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

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Abstract

Improving the water supply is a common policy response to endemic diarrhea in developing countries. However, water supply interventions may inadvertently worsen community sanitation by mitigating the consequences of unsanitary behavior. Since sanitation has large health externalities, the impact of declining sanitation may overwhelm the benefit of receiving clean water. This paper shows how the expansion of municipal piped water in Metro Cebu, the Philippines has exacerbated public defecation and garbage disposal. According to estimates, a neighborhood's complete adoption of piped water increases public defecation and garbage by 15-30 percent. I rely on fixed effects, instrumental variables, and other robustness checks to discount competing explanations for this finding. Next I develop and test a simple model in which sanitation is a local public good. Empirical tests demonstrate that sanitation has large positive externalities and that piped water can exacerbate diarrheal disease.

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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). The root cause of diarrhea is poor sanitation, since contaminated excrement is critical to the fecal-oral transmission of these diseases. Poorly contained waste creates a health hazard either through direct contact or through pollution of local groundwater sources. Children, who lack acquired immunity, are particularly vulnerable to diarrhea, and most diarrheal deaths occur among children younger than two.

Common interventions to combat diarrhea include improvements in water supply, latrine construction projects, 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 not examined the underlying incentives and behaviors that perpetuate diarrheal disease. Behavioral factors may be crucial, since individual sanitation choices ultimately determine the community's exposure to diarrheal pathogens. Interventions such as improved water supply may alter households' sanitation in ways that interfere with the goal of improving health. Lacking this perspective, policymakers have emphasized improvements in drinking water as a primary 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.

Sanitary behavior is inconvenient but has large positive externalities. In communities that lack public provision of waste disposal, households contribute to a clean environment by building and maintaining latrines, disposing of their waste correctly, and removing any existing waste from the environment. These behaviors are costly to the individual but reduce the community-wide risk of disease. In this context, social norms are likely to evolve to promote sanitation. These rules of behavior further the provision of a local public good by overcoming the short-term incentive to free-ride off of others' clean behavior. A social norm of cleanliness implies a degree of mutual inconvenience, and the sustainability of this regime depends upon how much the community values sanitation.

A water supply improvement may reduce the benefit of sanitation in two ways. With poor sanitation, waste enters the groundwater through the soil and pollutes 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 recip-

ient from waste in the local environment and makes unsanitary conditions less hazardous. In addition, piped water often boosts the recipient's health directly because it is cleaner than alternative sources. If the health inputs of sanitation and clean water are substitutes, receiving piped water reduces the marginal benefit of sanitation. Through either mechanism, piped water desensitizes the recipient to sanitary conditions, shrinking the benefit that he or she derives 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 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 they do not establish causality. To rule out competing explanations for these findings, I employ community fixed effects and instrumental variables, which are subject to divergent sources of bias. The estimated effect of piped water is comparable across these specifications, which is consistent with a behavioral response but is inconsistent with the most likely competing explanations. Depending on the specification, a neighborhood's complete adoption of piped water increases the likelihood of observing excrement or garbage by 15-30 percent. The frequency of diarrhea is around 10 percent higher in areas where piped water is available.

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. There may be multiple equilibria with either high or low levels of sanitation depending upon the community's ability to cooperate. Cleanliness is costly, and the households only participate if the benefit from the clean equilibrium outweighs 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. Piped water has two countervailing effects on health in the model. 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 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 the 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. These results, which are consistent with a public-good model of sanitation, provide additional evidence of an endogenous sanitary response.

Based on these findings, the effectiveness of water supply improvements may be contingent upon the presence of sanitary infrastructure in the community. Under the model, the community's ability to cooperate after receiving piped water depends upon the cost of sanitary behavior. Adding piped water is most likely to cause an adverse response in places where cleanliness is difficult and costly. Policymakers should invest jointly in water supply and sanitation to avoid this unintended consequence.

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." While urgent action is clearly necessary, 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). The variability in these studies is understandable since sanitary infrastructure, which facilitates sanitary behavior, differs from place to place. In fact, other studies (Jalan and Ravallion 2003, Esrey 1996) find that the health benefits of piped water are contingent upon sanitary infrastructure and wealth.[1]

[1]The economics literature examining sanitation or other public 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. Galiani, Gertler and Schargrodsky (2005) find that

The history of water supply development in the United States is also relevant for this point. Cutler and Miller (2005) correlate investments in public waterworks with mortality declines in US cities in the late 19th and early 20th centuries. However, Melosi (2000, ch. 8-9) documents the multiple sewer and garbage investments that occurred concurrently. The presence of parallel investment in sanitation distinguishes the US case from Metro Cebu, in which little or no investment occurred. Sanitary infrastructure, which lowers the cost of clean behavior in the model developed below, reduces the prospect of an adverse sanitary response.

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, recent technological advances encouraged these changes by reducing the influence of cleanliness on health. Sanitation requires time and effort, and people conserve on these inputs when the payoffs are low.

While this paper is apparently the first to examine the effects of water supply on sanitation, other contexts feature a behavioral response that offsets a technological improvement. 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. Peltzman 1975, Cohen and Einav 2003, Keeler 1994). 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 Medi-

privatization of water supply in Argentina has significantly reduced child mortality. Kremer et al. (2007) find marginally significant reductions in diarrhea from spring protection in rural Kenya.

caid 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 induce a behavioral response.

Externalities become important when comparing the magnitude of a technological benefit with its compensatory response. If the behavior in question is strictly private, the technological benefit should outweigh the behavioral response in most cases.[2] 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 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). These parallels between piped water and ARV technologies suggest that water supply improvements may also lead to 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

[2]Technologies may have unintended consequences for reasons other than externalities. Arcidiacono et al. (2007) find that offering contraception may increase teen pregnancy if teens' utility functions exhibit habit persistence.

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. The agency primarily serves the population center and does not offer piped water in some remote barangays. 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). These private wells are technically illegal, but the government does not enforce the ban because the MCWD would be unable 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.

Since it was established in 1976, the MCWD has modestly broadened its geographic coverage area and intensified its service within the coverage area. To illustrate this pattern, I classify the barangays in the paper's main dataset (described below) based on whether piped water is available in each survey round.[3] Figure 1A plots the percent of barangays in which piped water is available by year. The share rises from 27 percent in 1983 to 55 percent in 2005. Significant growth in piped water prevalence also comes about through greater intensity of use within these areas. Figure 1B plots the annualized growth in prevalence among barangays where piped water is available. Until the end of the time frame, prevalence grows in these barangays by 2-3 percent per year. These figures demonstrate that variation in piped water prevalence arises through both expansion of the service area and more intensive use within this area.

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.

[3]To account for measurement error in piped water prevalence, I define barangays as having piped water available if prevalence exceeds 10 percent.

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 Filipino 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. 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.[4] Defecation data are available in all six panel rounds, while garbage data are available in all but the first round. The 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 week. I prefer the combination of these measures (whether *anyone* in the household had diarrhea), although both variables 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.

I rely on several household characteristics to illustrate patterns in the data and to control for observed heterogeneity in regressions to follow. The household's education and age are proxies for its health preferences and wealth. The household's education is defined as the maximum number of years attained by any member of the household. The household's

[4]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. As a robustness check, columns 1 and 4 of Appendix Table 1 reproduce the baseline results from Table 2 using an ordered probit model and the uncollapsed sanitation variables.

age is the age of the person designated in the survey as the household head. Since dogs, pigs, and roosters are commonplace in Cebu and produce a substantial amount of waste, I construct a dummy variable for whether the household keeps any of these animals. An indicator for whether the household has access to a toilet or latrine accounts for variation in sanitary infrastructure. I measure the demographic features of the household by calculating the percent of the household's members who are male, as well as the percent that fall into four age bins: 4 and under, 5 to 10, 11 to 15, and older than 15. An additional proxy for the household's wealth is the robustness of its house. Respondents' houses may be either "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.

The negative correlation between piped water and sanitation is evident in a cross-sectional comparison of neighborhoods. Table 1 reports the mean and standard error of piped water, sanitation, diarrhea, and related covariates, and Columns 1 and 2 divide the sample into areas with high and low prevalence of piped water according to the sample mean (0.31). Households in high prevalence areas are 14 percent less likely to exhibit "no defecation" and 6 percent less likely to exhibit "no garbage." Diarrheal morbidity is also 12 percent higher among these households than those in low-prevalence areas. Moreover, differences in other household characteristics do not account for these findings. Households in high prevalence 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. Based on these features, areas with piped water should exhibit better sanitation. An effect of piped water on sanitation behavior may explain this anomaly.

