanitation is monotonically decreasing in soil thickness for piped and non-piped households. For "no garbage," piped households have significantly better sanitation in the "1-3 meters" category than with either thicker or thinner soil, a result that does not follow the theory. Apart from this result, coefficients for piped and non-piped households are roughly the same and are not statistically different. This finding validates the theoretical prediction that soil thickness uniformly affects the behavior of piped and non-piped households, offering additional evidence that equilibrium dynamics are important for household sanitation.[23]

Like piped water, soil thickness has countervailing health effects. Thick soil provides a direct benefit by protecting local groundwater, but may cause an adverse sanitary response. While thick soil unambiguously harms piped households, these effects partially offset each other for non-piped households. Columns 5 and 6 of Table 8 test these predictions (expressions (12) and (13) from the model), showing the effects of soil thickness on diarrhea for both piped and non-piped households. In Column 5, there is no significant effect of soil thickness on diarrhea for non-piped households, while thick soil significantly worsens diarrhea for piped households in Column 6. Piped households in areas with the thickest soil experience 0.53 more cases of diarrhea than piped households in areas with the thinnest soil. For both piped and non-piped households, the effects of soil thickness on health match the model's predictions.

7 Conclusion and Policy Implications

In developing countries, governments often inadequately provide local public goods, and community members must furnish these goods privately through their own actions. This is particularly true for sanitation in Metro Cebu, where the government does not provide

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[23] Given the correlation between piped water and soil thickness, I control for piped water prevalence in sanitation and health regressions as a robustness check. Under this specification, sanitation and diarrhea results are qualitatively similar, but results are now significant at the 10 or 15 percent threshold.

adequate sewage treatment or trash collection. In this context, being clean requires time and effort, and households are tempted to cut corners and pollute the environment. Social norms of cleanliness counteract this temptation, but are costly to enforce and are a burden upon everyone. When a technology such as piped water reduces the importance of providing the public good, the cooperative equilibrium may not survive. Policy interventions must tread lightly because slight changes in incentives can have drastic ramifications.

This paper makes the counterintuitive argument that efforts to improve the health of poor people by upgrading water supply can actually make them sicker. The policy implications of this argument are straightforward. To avoid disrupting a positive equilibrium in sanitation, policymakers should accompany water supply improvements with parallel investments in sanitary infrastructure. These investments–in latrine construction and maintenance, and sewage infrastructure–lower the convenience cost, c, in the model, offsetting reductions in sensitivity that water supply improvements bring about. By upgrading latrines concurrently, policymakers can avert the decline in sanitary conditions that may accompany a water supply improvement. This approach requires a change in orientation from the current focus on water.

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Table 1: Comparisons of Means for Water Supply, Sanitation and Household Characteristics

Partition:	By Piped Water Prevalence		Changes Over Time	
Group:	Low	High	1983	2005
	(1)	(2)	(3)	(4)
Piped Water	0.07	0.71	0.21	0.39
	(0.00)	(0.01)	(0.01)	(0.01)
Sanitation (no defecation)	0.57	0.43	0.67	0.59
	(0.01)	(0.01)	(0.01)	(0.01)
Sanitation (no garbage)	0.36	0.30	--	0.46
	(0.01)	(0.01)		(0.01)
Education (maximum)	9.47	11.46	9.40	11.97
	(0.04)	(0.05)	(0.06)	(0.08)
Age (head)	40.3	43.1	34.8	47.3
	(0.12)	(0.16)	(0.21)	(0.28)
Keeps animals	0.65	0.39	0.55	0.48
	(0.01)	(0.01)	(0.01)	(0.01)
Flush toilet	0.52	0.81	0.48	0.79
	(0.01)	(0.01)	(0.01)	(0.01)
No toilet	0.38	0.07	0.28	0.18
	(0.01)	(0.00)	(0.01)	(0.01)
Age Composition (%)				
Age < 5	0.16	0.11	0.24	0.10
	(0.00)	(0.00)	(0.003)	(0.003)
Age 5-10	0.14	0.11	0.10	0.05
	(0.00)	(0.00)	(0.002)	(0.002)
Age 11-15	0.14	0.14	0.06	0.09
	(0.00)	(0.00)	(0.002)	(0.003)
Age > 15	0.56	0.64	0.60	0.76
	(0.002)	(0.003)	(0.004)	(0.005)
Home construction (%)				
Light	0.39	0.29	0.43	0.26
	(0.01)	(0.01)	(0.01)	(0.01)
Mixed	0.45	0.52	0.39	0.58
	(0.01)	(0.01)	(0.01)	(0.01)
Strong	0.15	0.19	0.18	0.17
	(0.00)	(0.01)	(0.01)	(0.01)
Number of Observations	8209	4813	3327	1772

