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Environmental Interventions in Developing Countries: Interactions and Their Implications

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This study assesses the effect of drinking water quality on diarrheal disease in good and poor sanitary conditions using a random sample of 2,355 Filipino infants over the first year of life. The study provides powerful confirmation of the importance of environmental factors on diarrhea: The effects of water quality, household sanitation, and community sanitation are strong, consistent, and statistically significant. The positive impact of improved water quality is greatest for families living under good sanitary conditions, with the effect statistically significant when sanitation is measured at the community level but not significant when sanitation is measured at the household level. Improving drinking water quality would have no effect in neighborhoods with very poor environmental sanitation; however, in areas with better community sanitation, reducing the concentration of fecal coliforms by two orders of magnitude would lead to a 40 percent reduction in diarrhea. Providing private excreta disposal would be expected to reduce diarrhea by 42 percent, while eliminating excreta around the house would lead to a 30 percent reduction in diarrhea. The findings suggest that improvements in both water supply and sanitation are necessary if infant health in developing countries is to be improved. They also imply that it is not epidemiologic but behavioral, institutional, and economic factors that should correctly determine the priority of interventions. *Am J Epidemiol* 1995;141:135–44.

developing countries; diarrhea, infantile; sanitation; water supply

Improving health in developing countries through the provision of water supply and sanitation systems has been an important goal of development agencies for decades. Due to the shortage of economic resources available to address these problems, there has been vigorous debate in recent years regarding the "optimal" sequencing of environmental interventions: Which type of intervention (improving water quality, improving access to water to encourage greater use, or improving excreta disposal) has the greatest impact on health and, as a result, should be carried out first?

A large number of studies have attempted to estimate the health effects from improving water supply and sanitation in developing countries. Many studies have reported large impacts, while others report little or no effect. While many of these studies suffer from methodological shortcomings (1, 2), even among the better designed studies, a wide range of impacts have been observed (3, 4).

While some of this variability may be attributed to differences in study design and analytical methods, there is a more fundamental issue at work as well. Where there are interactions among interventions, the effects of a particular intervention will depend not only on the intervention in question, but also on the other factors with which it interacts, notably the other interventions (3, 5, 6). For example, if the interactions are strong, the health impact from an improved water supply may depend critically on whether sanitation conditions of the community or of the family are good or poor. As discussed in detail below, the existence of such interactions has profound policy implications.

Theoretical models suggest that such interactions do exist between water supply and sanitation interventions, such that the impact from improvements in both water supply and sanitation would be greater than the sum of the effects from improving water supply or sanitation alone (3, 5, 6). However, few empirical studies have compared the effects from single and multiple interventions, with mixed results emerging.

The findings of four studies are consistent with the hypothesized effect. Two case-control studies of diarrheal disease in children (one in the Philippines (7) and one in Malawi (8)) found some evidence that improved water quality did have larger effects among households with better sanitation. However, the sam-

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Abbreviation: FC, fecal coliform.

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ple sizes were relatively small, and the differences in effect were not statistically significant. A prospective study in Lesotho (9) found a significant interactive effect of increased water usage and latrine ownership on infant weight gain and linear growth over a 6-month period, even though only four of the 119 study infants fell into the "good water/good latrine" category.

Three other studies, however, have shown interactions opposite from those expected, with improved water quality appearing to have smaller impacts in better sanitary conditions. A study of infant mortality in Malaysia reported significant protective effects of having a piped water supply or a toilet on infant mortality. The effect of having both facilities, however, was "less than would be expected from their separate beneficial effects" (10, p. 525), suggesting that the effect of piped water was smaller in households with good sanitation. In an intervention study in the Philippines (11), cholera was monitored in four communities with different levels of water supply and sanitation. While the communities with improved water supply and/or sanitation experienced significantly less cholera than the control community, the incidence in the community provided both services was only marginally less than the single-intervention communities. A large case-control study conducted in Sri Lanka (12, 13) found some evidence that latrine users derived fewer health benefits from an improved water supply, although the authors cautioned that latrine ownership could be acting as a proxy for economic status.

In summary, although a comprehensive review of the literature concluded that improving water quality appeared to have larger health impacts in areas with better environmental sanitation (2), the results of studies that specifically addressed this issue are inconclusive. A major shortcoming in virtually all of these studies is that sample sizes were usually too small to establish the statistical significance of the main effects, much less that of the interactions.

In this paper we attempt to address this important policy issue by taking advantage of a very large, high-quality data set (emanating from the Cebu Longitudinal Health and Nutrition Survey) and extensive prior work on developing a sound understanding of the determinants of diarrheal disease in the study population (14–18). The study assesses how the impact of improved drinking water quality varies with the level of community and household sanitation.

MATERIALS AND METHODS

Data collection

Household surveys. This analysis uses data from the Cebu Longitudinal Health and Nutrition Survey, a prospective study of children from birth to 2 years of age. The study setting is the island of Cebu, located in the central Visayan region of the Philippines, and includes two large cities, four smaller towns, and the surrounding periurban areas. The region has an estimated population of 1 million. Seventeen of the 155 urban barangays (political districts) were randomly selected, and all women residing in these barangays who gave birth between April 1983 and May 1984 were recruited. Of the 2,555 eligible women, 2,355 had single live births and agreed to participate in the study. The number of children in the study decreased over the study period from 2,220 at 2 months to 1,930 at the end of the first year. Most of the attrition was due to out-migration. There did not appear to be any selection bias associated with loss to follow-up (14).