Trends over time depict 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.[5] Again, trends in other household characteristics seemingly favor improved sanitation. Education 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.[6]

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

[6]Attrition is high in the CLHNS, and could potentially drive some of these trends. However, summary

4 Sanitation and Piped Water Prevalence

In this section I estimate the relationship between barangay-wide piped water prevalence and household sanitation. Piped water, which is extracted elsewhere and is purer than alternative sources, reduces the household's marginal utility of sanitation. If community-wide choices and social norms determine sanitation, then average prevalence of piped water may affect household behavior. Regressions are based on the following equation:

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

where i indexes the household, j indexes the barangay, and t indexes the survey round. s is a binary measure of the household's sanitation and $\overline{w}$ is the proportion of the barangay's households with piped water, which is calculated in-sample and includes the index household. X is a vector of household characteristics that I use to control for observable heterogeneity across households. The most basic specification only controls for age and education, which are proxies for the household's health preferences and wealth.[7] Other specifications also control for the household's size, age and gender composition, and whether it keeps animals. Like education and age, these are determinants of sanitation that may be correlated with water supply. I estimate equation (1) using OLS, community fixed effects, and instrumental variables. By clustering standard errors within the barangay, I allow for an arbitrary correlation between the error terms of neighboring households, either contemporaneously or over time. Standard errors are also robust to heteroskedasticity.

Absent the random assignment of piped water to neighborhoods, several sources of bias may confound estimates of α_1. Cross-sectional heterogeneity in area characteristics may be correlated with the availability of piped water. For example, urban areas, which are dirtier and more congested, are more likely to receive piped water because of economies of scale in water delivery. Trends over time in sanitation and piped water may also interfere with estimates. As the area's population has grown from 1.0 million in 1980 to 1.6 million in 2000, the city center (where piped water is prevalent) has seen a differential increase in population density.[8]

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.

[7] Fixed effects regressions control for other barangay features that may affect sanitation; however, as an added robustness check, Columns 2 and 5 of Appendix Table 1 also include controls for the barangay's average age and education. Including these controls in the OLS regressions attenuates the coefficients by 7-15 percent but does not affect their significance.

[8] Residential sorting may introduce bias if households locate throughout the city based on their sanitation preferences. In order for residential sorting to bias in favor of the observed effects, inherently-clean households must *avoid* high-prevalence areas. This form of sorting is inconsistent with Table 1, which indicates that

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. 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 jointly determined, and local conditions may affect whether a household chooses to obtain piped water. A sanitation or health shock could, in principle, either persuade or dissuade a household to change water sources. In one natural story, households seek better health by adopting piped water in response to a negative shock; however the reverse response is also possible if a positive health shock reveals the benefit of avoiding infection.[9]

Measurement error in piped water prevalence introduces additional bias. $\overline{w}$ is the 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 $\overline{w}$. With a median of 52 annual observations per barangay, the attenuation bias due to sampling variation amounts to less than 1 percent of the magnitude of the coefficient estimates. 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 measurement error, which exerts an unknown bias.

Given these concerns, I approach identification by exploiting two distinct sources of variation. Both cross-sectional and time-series variation identify the effects of water supply on sanitation in OLS regressions. Regressions with barangay 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. This approach purges any bias due to fixed geographic heterogeneity. However, fixed effects regressions do not address the possible bias due from trends in sanitation or endogenous targeting of piped water to poor areas. To investigate this possible source of bias, I also carry out instrumental variables regressions that take advantage of exogenous cross-sectional variation. The instruments, discussed further below, exploit geological differences between barangays that are arguably uncorrelated with sanitation-related unobservables. In general, the OLS, fixed effects and IV

residents of high-prevalence areas should prefer better sanitation based on several characteristics.

[9]For some households sanitation may be associated with a monetary cost (for instance, if a proper toilet can only be used for a fee). In this case, the household's budget constraint may force a tradeoff between piped water and sanitation. Subsequent results, which show that $\overline{w}$ rather than w_i affects sanitation, minimize the importance of this scenario.

approaches give similar results, suggesting that the bias in these regressions is not extreme. Common explanations involving spurious correlation are incompatible with this consistency across diverse specifications.

4.1 OLS and Fixed Effects

Table 2 reports results for OLS and community fixed-effects estimates of equation (1). Columns 1 and 4 present the most parsimonious specification for "no defecation" and "no garbage" respectively, with controls for age and education. Columns 2 and 5 replicate these regressions, but also control for the household's demographic composition, 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 (0.34) is associated with a 7 point increase in the likelihood of defecation and a 5 point increase in the likelihood of garbage. Figure 2 represents these effects graphically by plotting barangay-average sanitation against piped water prevalence in the cross-section of barangays.

On their own, OLS regressions in Table 2 are partially identified from diverging trends in water supply and sanitation. It is possible to include year or municipality-year controls and obtain the effect of piped water based on 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).[10] Population density is the most likely sanitation shock that may spuriously generate an effect of piped water. Population growth may simultaneously spur the provision of piped water and strain existing 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. I control for population density in Columns 3 and 6 of Appendix Table 1 as a robustness check. 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.[11]

To account for bias due to heterogeneity across barangays, Columns 3 and 6 of Table 2

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

[11] 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. The results for these groups are qualitatively similar.

expand upon prior specifications and include barangay fixed effects. For the "no defecation" outcome, the fixed effects estimate is -0.34, which is even larger than under OLS. For "no garbage," the coefficient is correctly signed but the effect is attenuated and insignificant. The lack of data for this variable in the first round of the survey appears to explain this discrepancy.[12] Figure 3 illustrates these effects graphically by plotting each barangay's change in sanitation against its change in piped water prevalence. Both outcomes exhibit a negative relationship in changes, although there is a weaker relationship for "no garbage" in Figure 3B. The difficulty with Column 6 notwithstanding, fixed effects results indicate that cross-sectional heterogeneity among communities does not explain the correlation between water supply and sanitation.

4.2 Instrumental Variables

While time-constant heterogeneity does not appear to drive the relationship between water supply and sanitation, time-varying factors such as endogenous piped water adoption may contribute to a spurious correlation. To consider the relevance of this concern, I estimate specification (1) 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. Extraction is not feasible in the mountains because this volcanic rock conducts groundwater poorly. The following instruments reflect technical realities of groundwater extraction. The first two capture 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 4 is a map of Cebu that shows the main geological formations in the area and plots the locations of the

[12] To diagnose this problem, I exclude the first round from the "no defecation" fixed effects regressions. Without the first round, regressions for "no defecation" are also attenuated, though less severely. The coefficient on $\overline{w}$ becomes -0.17 with a standard error of 0.11. The large change in the coefficient relative to the standard error suggests that the effect of piped water is stronger early in the sample time frame, so that excluding these observations weakens the effect.

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.

- *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, than to face the technical challenge and expense of transporting it uphill. 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 5 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 and are much more difficult to serve.[13]

- *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 a map of Cebu, Figure 6 shows the salinity gradient for groundwater extracted at the water table in 1985. This estimate is based on MCWD salinity contour maps. 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

[13]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.

reflect natural salinity to a greater degree.[14]

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, which is significant at under 5 percent. 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. Elevation has a strong effect on the availability of piped water: the prevalence is around 25 percent lower in high elevation areas. The instruments are jointly significant in predicting piped water prevalence. First stage F statistics are between 8 and 10, indicating strong predictive power.

Second-stage estimates based on these instruments appear in Table 4. For both sanitation outcomes, the estimated coefficient on piped water prevalence is -0.26 to -0.29. Based on these estimates, a one standard deviation increase in piped water prevalence (0.34) increase the likelihood observing defecation or garbage by 9-10 percentage points. For "no defecation", the magnitude of the IV estimate falls in between the OLS (-0.24) and the fixed effects estimates (-0.36). For "no garbage," the IV estimate is larger in magnitude than either OLS or fixed effects. These regressions perform similarly in specifications that include year effects to control for generalized time trends (results not reported).

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 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. Conceptually, this test evaluates whether the instruments give similar predictions individually as they do jointly. Such a test is sensible in this context because the instruments affect adoption at different levels of prevalence. Table 4 reports the Hansen J statistic from a joint test of overidentifying restrictions. With p values greater than 0.8 in every case, the tests fail to reject the null hypothesis that the instruments are exogenous.