Note: standard errors appear in parentheses.
Sanitation is an indicator that there is little or no defecation/garbage near the respondent's home. Piped water is an indicator that the households receives MCWD piped water.
Education is the maximum individual level within the household. Age is for the household head, as reported in the survey.
"Light" home construction: only nipa or similar construction materials. "Medium" home construction: foundation of wood or cement with nipa walls or roof. "Strong" home construction: wood or cement foundation and walls, galvanized iron roof.
High and low prevalence samples are split according to the mean piped water prevalence, 0.306.

Table 2: OLS and Fixed Effects Regressions of Sanitation and Diarrhea on Piped Water Prevalence

Dependent variable:	Sanitation (no defecation)			Sanitation (no garbage)			Diarrhea	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Piped water (bgy mean)	-0.242	-0.240	-0.224	-0.145	-0.147	0.063	0.695	0.662
	(0.055)	(0.055)	(0.063)	(0.051)	(0.051)	(0.070)	(0.256)	(0.257)
Education (max)	0.023	0.021	-0.005	0.026	0.023	0.002	-0.016	-0.008
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.011)	(0.011)
Age (head)	-0.003	-0.003	-0.001	0.000	-0.001	0.000	0.0001	0.00003
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.003)	(0.003)
Household characteristics	No	Yes	Yes	No	Yes	Yes	No	Yes
Household fixed effects	No	No	Yes	No	No	Yes	No	No
F statistic (household chars.)	--	17.62	7.52	--	8.33	8.28	--	6.08
		(0.00)	(0.00)		(0.00)	(0.00)		(0.00)
Number of observations	12,861	12,861	12,861	9,538	9,538	9,538	3,259	3,259
R squared	0.041	0.052	0.347	0.036	0.044	0.322	0.197	0.205

Note: standard errors, which appear in parentheses, are clustered at the barangay and are robust to heteroskedasticity.

Sanitation is an indicator that there is little or no defecation/garbage near the respondent's home. Diarrhea is the frequency of morbidity for any household member over twelve intervals. Defecation data are present in all rounds, while garbage is not available in round 1, and diarrhea is only available in round 1.

Piped water (bgy mean) is the percent of sample households in the barangay who use MCWD piped water, including the index household.

Education is the maximum individual level within the household. Age is for the household head, as reported in the survey.

Household characteristics include (1) the household size, (2) whether the household keeps animals, (3) age composition categories following Table 1, and (4) the percent of the household that is male.

Table 3: Instrumental Variables Regressions (First Stage) of Sanitation and Diarrhea on Piped Water Prevalence

Sample:	Sanitation (no defecation)		Sanitation (no garbage)		Diarrhea	
Dependent variable:	Piped water (bgy mean)					
	(1)	(2)	(3)	(4)	(5)	(6)
Distance to boundary	-0.042	-0.040	-0.049	-0.048	-0.023	-0.020
	(0.015)	(0.014)	(0.015)	(0.015)	(0.014)	(0.013)
Groundwater salinity	0.002	0.002	0.002	0.002	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Elevation threshold	-0.245	-0.227	-0.268	-0.254	-0.190	-0.170
	(0.090)	(0.087)	(0.096)	(0.094)	(0.083)	(0.077)
Education (max)	0.013	0.011	0.012	0.009	0.012	0.010
	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)
Age (head)	0.003	0.002	0.001	0.001	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)
Household characteristics	No	Yes	No	Yes	No	Yes
F statistic (IVs)	9.06	8.41	9.62	8.89	3.96	3.66
	(0.00)	(0.00)	(0.00)	(0.00)	(0.02)	(0.02)
Number of observations	12861	12861	9538	9538	3259	3259
R squared	0.347	0.366	0.397	0.411	0.246	0.275

Note: standard errors, which appear in parentheses, are clustered at the barangay and are robust to heteroskedasticity. For diagnostic statistics, p values appear in parentheses.