The household survey consisted of a series of interviews by highly trained local fieldworkers. In the baseline survey conducted during the third trimester, detailed demographic and socioeconomic data were collected, the household's excreta disposal facility and drinking water source were identified, and the yard was inspected for the presence of fecal material. At each bimonthly interview, data were gathered on infant feeding and food preparation practices (including water boiling), the child's height and weight, preventive health care use, and diarrheal morbidity over the previous 7 days. The household's source of drinking water was verified at each survey. More information regarding the survey design and content is available elsewhere (14, 15).

Neighborhood environmental assessments. To assess the level of exposure to fecal material in the family's neighborhood, an experienced sanitary engineer carried out a series of environmental assessments. The 17 barangays were divided into 41 homogeneous areas or "neighborhoods." Each area was rated using structured observations in terms of housing density, type of settlement (e.g., squatter or periurban), presence of observable fecal material, predominant types of excreta disposal facilities, and frequency of flooding. The same individual conducted all assessments, and each area was surveyed twice over the course of the study to check for internal consistency.

Water quality sampling. The water source used by the family for drinking was identified at each bimonthly interview, and sanitary surveys were carried out at each source. Between two and five water samples were collected from each source over the course of a year; water sources with more variable quality (such as open dug wells) were sampled more frequently. The water samples were transported on ice to a laboratory where they were analyzed the following morning. Three serial volumes (1, 10, and 100 ml) were filtered through 45-μm glass fiber filters and incubated on M-FC agar at 44.5°C for 24 hours (19). The concentration of fecal coliforms (FCs) per 100 ml was estimated from the number of dark blue colonies observed on each filter. Nine percent of the samples analyzed (154 of 1,650) were not used due to uncharacteristic colonies or heavy background growth.

Model specification

This analysis uses a model of diarrheal disease in which the explanatory variables are partitioned into proximate biologic and behavioral determinants (e.g., nutritional status, breast-feeding practice) and underlying socioeconomic determinants (e.g., income, education). The latter factors do not directly affect the child's risk of diarrhea but have an indirect effect, influencing the parents' child-care choices such as how long to breast-feed or whether to boil their child's water. Only the proximate factors thought to directly affect the child's risk are included in the model. This approach was first proposed by Mosley and Chen (20) and later adapted by the Cebu Study Team to investigate the determinants of child health and growth (14, 15, 17).

Diarrheal disease. Diarrhea is measured by a dichotomous variable that, if positive, indicates that the child experienced diarrhea in the 7 days before the interview, as reported by the mother. The local term for diarrhea used in the questionnaire (*kalibang*) denotes frequent, watery stools. In a separate study conducted in the study area, the mother's recall of diarrheal morbidity based on the observation of frequent or loose stools had a sensitivity of 95–97 percent and a specificity of 80 percent when compared with diagnoses made at health clinics and hospitals (21).

Drinking water quality. Exposure to contaminated drinking water is measured as the $\log_{10}$ daily dose of fecal coliforms. As described in detail elsewhere (18), the dose for each child was estimated by multiplying the predicted concentration of fecal coliforms in their water source at the time of the interview by the amount of water that the child consumed. This dose was adjusted for water boiling as boiling significantly reduced the risk posed by contaminated drinking water (18).

Sanitation. Three variables are used to measure exposure to feces related to excreta disposal. The first variable measures the presence of fecal material in the yard and is used as an indicator of household sanitation practices.

Individuals may also be at risk when facilities are used but are in poor condition, exposing the user to the feces of previous users. A small observational study showed marked differences in the sanitary condition of 49 private and 70 public toilet facilities used by the study households (J. DeClerque, Sheps Center for Health Services Research, University of North Carolina at Chapel Hill, unpublished data, 1985). Fecal material was evident less frequently in private than in public facilities (0.18 vs. 0.34, $p < 0.08$), and littered paper, used for anal cleansing, was present far less frequently in private facilities (0.16 vs. 0.47, $p < 0.0001$). Accordingly, the second measure of sanitation is whether the excreta disposal facility used by the family was private or public.

The purpose of an excreta disposal facility is to isolate human wastes from the human environment so that pathogens in those wastes are not passed on to other individuals. A child whose family uses a toilet or latrine is less likely to come in contact with fecal material than a child whose family defecates indiscriminately in areas near the house. However, a child's exposure is affected not only by the way in which the family disposes of its excreta; children from households that use toilet facilities may still face considerable exposure if their neighbors do not use such facilities. Thus, a child's exposure is affected not only by his or her family's excreta disposal practices, but also by the practices of the community as a whole.