If the sanitation declines are a behavioral response to piped water adoption, regressions of unrelated outcomes on water supply should not show a negative relationship. As a final

[14] 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.

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 of educational attainment would 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 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 construct 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. Children who begin schooling at age 6 and remain 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 estimates for sanitation are not spurious.[15]

[15]By construction, regression samples for these outcomes only include households with school-aged children. In later survey rounds, some households do not have a value for these variables because their children are too old. To ensure that the changes in sample composition do not drive the findings in Table 5, I repeat the sanitation regressions (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

5 Sanitation as a Local Public Good

Results in the previous section indicate that adoption of piped water leads to declines in community sanitation. Table 1 also shows that areas with piped water have more frequent diarrheal morbidity. This section illustrates formally how these results may arise when sanitation has large positive externalities. I construct a model that parameterizes the extent of the positive externality, and I derive results for the limiting cases in which sanitation is either a purely public or private good. The public-good case is the basis for subsequent empirical tests while the private-good case provides a point of contrast.

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 are necessary to represent an infinitely repeated game, the outcome is based on time-constant parameters. Individual sanitation choices aggregate into community-wide sanitation, $\overline{s}_t = \frac{1}{n}\sum s_{it} \in [0, 1]$. Households incur an inconvenience cost, c, whenever $s_{it} = 1$, which reflects the time and effort required to stay clean. Each household has a health endowment, $\phi^w \geq 0$, and a sensitivity to dirtiness, $\gamma_i^w \geq 0$. The sensitivity is household-specific, and households with high values of γ_i^w suffer differentially as sanitation deteriorates. $F^w(\gamma)$ is the cumulative distribution function of γ^w. Both ϕ^w and γ_i^w depend upon the household's water source, $w \in \{p, a\}$, which is either "piped" or "alternative."

The household's health is defined in terms of the sanitary environment and its health endowment. In general, health depends upon the linear combination of s_{it} and $\overline{s}_t$: $\alpha s_{it} + (1 - \alpha)\overline{s}_t$, where $\alpha \in [0, 1]$:

$$h_{it}^w = \gamma_i^w(\alpha s_{it} + (1 - \alpha)\overline{s}_t - 1) + \phi^w \tag{2}$$

This formulation allows the parameter α to modulate the strength of the positive sanitation externality. Setting α to zero converts sanitation into a pure public good, while setting α to one converts it into a pure private good. For intermediate values of α, sanitation has a private benefits but also exhibits positive externalities. Below I develop the model for each of the limiting cases.

In the private-good case ($\alpha = 1$), the household's utility depends entirely on its own behavior. $s_{it} = 1$ gives utility of $\phi^w - c$ while $s_{it} = 0$ gives utility of $\phi^w - \gamma_i^w$, so that households choose $s_{it} = 1$ if and only if $\gamma_i^w \geq c$. In equilibrium, the unique level of provision

similar in the grade for age sample, but are insignificant in the enrollment sample.

is $\overline{s}_t = 1 - F^w(c)$, which is the proportion of the community for whom γ_i^w exceeds the cost threshold. The household's health is entirely a function of its own behavior and endowment: clean households receive $h_{it} = \phi^w$ while dirty households receive $h_{it} = \phi^w - \gamma_i^w$. Households' payoffs are independent of each other, leaving no scope for strategic play in either the one-shot or infinitely-repeated settings.

In the public-good case ($\alpha = 0$), strategy becomes relevant since households benefit from the cleanliness of their neighbors. I assume that $n > \gamma_i^w/c$ for all i, so that the household's choice of s_{it} is not influenced by any effect it may have on $\overline{s}_t$.[16] Each household now faces the following payoffs in a one-shot game:

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

Everyone prefers a high level of $\overline{s}_t$ but faces an incentive to free ride by exhibiting poor sanitation. Defection ($s_{it} = 0$) dominates cooperation ($s_{it} = 1$) as a strategy, and the household chooses to be dirty. The collective outcome in the one-shot game is a unique Nash equilibrium of non-provision ($\overline{s}_t = 0$), which is the standard "tragedy of the commons."

With infinite repetition of the game, the community can overcome the equilibrium of non-provision by threatening to punish defectors. Now, each household must weigh the stream of payoffs from cooperating and defecting under the community's punishment regime. Although the Folk Theorem assures that any $\overline{s}_t \in [0, 1]$ may be the outcome of Nash equilibrium strategies, I focus for tractability on the equilibria that arise when players follow "grim strategies." Players following grim strategies begin by cooperating, but respond to any defection by defecting in the subsequent period and in perpetuity thereafter. With discount factor δ and given previous cooperation, households face the following discounted payoff streams:

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

In this expression, the household obtains $v(s_{it} = 1)$ by cooperating and receiving $\overline{s}_t = 1$ from period t to ∞, while it obtains $v(s_{it} = 0)$ by defecting in period t and receiving $\overline{s}_t = 0$ from period $t + 1$ to ∞. Households maximize utility by cooperating if and only if

[16] Without this assumption, a household with a sufficiently large value of γ_i^w may prefer $s_{it} = 1$ because it can influence $\overline{s}_t$ through its contribution. Allowing for this possibility would depart from the Prisoner's Dilemma framework.

$\gamma_i^w \geq cn/(1-\delta+\delta n) \equiv \tau$. Since a defection brings unanimous and perpetual punishment under the grim strategies assumption, complete cooperation ($\overline{s}_t = 1$) and non-cooperation ($\overline{s}_t = 0$) are the only possible equilibrium outcomes. The community only achieves full cooperation when $\gamma_i^w \geq \tau$ for all i.

Because households are motivated by the threat of punishment, rather than the direct benefit of their sanitation, a unanimous preference for the clean outcome may be insufficient to sustain cooperation. Whenever $\gamma_i^w > c$, the household receives a higher one-shot payoff from joint cooperation than from joint defection. However, households only cooperate when $\gamma_i^w \geq cn/(1-\delta+\delta n)$, which is greater than c as long as $n > 1$. For values of γ_i^w that are between c and $cn/(1-\delta+\delta n)$, the household chooses to defect even though it prefers the one-shot cooperative payoff. This result illustrates that the community may be unable to sustain even a Pareto optimal outcome.[17]

5.2 The Impact of Piped Water

Piped water directly benefits the recipient household by exposing it to fewer pathogens, but the technology also desensitizes the household to unsanitary conditions. To formalize these ideas, let $\phi^p > \phi^a$, so that piped households have larger health endowments than non-piped households. Suppose as well that γ^a first order stochastically dominates γ^p: $F^p(\gamma) \geq F^a(\gamma)$. By this assumption, piped water tends to diminish a household's sensitivity to dirtiness, though households remain heterogeneous. The predicted effect of piped water depends upon whether sanitation is a public or private good.

5.2.1 Predictions of the Private-Good Framework

When sanitation is a pure private good ($\alpha = 1$), a household chooses $s_{it} = 1$ if and only if $\gamma_i^w \geq c$. For each water source, the probability that a household chooses $s_{it} = 1$ equals $1 - F^w(c)$. Piped households have worse sanitation than non-piped households because they have lower values of γ_i^w on average. However, the community-wide prevalence of piped water, $\overline{w} = \frac{1}{n}\sum w_i$, has no effect on behavior since each household's utility is independent of its neighbors' sanitary decisions.

[17] A straightforward generalization allows for non-unanimous sanitation behavior. Suppose the community detects and punishes a defector with exogenous probability, $\beta \in (0,1)$. Now a household only cooperates if $\gamma_i^w \geq cn(1-\delta+\delta\beta)/(1-\delta+\beta\delta n)$, which equals the original threshold when $\beta = 1$. For sufficiently low values of β, a subset of the community can cheat on the cooperative equilibrium without being detected, thereby preserving cooperation. 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.

Similarly, the household's own water source, rather than community-wide prevalence, determines the household's health. Setting $\alpha = 1$ in equation (2) and taking the expectation of health across the distribution of γ_i^w shows the average health by water source:

$$E(h_{it}^w) = \phi^w - F^w(c) \times E(\gamma_i^w \mid \gamma_i^w < c) \tag{5}$$

Piped water has two countervailing effects on health: it directly increases the health endowment, ϕ^w, while decreasing the likelihood of being clean. In general, the health effect of w_i is ambiguous because either effect may dominate. However, piped water improves health as long as ϕ^p is much larger than ϕ^a, so that piped water is substantially cleaner than non-piped water. Since $\overline{w}$ does not appear in expression (5), piped water prevalence does not affect health in this framework.