Sanitation is an indicator that there is little or no defecation/garbage near the respondent's home. Diarrhea is the frequency of morbidity for any household member over twelve intervals. Defecation data are present in all rounds, while garbage is not available in round 1, and diarrhea is only available in round 1.

Piped water (bgy mean) is the percent of sample households in the barangay who use MCWD piped water, including the index household.

Education is the maximum individual level within the household. Age is for the household head, as reported in the survey.

The Hansen J statistic and the Anderson-Rubin statistic are distributed chi squared. The Hansen J statistic tests whether the instruments are exogenous. The Anderson-Rubin statistic tests the significance of the endogenous regressor under weak instruments.

First-stage regressions include all independent variables from the second stage.

"Distance to boundary" is the distance from the barangay to the nearest point on the boundary between limestone and alluvial suface geology (see Figure 4). "Groundwater salinity" is the estimated salinity (ppm) in a barangay in 1985. "Elevation threshold" is an indicator for barangays that lie above 40 meters.

Table 4: Instrumental Variables Regressions (Second Stage) of Sanitation and Diarrhea on Piped Water Prevalence

Dependent variable:	Sanitation (no defecation)		Sanitation (no garbage)		Diarrhea	
	(1)	(2)	(3)	(4)	(5)	(6)
Piped water (bgy mean)	-0.279	-0.292	-0.260	-0.279	1.623	1.746
	(0.099)	(0.108)	(0.072)	(0.079)	(0.686)	(0.753)
Education (max)	0.024	0.022	0.028	0.026	-0.036	-0.027
	(0.003)	(0.004)	(0.003)	(0.003)	(0.014)	(0.014)
Age (head)	-0.003	-0.003	0.000	-0.001	0.001	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.003)
Household characteristics	No	Yes	No	Yes	No	Yes
F statistic (household chars.)	--	19.41	--	9.77	--	6.20
		(0.00)		(0.00)		(0.00)
Hansen J statistic	0.16	0.20	0.37	0.39	1.10	0.95
	(0.92)	(0.91)	(0.83)	(0.82)	(0.58)	(0.62)
Anderson-Rubin statistic	8.64	8.76	19.19	20.46	9.75	9.76
	(0.03)	(0.03)	(0.00)	(0.00)	(0.02)	(0.02)
Number of observations	12861	12861	9538	9538	3259	3259
R squared	0.041	0.051	0.030	0.036	0.181	0.185

Note: standard errors, which appear in parentheses, are clustered at the barangay and are robust to heteroskedasticity. For diagnostic statistics, p values appear in parentheses.

Sanitation is an indicator that there is little or no defecation/garbage near the respondent's home. Diarrhea is the frequency of morbidity for any household member over twelve intervals. Defecation data are present in all rounds, while garbage is not available in round 1, and diarrhea is only available in round 1.

Piped water (bgy mean) is the percent of sample households in the barangay who use MCWD piped water, including the index household.

Education is the maximum individual level within the household. Age is for the household head, as reported in the survey.

The Hansen J statistic and the Anderson-Rubin statistic are distributed chi squared. The Hansen J statistic tests whether the instruments are exogenous. The Anderson-Rubin statistic tests the significance of the endogenous regressor under weak instruments.

Household characteristics include (1) the household size, (2) whether the household keeps animals, (3) age composition categories following Table 1, and (4) the percent of the household that is male.

Table 5: OLS, Fixed Effects and IV Regressions of Educational Outcomes on Piped Water Prevalence

Model:	OLS		IV	OLS		IV
Dependent variable:	Enrollment			Grade for age		
	(1)	(2)	(3)	(4)	(5)	(6)
Piped water (bgy mean)	-0.028	0.272	-0.064	0.009	0.080	0.003
	(0.051)	(0.225)	(0.068)	(0.014)	(0.028)	(0.027)
Education (max)	0.027	0.007	0.028	0.023	0.010	0.023
	(0.003)	(0.004)	(0.003)	(0.002)	(0.002)	(0.002)
Age (head)	-0.001	0.002	-0.001	0.000	0.001	0.000
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.000)
Household characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Household fixed effects	No	Yes	No	No	Yes	No
F statistic (household chars.)	8.71	1.27	8.56	304.23	335.22	292.26
	(0.00)	(0.30)	(0.00)	(0.00)	(0.00)	(0.00)
Hansen J statistic	--	--	0.122	--	--	1.186
			(0.941)			(0.553)
Number of observations	6143	6143	6143	7869	7869	7869
R squared	0.062	0.433	0.061	0.422	0.707	0.4219

Note: standard errors, which appear in parentheses, are clustered at the barangay and are robust to heteroskedasticity.

Enrollment (available rounds 3-6) is the percent of the household's school-aged (6-16) children who are currently enrolled in school.

Grade for age (available rounds 1 and 3-6) is the ratio of the highest grade attained to (age-6), averaged across school-aged children.

Piped water (bgy mean) is the percent of sample households in the barangay who use MCWD piped water, including the index household.

Education is the maximum individual level within the household. Age is for the household head, as reported in the survey.

Instruments include distance to the limestone-alluvial boundary, groundwater salinity, and the 40 meter elevation threshold.

Table 6: OLS and Fixed Effects Regressions of Sanitation and Diarrhea on Own Water Supply and Piped Water Prevalence

Dependent variable:	Sanitation (no defecation)			Sanitation (no garbage)			Diarrhea	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Piped water (own)	0.018	0.019	-0.012	0.002	0.003	-0.033	-0.178	-0.183
	(0.018)	(0.017)	(0.019)	(0.023)	(0.022)	(0.013)	(0.093)	(0.096)
Piped water (bgy mean)	-0.260	-0.259	-0.212	-0.147	-0.150	0.096	0.870	0.840
	(0.056)	(0.056)	(0.068)	(0.057)	(0.057)	(0.073)	(0.305)	(0.312)
Education (max)	0.023	0.020	-0.005	0.025	0.023	0.002	-0.014	-0.006
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.011)	(0.011)
Age (head)	-0.003	-0.003	-0.001	0.000	-0.001	-0.001	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.003)	(0.003)
Household characteristics	No	Yes	Yes	No	Yes	Yes	No	Yes
Household fixed effects	No	No	Yes	No	No	Yes	No	No
F statistic (household chars.)	--	17.87	7.46	--	8.34	8.27	--	6.22
		(0.00)	(0.00)		(0.00)	(0.00)		(0.00)
Number of observations	12861	12861	12861	9538	9538	9538	3259	3259
R squared	0.041	0.052	0.347	0.036	0.044	0.322	0.198	0.206

Note: standard errors, which appear in parentheses, are clustered at the barangay and are robust to heteroskedasticity.

Sanitation is an indicator that there is little or no defecation/garbage near the respondent's home. Diarrhea is the frequency of morbidity for any household member

Piped water is an indicator that the household receives MCWD piped water. Piped water (bgy mean) is the percent of sample households in the barangay who use MCWD piped water, including the index household.

Education is the maximum individual level within the household. Age is for the household head, as reported in the survey.

Household characteristics include (1) the household size, (2) whether the household keeps animals, (3) age composition categories following Table 1, and (4) the percent of the household that is male.

Table 7: OLS Regressions of Water Quality on Soil Thickness

Sample:	Non-piped		Piped	
Dependent variable:	Water quality (ecoli: <100 colonies per 100 ml)			
	(1)	(2)	(3)	(4)
Soil thickness				
1-3 meters	0.200	0.196	0.126	0.128
	(0.090)	(0.090)	(0.080)	(0.076)
>3 meters	0.283	0.275	0.121	0.118
	(0.089)	(0.089)	(0.086)	(0.082)
Education (max)	0.005	0.004	-0.001	-0.001
	(0.003)	(0.003)	(0.001)	(0.001)
Age (head)	-0.001	-0.001	0.001	0.001
	(0.001)	(0.001)	(0.000)	(0.000)
Household characteristics	No	Yes	No	Yes
F statistic (household chars.)	--	2.67	--	1.68
		(0.03)		(0.22)
Number of observations	1940	1940	664	664
R-squared	0.147	0.155	0.117	0.135

Note: standard errors, which appear in parentheses, are clustered at the barangay and are robust to heteroskedasticity.