5.2.2 Predictions of the Public-Good Framework

In the public-good case ($\alpha = 0$), the community achieves cleanliness by enforcing the cooperative regime. The probability of obtaining the good outcome is the product of the individual probabilities that $\gamma_i^w \geq \tau$: $pr(\overline{s}_t = 1) = \prod_i (1 - F^w(\tau))$. With prevalence $\overline{w}$, the probability of cooperation is given by:

$$pr(\overline{s}_t = 1) = (1 - F^p(\tau))^{n\overline{w}}(1 - F^a(\tau))^{n(1-\overline{w})} \tag{6}$$

The prevalence of piped water matters critically, since piped households are more likely to defect. Differentiating this expression with respect to $\overline{w}$ 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.

$$\frac{\partial pr(\overline{s}_t = 1)}{\partial \overline{w}} = pr(\overline{s}_t = 1) \times n\Big(ln(1 - F^p(\tau)) - ln(1 - F^a(\tau))\Big) \leq 0 \tag{7}$$

Since sanitation behavior is unanimous within the community, the household's own water source is irrelevant for its sanitation. These predictions for w_i and $\overline{w}$ diverge from the private-good framework, in which the household's own water supply affects its sanitation but piped water prevalence does not.

In the public-good framework, household's health depends upon both w_i and $\overline{w}$. To show these results formally, I rely on the finding that only $\overline{s}_t = 0$ and $\overline{s}_t = 1$ are subgame-perfect Nash equilibria under the grim strategies assumption. Setting $\alpha = 0$ in equation (2) and taking the expectation over the distribution of γ_i^w gives an expression for expected

health that is parallel to equation (5):

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

According to this expression, expected health equals the health endowment minus the expected disutility of the dirty equilibrium. Now the effect of w_i is unambiguously positive: piped households have larger health endowments and lower sensitivities to dirty conditions. Health is decreasing in $\overline{w}$ because greater prevalence increases the probability of realizing the dirty equilibrium. Whereas the effect of w_i captures both the technological benefit and the sanitary response in the private-good case, here w_i isolates the benefit of the technology and $\overline{w}$ captures behavioral reaction. Panel A of Table 6 summarizes the theoretical predictions of the public-good and private-good frameworks.

5.3 Soil Thickness: Another Dimension of Sensitivity

In this model, the community's exposure to local pollution determines its support for the sanitation regime. This section shows how sanitation and health respond to soil thickness, which similarly affects the community's exposure to contamination. For families that drink from local groundwater, the soil is a natural shield against unsanitary conditions. Predatory organisms and sunlight and moisture fluctuations within the soil 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 and insulates the community from ambient contamination. In this respect, soil thickness is similar, though not precisely analogous, to piped water prevalence.[18]

This subsection distinguishes between piped and non-piped households to derive predictions for the effect of soil thickness on sanitation and health. The direct benefits of thick soil only extend to non-piped households, whose water supply is subject to contamination through the ground. By reducing groundwater contamination, thick soil increases the health endowment for this group. It also weakens the link between the quality of non-piped water and the level of surface contamination, and thereby desensitizes non-piped households to unsanitary conditions. To incorporate these features into the model, let the sensitivity and endowments of non-piped households, ϕ_a and γ_i^a, depend on soil thickness, ρ, and assume that $\partial\phi^a/\partial\rho > 0$ and that $\partial\gamma_i^a/\partial\rho < 0$. Soil thickness does not affect the endowments or sensitivity of piped households, so that ϕ^w and γ_i^w do not depend on ρ. The predicted

[18]Piped water is household specific, so it is sensible to distinguish between piped water prevalence and the household's own water supply. Since soil thickness is roughly constant within a community, it is impossible to disaggregate the individual benefit of thick soil from the health impact of the community-wide response.

effects of soil thickness on sanitation and health depend upon whether sanitation is a public or private good.

In the private-good framework ($\alpha = 1$), households choose to be clean if and only if $\gamma_i^w(\rho) \geq c$. Along with the household's water source, soil thickness determines whether the household is above or below the threshold. As developed above, the probability that a household is clean is: $pr(s_{it}^w = 1) = 1 - F^w(c, \rho)$. Differentiating this expression with respect to ρ shows that soil thickness decreases the sanitation of non-piped households but does not affect the sanitation of piped households. The health impact of soil thickness is clear from the modified expression (5), which shows each household's expected health: $E(h_{it}^w) = \phi^w(\rho) - F^w(c, \rho) \times E(\gamma_i^w(\rho) \mid \gamma_i^w(\rho) < c)$. For non-piped households, the sign of $\partial E(h_{it}^a)/\partial\rho$ is ambiguous since these households trade off thicker soil by polluting more. There is no effect of soil thickness on health for piped households, since ϕ^p and γ_i^p are independent of ρ.

In the public-good framework ($\alpha = 0$), households face an infinitely repeated Prisoner's Dilemma as before, and choose to cooperate if and only if $\gamma_i^w(\rho) > cn/(1 - \delta + \delta n) \equiv \tau$ 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 matches expression (6), 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.

$$\frac{\partial pr(\overline{s}_t = 1)}{\partial\rho} = -pr(\overline{s}_t = 1) \times \frac{n(1-q)}{1 - F^a(\tau, \rho)} \times \frac{\partial F^a(\tau, \rho)}{\partial\rho} < 0 \tag{9}$$

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 directly protects non-piped households by insulating groundwater from pollution; however, thick soil worsens health for everyone by exacerbating unsanitary conditions. For non-piped households, these effects counteract each other and the overall effect of soil thickness is ambiguous. Piped households do not receive any benefits from thick soil, so the effect on their health is negative. Panel B of Table 6 summarizes the theoretical predictions for soil thickness.

6 Empirical Tests

The model illustrates that expanding piped water provision may have unintended consequences if sanitation exhibits large positive externalities. In this case, improved water supplies can undermine a cooperative equilibrium and cause sanitation to worsen. Piped water may paradoxically make people sicker if this sanitation decline overwhelms the direct benefit of a cleaner water supply. This section tests the public-good framework by distinguishing between piped water prevalence and the household's own water supply. Results based on soil thickness provide additional support for this approach.

6.1 Effects of Piped Water

The regressions in Section 4 show an effect of piped water prevalence on sanitation that matches the prediction of the public-good framework and that is not consistent with competing hypotheses involving spurious correlation. An additional prediction of the public good approach is that piped water prevalence, rather than the household's particular water source, should determine its sanitation. By contrast, neither sanitation or health depends upon $\overline{w}$ in the private good framework. To test the extent to which the data from Cebu comply with either model, I regress sanitation and diarrhea on the household's own water source as well as piped water prevalence:

$$s_{ijt} = \alpha_0 + \alpha_1 w_{ijt} + \alpha_2 \overline{w}_{jt} + X'_{ijt}\alpha_3 + \epsilon_{ijt} \tag{10}$$

$$d_{ij} = \beta_0 + \beta_1 w_{ij} + \beta_2 \overline{w}_j + X'_{ij}\beta_3 + u_{ij} \tag{11}$$

In these specifications, w_i is an indicator that the household receives MCWD piped water, $\overline{w}$ 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 barangay 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 predictions of the public-good framework are that $\alpha_1 = 0$ and that $\alpha_2 < 0$, while $\beta_1 < 0$ and $\beta_2 > 0$.

Regressions for the sanitation outcomes appear in Table 7. Columns 1-3 show results for "no defecation" while Columns 4-6 show results for "no garbage." For each outcome, the table shows a short OLS specification, a specification that controls for additional household characteristics, and a specification that adds barangay fixed effects. For the "no defecation"

outcome, these regressions find a precisely estimated zero effect of w_i and a large negative effect of $\overline{w}$. For "no garbage," all specifications find zero effect of w_i and a negative effect of $\overline{w}$. The effect of $\overline{w}$ is significant in OLS regressions but is not significant under barangay fixed effects. As discussed in Section 4.1, the lack of data for "no garbage" in the first round of the survey may explain why this specification is inconsistent with other estimates. On the whole, an increase in prevalence of one standard deviation (0.34) increases the probability of observing defecation by around 8 percent and increases the probability of observing garbage by around 4 percent. These findings support the public-good framework by demonstrating that piped water prevalence, rather than the household's own water source, determines its sanitation behavior.

Table 7 also shows regressions for diarrhea. Column 7 shows a short OLS regression, while Column 8 also includes controls for household characteristics. Since the diarrhea data come from a cross-section, fixed effects are not available for these regressions. Piped households experience 0.18 fewer cases of diarrhea within the sample time frame than non-piped households, a 9 percent decline that is statistically significant at under 5 percent when additional controls are included. This finding supports the model's assumption that piped households have larger health endowments: $\phi^w > \phi^a$. It also provides a basis for the assumption that piped households have smaller sensitivities to dirtiness, γ_i^w: 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 regressions additionally show large effects of $\overline{w}$, conditional upon w_i. Point estimates range from 0.84 to 0.87, indicating that an increase in prevalence of one standard deviation (0.27) leads to a 12 percent increase in morbidity. These estimates are 25 percent larger than estimates that combine w_i and $\overline{w}$ (Table 2, Columns 7-8).[19] The sanitation effect of piped water prevalence counteracts the technology's direct health benefit.

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 and contaminate the non-piped water supply. In the private-good framework thick soil worsens the sanitation and ambiguously affects the health of non-piped households; it does not affect the sanitation or health of piped households. In the public-good framework, thick soil uniformly worsens

[19] 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.

the sanitation of both piped and non-piped households. It reduces the health of piped households but ambiguously affects the health of non-piped households. After using water quality measurements to confirm that thick soil protects the underlying groundwater, this section evaluates these sanitation and health predictions.

The CLHNS measures soil thickness through a categorical variable recorded in the first survey round. The possible values, which are 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. Given their similarity, I combine groups (1) and (2) and regress on two soil thickness categories (with one excluded). Appendix Table 2 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 positively 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).

The specifications below show the effects of soil thickness on 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. In the public good framework, thick soil leads to worse sanitation for both piped and non-piped households. For piped households, this sanitation decline exacerbates diarrhea; but for non-piped households, the protective properties of thick soil offset this decline. Because the model's sanitation and health predictions are conditional upon the household's water source, the following specifications treat piped and non-piped households separately.

$$s_{ijt} = \alpha_0 + \alpha_1 \rho_j + X'_{ijt}\alpha_2 + \epsilon_{ijt} \tag{12}$$

$$y_{ij} = \beta_0 + \beta_1 \rho_j + X'_{ij}\beta_2 + u_{ij} \tag{13}$$

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. I rely on this finding and use an indicator for whether the household's sample contains fewer than 100 colonies per 100 ml as a water quality outcome.[20] 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 8. 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 is associated with 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, which are also jointly significant. Results for piped households (Columns 3 and 4) are a falsification test for the non-piped results since soil thickness does not affect the quality of piped water in principle. As expected, these regressions find no effect of soil thickness on water quality, which is consistent with the claim that pathogenic attenuation drives the non-piped results.[21] Table 8 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 piped water is also insensitive to the level of surface contamination, which is modulated by soil thickness.

Table 9 evaluates the effect of soil thickness on the sanitation outcomes. Under the public-good case, thick soil leads to declines in sanitation for both piped and non-piped households. Columns 1 and 2 show results for "no defecation," while Columns 3 and 4 show results for "no garbage." For each outcome, the table shows results separately by household water source. Households in the thickest soil category are 10-13 percent more likely than those in the thinnest category to exhibit defecation and garbage. This effect is significant at under 10 percent, and pooling piped and non-piped households together improves significance to under 5 percent (not reported). Given the correlation between piped water prevalence and soil thickness, I include $\overline{w}$ in these specifications as a robustness check. Coefficients of ρ are attenuated and less precisely estimated in these regressions, but the qualitative results are unchanged (also not reported). These results show a community-

[20] 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.

[21] This interpretation relies on the assumption that surface pollution is uncorrelated with soil thickness. However, the model predicts and Table 9 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.

wide response to soil thickness that is consistent with the public-good framework.

Table 9 also examines the health impact of soil thickness. In the public-good case, thick soil clearly harms piped households by reducing community-wide sanitation. Its effect on non-piped households is ambiguous because thick soil's direct benefit offsets this sanitation decline to an unknown degree. Columns 5 and 6 show the health impact of soil thickness on non-piped and piped households, respectively. For non-piped households, there is no statistically significant effect of soil thickness on diarrhea, a result that is consistent with the offsetting effects of soil thickness for this group. However, soil thickness adversely affects the health of piped households, as the model predicts. Piped households in areas with the thickest soil experience 0.54 more cases of diarrhea within the sample time frame than piped households with the thinnest soil. These results provide further evidence in favor of the public-good formulation of sanitation.

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 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 they 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.

This paper makes the counterintuitive argument that efforts to help poor people by upgrading their 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)
Diarrhea	1.89	2.12	1.96	--
	(0.04)	(0.07)	(0.03)	
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)
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.

Diarrhea is the frequency of morbidity for anyone within the household over twelve one-week intervals. For this variable, Columns 1 and 2 divide the sample according to the mean prevalence in 1983: 0.21.

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 on Piped Water Prevalence

Dependent variable:	Sanitation (no defecation)			Sanitation (no garbage)		
	(1)	(2)	(3)	(4)	(5)	(6)
Piped water (bgy mean)	-0.242	-0.240	-0.358	-0.145	-0.147	-0.038
	(0.055)	(0.055)	(0.090)	(0.051)	(0.051)	(0.094)
Education (max)	0.023	0.021	0.019	0.026	0.023	0.022
	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)	(0.003)
Age (head)	-0.0032	-0.0027	-0.0025	0.0003	-0.0005	-0.0009
	(0.0010)	(0.0007)	(0.0006)	(0.0007)	(0.0007)	(0.0006)
Household characteristics	No	Yes	Yes	No	Yes	Yes
Barangay fixed effects	No	No	Yes	No	No	Yes
F statistic (household chars.)	--	17.62	28.12	--	8.33	11.03
		(0.00)	(0.00)		(0.00)	(0.00)
Number of observations	12861	12861	12861	9538	9538	9538
R squared	0.041	0.052	0.094	0.036	0.044	0.080

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. Defecation data are present in all rounds, while garbage is not 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: IV Regressions (First Stage) of Sanitation on Piped Water Prevalence

Dependent variable:	Piped water (bgy mean)			
Data rounds:	All		2-6	
	(1)	(2)	(3)	(4)
Distance to boundary	-0.042	-0.040	-0.049	-0.048
	(0.015)	(0.014)	(0.015)	(0.015)
Groundwater salinity	0.002	0.002	0.002	0.002
	(0.001)	(0.001)	(0.001)	(0.001)
Elevation threshold	-0.245	-0.227	-0.268	-0.254
	(0.090)	(0.087)	(0.096)	(0.094)
Education (max)	0.013	0.011	0.012	0.009
	(0.003)	(0.003)	(0.003)	(0.003)
Age (head)	0.003	0.002	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Household characteristics	No	Yes	No	Yes
F statistic (IVs)	9.06	8.41	9.62	8.89
	(0.00)	(0.00)	(0.00)	(0.00)
Number of observations	12861	12861	9538	9538
R squared	0.347	0.366	0.397	0.411

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. Defecation data are present in all rounds, while garbage is not 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: IV Regressions (Second Stage) of Sanitation on Piped Water Prevalence

Dependent variable:	Sanitation (no defecation)		Sanitation (no garbage)	
	(1)	(2)	(3)	(4)
Piped water (bgy mean)	-0.279	-0.292	-0.260	-0.279
	(0.099)	(0.108)	(0.072)	(0.079)
Education (max)	0.024	0.022	0.028	0.026
	(0.003)	(0.004)	(0.003)	(0.003)
Age (head)	-0.003	-0.003	0.000	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Household characteristics	No	Yes	No	Yes
F statistic (household chars.)	--	19.41	--	9.77
		(0.00)		(0.00)
Hansen J statistic	0.16	0.20	0.37	0.39
	(0.92)	(0.91)	(0.83)	(0.82)
Number of observations	12861	12861	9538	9538
R squared	0.041	0.051	0.030	0.036