Ecoli>100 is an indicator of greater than 100 E. coli colonies per 100 ml in the respondent's water supply.

Soil thickness categories, which are the modal values within a barangay, represent the distance from the surface to underlying bedrock. Estimates show the effect relative to the excluded category, which is "<1 meter."

Education is the maximum individual level within the household. Age is for the household head, as reported in the survey.

Table 8: OLS Regressions of Sanitation and Diarrhea on Soil Thickness

Sample:	Non-piped	Piped	Non-piped	Piped	Non-piped	Piped
Dependent variable:	Sanitation (no defecation)		Sanitation (no garbage)		Diarrhea	
	(1)	(2)	(3)	(4)	(5)	(6)
Soil thickness						
1-3 meters	-0.043	0.026	-0.011	0.088	0.157	0.308
	(0.047)	(0.046)	(0.030)	(0.037)	(0.120)	(0.205)
>3 meters	-0.130	-0.105	-0.125	-0.092	0.164	0.536
	(0.055)	(0.059)	(0.040)	(0.052)	(0.190)	(0.182)
Education (max)	0.016	0.030	0.020	0.026	0.003	-0.038
	(0.003)	(0.002)	(0.003)	(0.004)	(0.011)	(0.010)
Age (head)	-0.003	-0.003	0.000	-0.001	-0.001	0.006
	(0.001)	(0.001)	(0.001)	(0.001)	(0.003)	(0.010)
Household characteristics	Yes	Yes	Yes	Yes	Yes	Yes
F statistic (household chars.)	17.86	4.57	14.34	1.09	4.96	8.04
	(0.00)	(0.00)	(0.00)	(0.40)	(0.00)	(0.00)
Observations	8913	3948	6271	3267	2593	666
R-squared	0.046	0.058	0.054	0.061	0.206	0.182

Note: standard errors, which appear in parentheses, are clustered at the barangay and are robust to heteroskedasticity.

Sanitation is an indicator that there is little or no defecation/garbage near the respondent's home. Diarrhea is the frequency of morbidity for any household member over twelve intervals. Defecation data are present in all rounds, while garbage is not available in round 1, and diarrhea is only available in round 1.

Soil thickness categories, which are the modal values within a barangay, represent the distance from the surface to underlying bedrock. Estimates show the effect relative to the excluded category, which is "<1 meter."

Education is the maximum individual level within the household. Age is for the household head, as reported in the survey.

The "piped" sample consists of households who receive MCWD piped water. Households without piped water make up the "non-piped" sample.

Appendix Table 1: Piped Water, Sanitation, and Household Characteristics by Soil Thickness

Soil thickness:	<1 meter (3)	1-3 meters (2)	>3 meters (1)
Piped Water	0.14	0.32	0.51
	(0.00)	(0.01)	(0.01)
Education (maximum)	9.4	10.9	10.8
	(0.05)	(0.07)	(0.05)
Age (head)	41.2	42.0	41.0
	(0.14)	(0.22)	(0.17)
Household size	6.55	6.48	6.54
	(0.03)	(0.05)	(0.04)
Keeps animals	0.67	0.53	0.41
	(0.01)	(0.01)	(0.01)
Flush toilet	0.48	0.79	0.72
	(0.01)	(0.01)	(0.01)
No toilet	0.45	0.11	0.11
	(0.01)	(0.01)	(0.00)
Age Composition (%)			
Age < 5	0.15	0.13	0.14
	(0.00)	(0.00)	(0.00)
Age 5-10	0.13	0.13	0.12
	(0.00)	(0.00)	(0.00)
Age 11-15	0.15	0.14	0.13
	(0.00)	(0.00)	(0.00)
Age > 15	0.58	0.60	0.60
	(0.00)	(0.00)	(0.00)
Home construction (%)			
Light	0.39	0.32	0.32
	(0.01)	(0.01)	(0.01)
Mixed	0.46	0.46	0.51
	(0.01)	(0.01)	(0.01)
Strong	0.14	0.21	0.17
	(0.00)	(0.01)	(0.01)
Number of Observations	5835	2648	4539

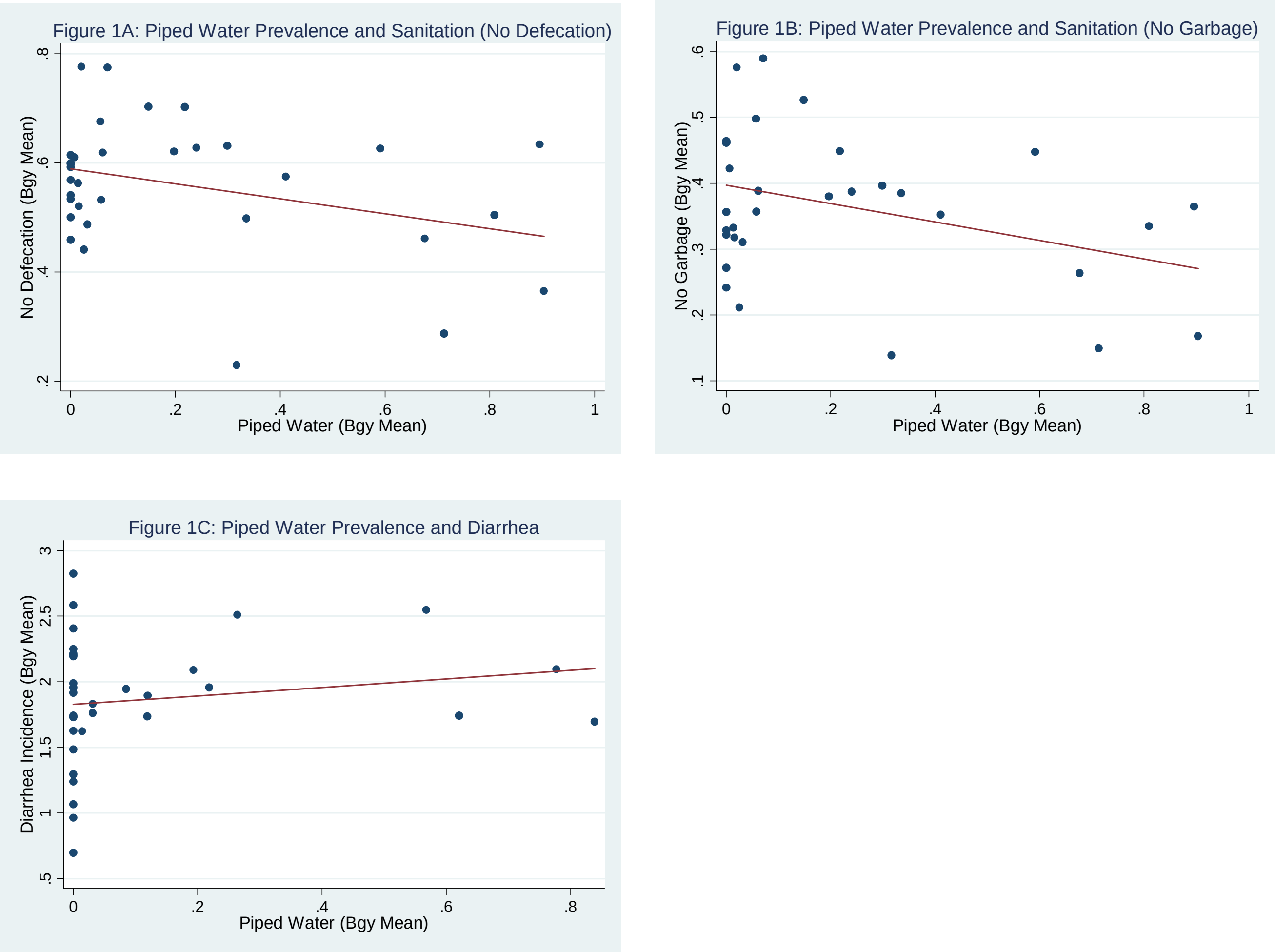
Note: standard errors appear in parentheses.

Soil thickness categories, which are the modal values within a barangay, represent the distance from the surface to underlying bedrock.

Education is the maximum individual level within the household. Age is for the household head, as reported in the survey.