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. Defecation data are present in all rounds, while garbage is not 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	0.331	-0.064	0.009	0.123	0.003
	(0.051)	(0.273)	(0.068)	(0.014)	(0.026)	(0.027)
Education (max)	0.027	0.026	0.028	0.023	0.022	0.023
	(0.003)	(0.002)	(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)	(0.000)	(0.000)
Household characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Barangay fixed effects	No	Yes	No	No	Yes	No
F statistic (household chars.)	8.71	14.79	8.56	304.23	280.20	292.26
	(0.00)	0.00	(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: Theoretical Predictions for Water Supply and Soil Thickness

Prediction for:	Sanitation		Diarrhea	
Framework:	Public	Private	Public	Private
	(1)	(2)	(3)	(4)
Panel A: Water Supply				
Piped water (own)	Zero	Negative	Negative	Ambiguous
Piped water prevalence	Negative	Zero	Positive	Zero
Panel B: Soil Thickness				
Piped households	Negative	Zero	Positive	Zero
Non-piped households	Negative	Negative	Ambiguous	Ambiguous

Table 7: 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	0.020	0.002	0.003	0.002	-0.178	-0.183
	(0.018)	(0.017)	(0.017)	(0.023)	(0.022)	(0.022)	(0.093)	(0.096)
Piped water (bgy mean)	-0.260	-0.259	-0.377	-0.147	-0.150	-0.040	0.870	0.840
	(0.056)	(0.056)	(0.097)	(0.057)	(0.057)	(0.105)	(0.305)	(0.312)
Education (max)	0.023	0.020	0.019	0.025	0.023	0.022	-0.014	-0.006
	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)	(0.003)	(0.011)	(0.011)
Age (head)	-0.0032	-0.0027	-0.0025	0.0003	-0.0005	-0.0009	0.0002	0.0001
	(0.0010)	(0.0007)	(0.0006)	(0.0007)	(0.0007)	(0.0006)	(0.0026)	(0.0030)
Household characteristics	No	Yes	Yes	No	Yes	Yes	No	Yes
Barangay fixed effects	No	No	Yes	No	No	Yes	No	No
F statistic (household chars.)	--	17.87	28.54	--	8.34	11.20	--	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	0.094	0.036	0.044	0.080	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. Defecation data are present in all rounds, while garbage is not available
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 8: 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 9: 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. Defecation data are present in all rounds, while garbage is not 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.

Table A1: Additional Robustness Regressions of Sanitation on Piped Water Prevalence

Dependent variable:	Sanitation (no defecation)			Sanitation (no garbage)		
Model:	Ordered Probit	Linear Probability Model		Ordered Probit	Linear Probability Model	
	(1)	(2)	(3)	(4)	(5)	(6)
Piped water (bgy mean)	-0.691	-0.222	-0.141	-0.439	-0.125	-0.101
	(0.142)	(0.066)	(0.051)	(0.136)	(0.060)	(0.051)
Education (max)	0.060	0.026	0.027	0.076	0.027	0.027
	(0.008)	(0.002)	(0.002)	(0.007)	(0.003)	(0.003)
Age (head)	-0.011	-0.0004	-0.001	-0.001	0.0004	0.0001
	(0.003)	(0.0005)	(0.001)	(0.002)	(0.0005)	(0.0007)
Education (bgy mean)		-0.015			0.002	
		(0.005)			(0.005)	
Age (bgy mean)		0.004			-0.010	
		(0.011)			(0.010)	
Houses within 50 meters			-0.008			-0.008
			(0.002)			(0.002)
Number of observations	12861	12861	9538	9538	9538	9538
R squared	0.026	0.057	0.041	0.026	0.037	0.043

Note: standard errors, which appear in parentheses, are clustered at the barangay and are robust to heteroskedasticity.
Ordered probit estimates use the four original sanitation categories. Linear probability estimates use the binary measure of sanitation.
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.
Education (bgy mean) and Age (bgy mean) are averages across households of "Education (max)" and "Age (head)"
Houses within 50 meters is the number of dwellings within a 50 meter radius of the index household. This variable is not available in the first survey round.

Table A2: Piped Water, Sanitation, and Household Characteristics by Soil Thickness

Soil thickness:	<1 meter	1-3 meters	>3 meters
	(3)	(2)	(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 1A: Percent of Barangays in which Piped Water is Available by Year

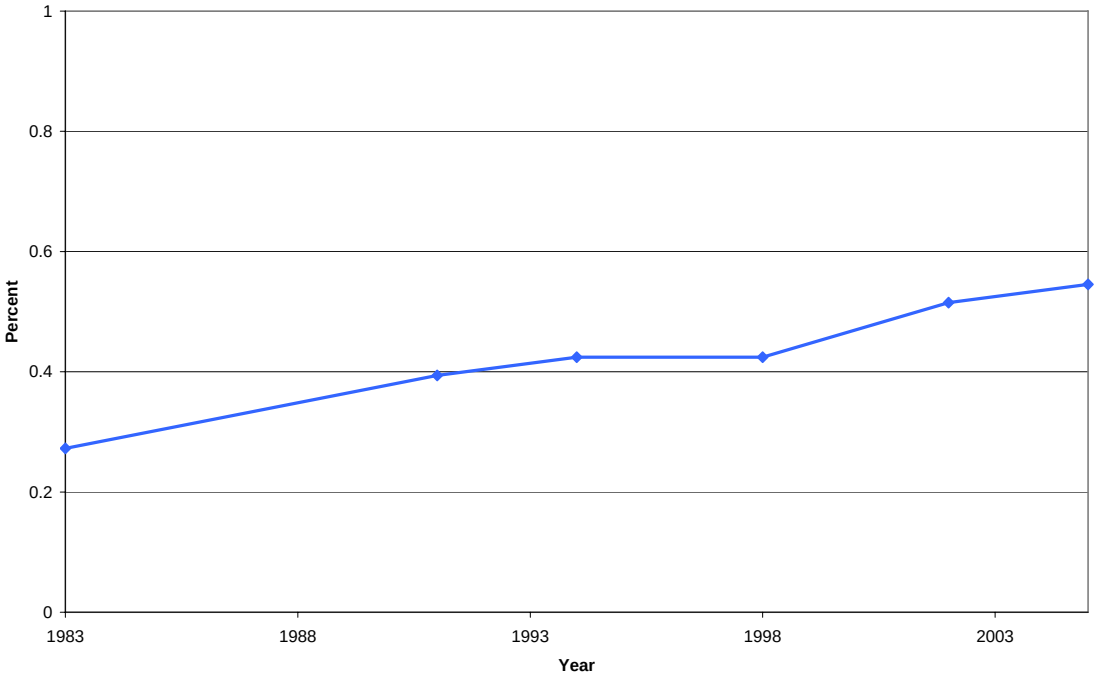


Figure 1B: Annualized Growth in Piped Water Prevalence for Barangays in Which Piped Water is Available by Year

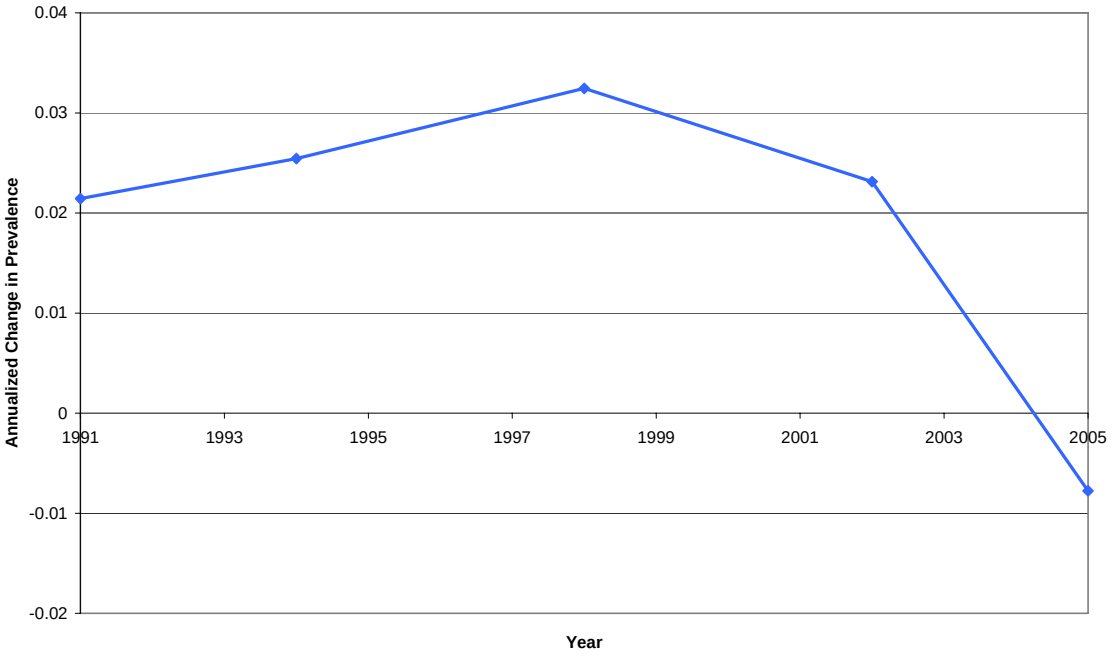


Fig. 2A: Piped Water Prevalence and Sanitation (No Defecation)

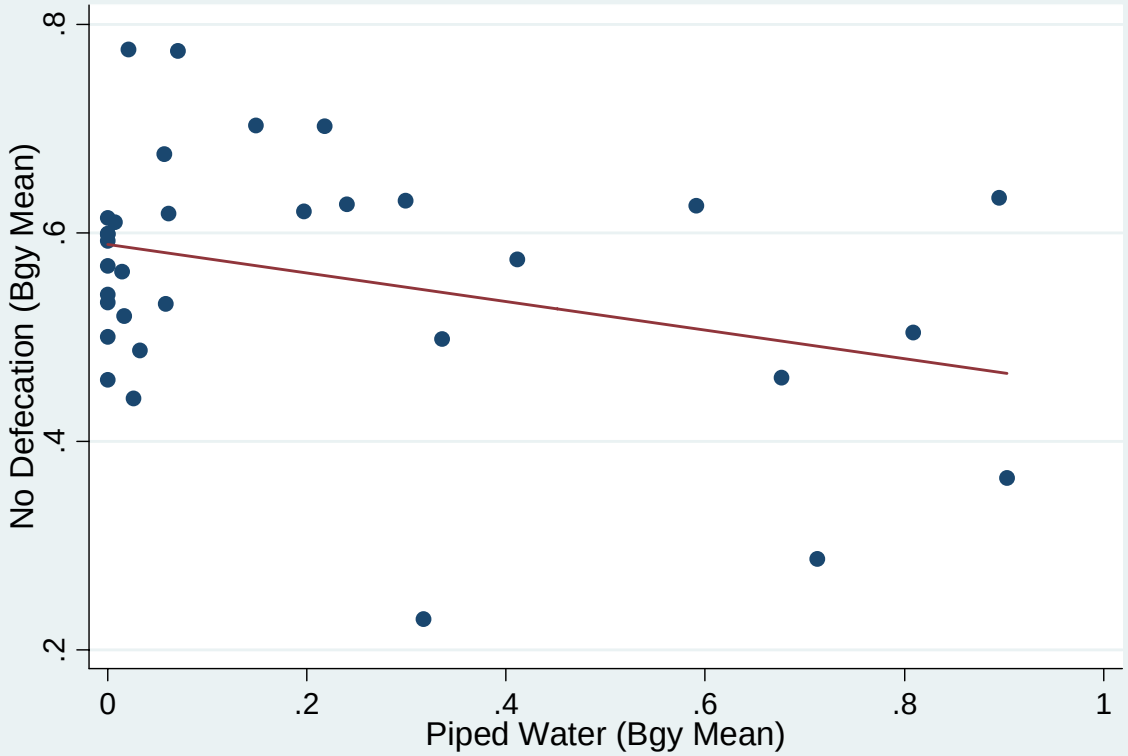


Fig. 2B: Piped Water Prevalence and Sanitation (No Garbage)

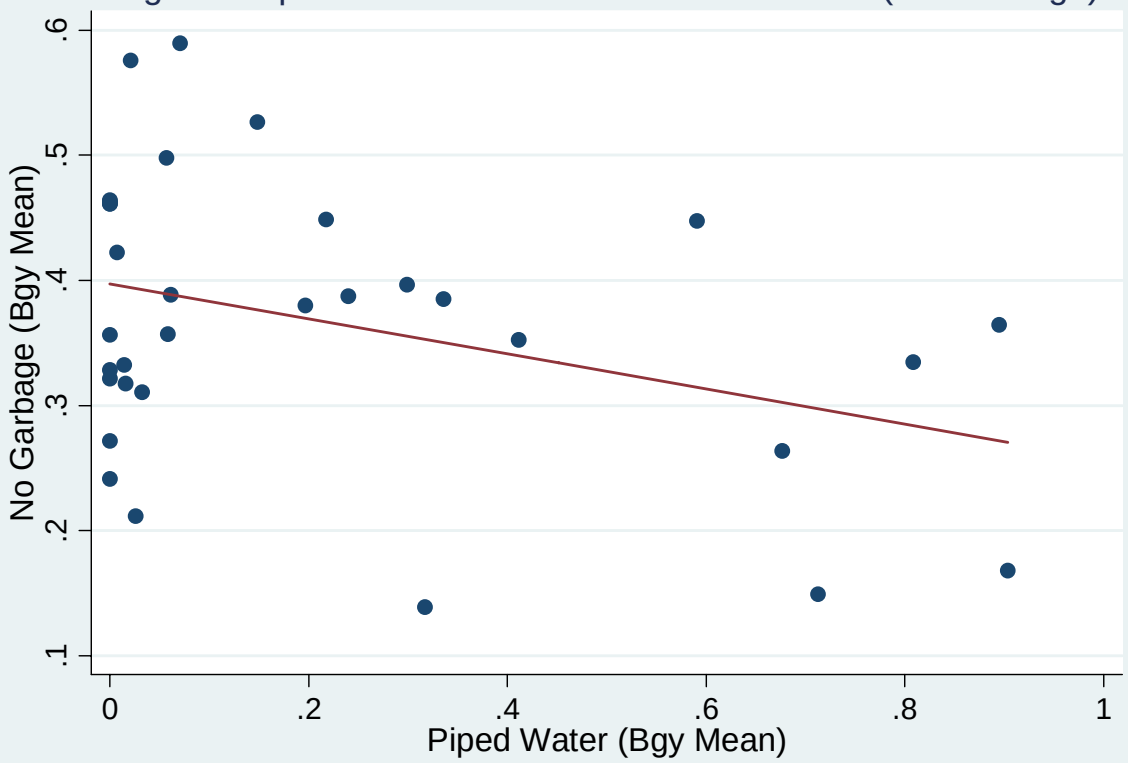


Fig. 3A: Changes in Piped Water Prev. and Sanitation (No Defecation)