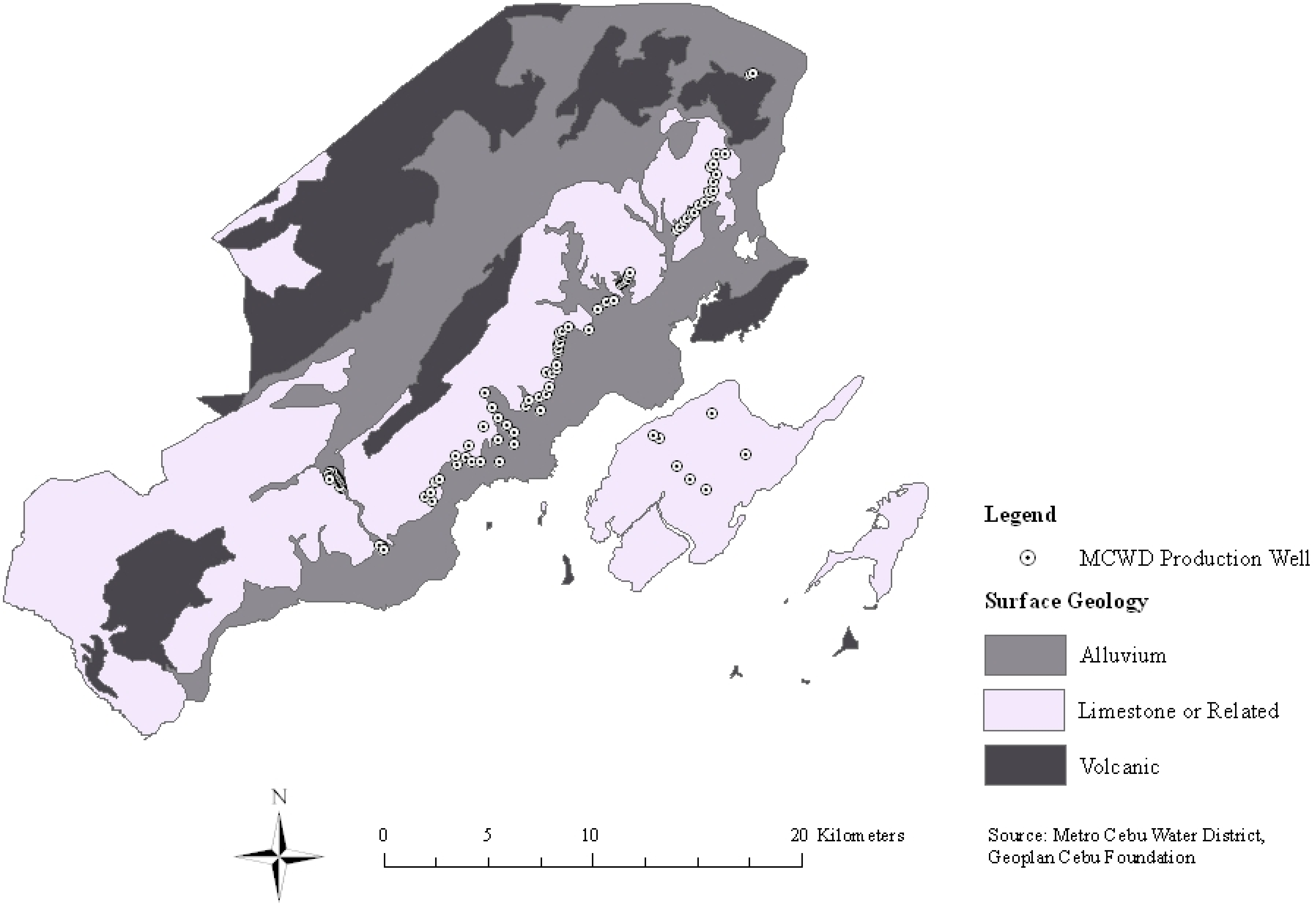
"Light" home construction: only nipa or similar construction materials. "Medium" home construction: foundation of wood or cement with nipa walls or roof. "Strong" home construction: wood or cement foundation and walls, galvanized iron roof.

Figure 1: Sanitation, Health, and the Prevalence of Piped Water



Note: Sanitation, health, and water supply outcomes are averages within the 33 sample barangays over all survey rounds in which data are available. Defecation data are present in rounds 1-6, garbage data are present in rounds 2-6, and diarrhea data are present in round 1.