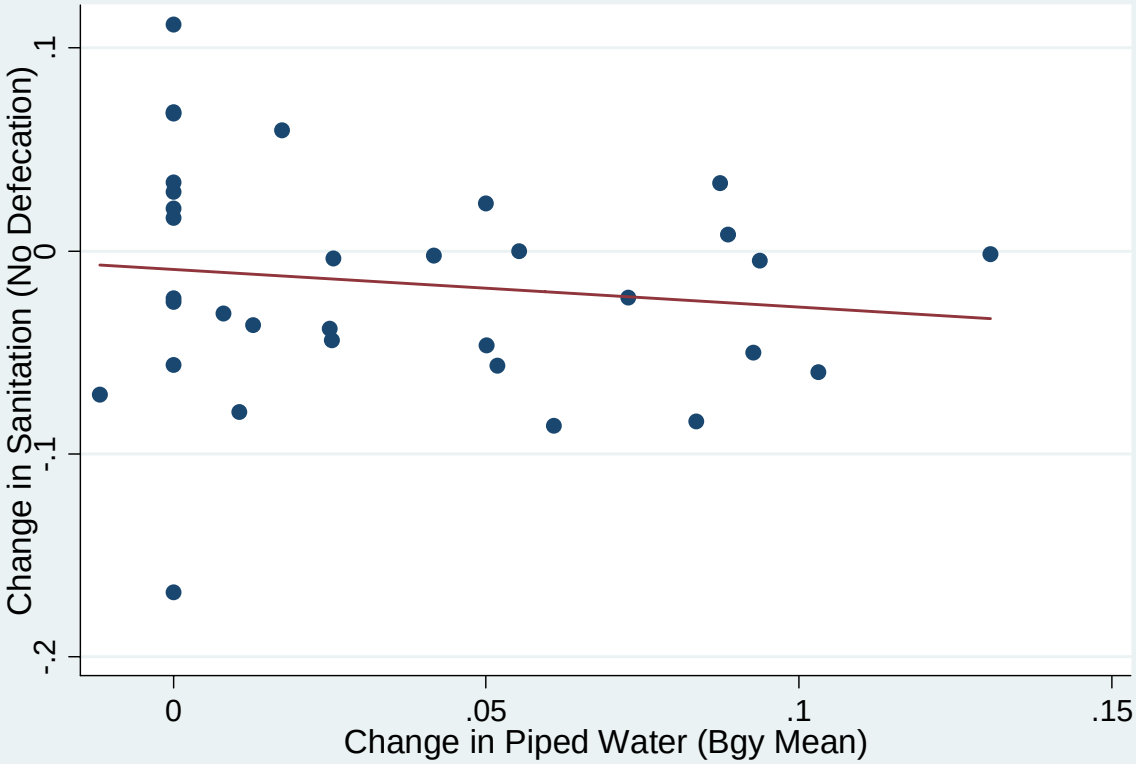


Fig. 3B: Changes in Piped Water Prev. and Sanitation (No Garbage)

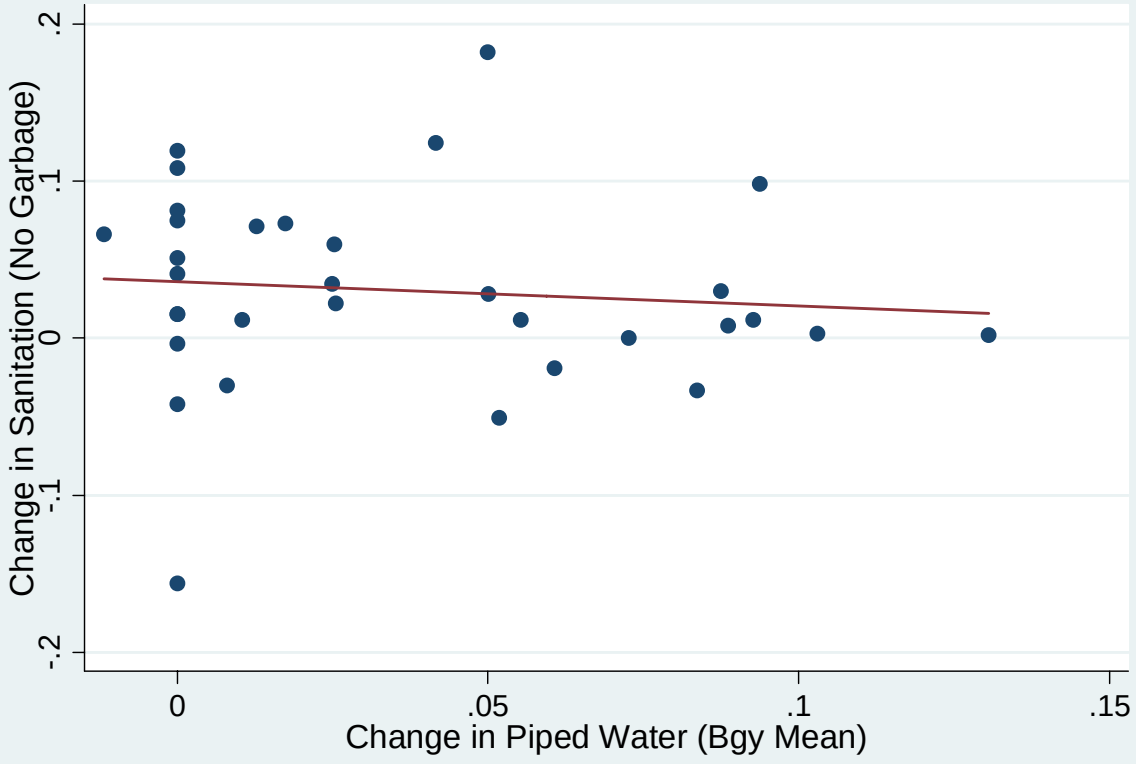


Figure 4: Surface Geology and the Location of Municipal Source Wells in Metro Cebu

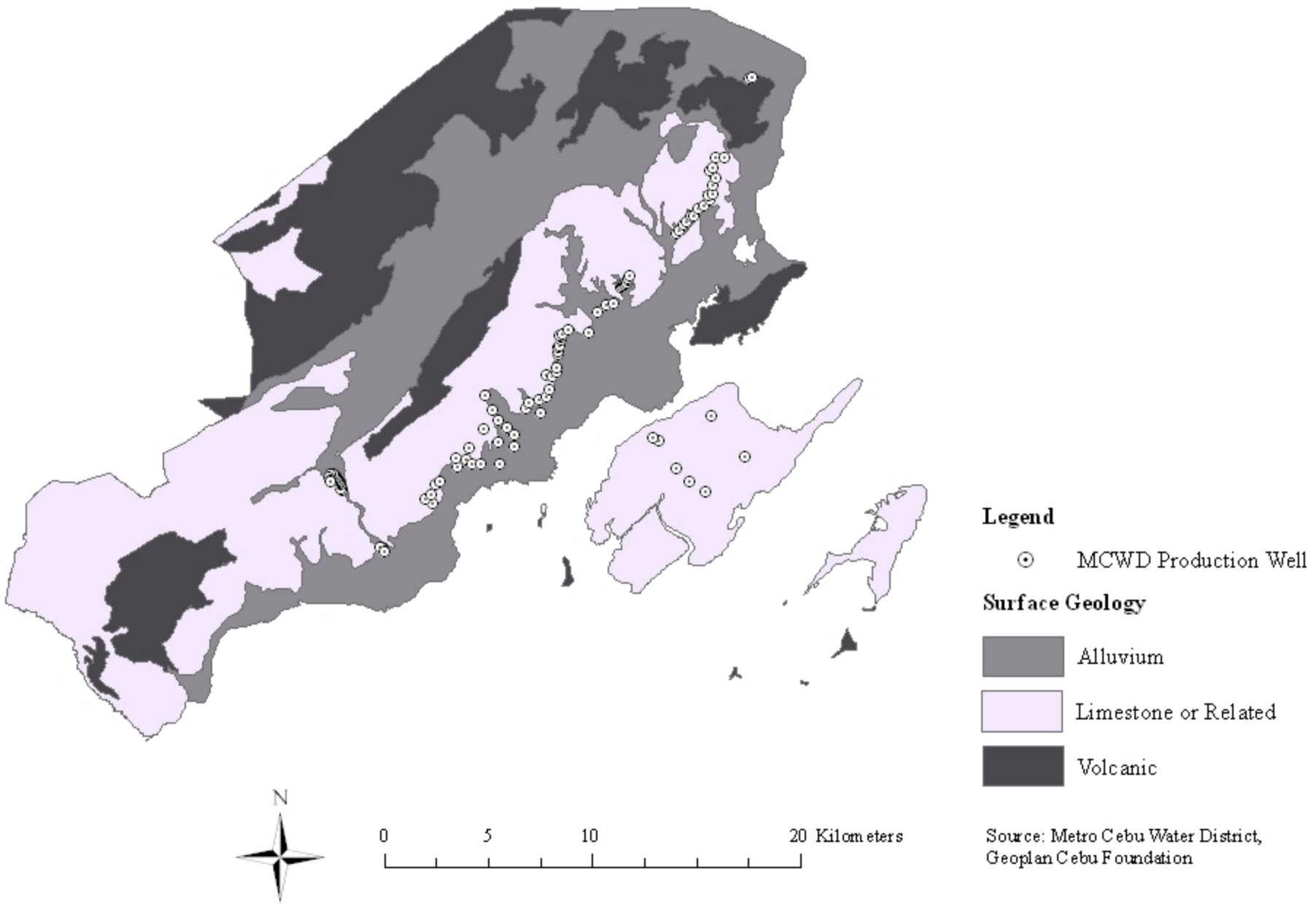


Figure 5: Areas Above and Below 40 Meters and the Location of Municipal Wells in Metro Cebu



Figure 6: Groundwater Salinity (Parts per Million) in Metro Cebu, 1985