Figure 2: Surface Geology and the Location of Municipal Source Wells in Metro Cebu

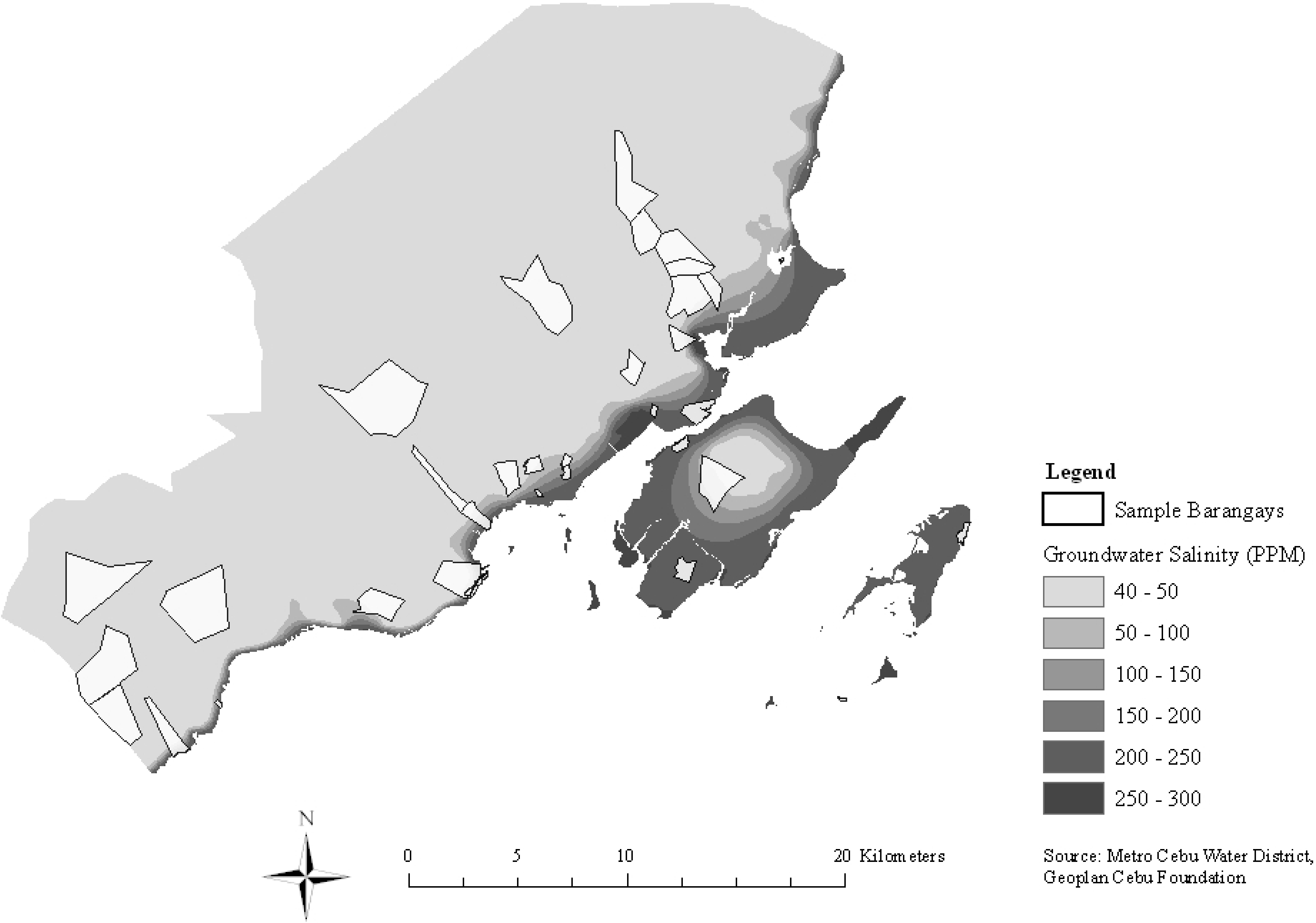


Source: Metro Cebu Water District,
Geoplan Cebu Foundation

Figure 3: Areas Above and Below 40 Meters and the Location of Municipal Wells in Metro Cebu

Source: Metro Cebu Water District, Geoplan Cebu Foundation

Figure 4: Groundwater Salinity (Parts per Million) in Metro Cebu, 1985



Source: Metro Cebu Water District, Geoplan Cebu Foundation