Housing density can have marked impact on the exposures due to indiscriminate defecation. In sparsely settled rural areas, defecation in fields may pose little risk to the community as a whole, while in crowded urban areas indiscriminate defecation by a small proportion of the population may significantly increase the entire community's exposure to pathogens. Thus, in high-density urban areas, inadequate excreta disposal can have the greatest impact on the transmission of diarrheal disease.

The neighborhood environmental assessments were used to identify neighborhoods facing the greatest risks due to inadequate excreta disposal. Neighborhoods with dense housing, poor drainage, and readily observable fecal material were classified as having "poor community sanitation."

Household hygiene. The level of water service (in-house vs. carried to the house) is used as a proxy for water use and water-related hygiene. The number of other preschool children and household crowding (number of persons/room) are included as measures of the likelihood of person-to-person transmission. The presence of animals in the house is used to measure exposure to pathogens from animal feces.

Feeding practices. Breast feeding may reduce or eliminate exposure to pathogens in contaminated foods (22–24) and may decrease the susceptibility to infection through antibodies present in breast milk (25, 26). Feeding practices 1 week prior to the survey are measured by two dichotomous variables indicating whether the infant was fully breast-fed or mixed-fed. Fully breast-fed infants were those who were exclusively breast-fed or who received nonnutritive liquids (e.g., water, teas, brews) in addition to breast milk. Exposure to pathogens in contaminated water used to make teas and brews was captured by the water quality variable. Mixed-fed infants were those given nutritive supplements such as formulas or gruels in addition to breast milk. Infants who were completely weaned were used as the comparison group.

Susceptibility factors. Children with poor nutritional status may be more susceptible to infection. The infant's weight at the previous interview, expressed in units of standard deviations from the sample mean of that age group, was used as a measure of nutritional status. The use of preventive health care (e.g., immunizations or well-baby checkups) in the past 2 months was also used as a measure of susceptibility.

Biologic factors. As in the other Cebu publications, changes in immunologic development over time were captured by including both age and age squared in the model (14, 15). The child's sex was included as a proxy for differential immunologic development. Rainfall in the past 2 weeks was used to capture seasonal effects such as enhanced survival of enteric pathogens in humid conditions.

Statistical methods

The severity of diarrhea for child i at time t ($D^*_{t,i}$) is specified as a function of the health-related behaviors affecting the child's exposure to pathogens and susceptibility to infection ($Y_{t-1,i}$), the child's nutritional status as measured by growth in the previous time period ($G_{t-1,i}$), and biologic exposure and susceptibility factors ($Z_{t,i}$):

$$D^*_{t,i} = \beta_1 Y_{t-1,i} + \beta_3 Z_{t,i} + \mu_{Di} + \epsilon_{Dt,i}. \quad (1)$$

However, since the severity of diarrhea is difficult to assess, the outcome used in this analysis is simply whether the mother reported the child to have experienced any diarrhea in the week preceding the interview. When the severity of diarrheal episode ($D^*_{t,i}$) exceeds some threshold, it is observed by the mother and reported at the interview:

$$D_{t,i} = \begin{cases} 0 \text{ when } D^*_{t,i} \leq 0 \\ 1 \text{ when } D^*_{t,i} > 0. \end{cases} \quad (2)$$

While several exposure and susceptibility factors are included in this analysis, there are other unobserved factors that affect the child's risk of diarrhea. These include the child's inherent ability to resist infection or particular practices in the child's family that increase or decrease the risk of diarrhea. These "omitted" factors are represented in equation 1 by the random error term μ_{Di}. The second error term ($\epsilon_{Dt,i}$) is a standard random disturbance assumed to be normally distributed and independent across individuals and through time.

Biases may arise if the unobserved factors affecting the child's risk of diarrhea are correlated with other unobserved factors affecting their exposure status. For example, a child with a poor ability to resist infection may be at a greater risk of diarrhea. If the child's mother recognizes this risk, she may be more apt to prolong breast feeding. Thus, the child's "unobserved" ability to resist infection would be correlated with his or her risk of diarrhea and with his or her feeding status. Ignoring this correlation could lead to a biased estimate of the effect of breast feeding on the risk of diarrheal disease. An instrumental variables technique, which has been described in detail elsewhere (14–16), was used to correct for this source of bias.

The data from the six longitudinal surveys covering the first year of life were combined into a data set containing one observation for each child at each point in time. A "random effects" probit model was used to describe the probability of diarrhea as a function of the explanatory variables. The random effects model specifies that the error term is made up of two components, a standard disturbance that is uncorrelated between cross-sections and time periods and an error term that is unique for each cross-section and does not vary with time. The parameters of the probit model were estimated using a maximum likelihood procedure found in the HOTZTRAN software (27).

Unlike logistic regression, the parameter estimates from a probit model cannot be directly interpreted in terms of epidemiologic measures of effect such as risk differences or risk ratios. Rather, simulations must be used to estimate these measures of effect. Once the parameters of the probit model ($\boldsymbol{\beta}$) have been estimated, a predicted probability of diarrhea can be computed given any set of values of the independent variables ($\mathbf{X}$) using the cumulative normal distribution function (ϕ):

Predicted $Pr(\text{diarrhea}|\mathbf{X})$ =

$$P(D = 1|\mathbf{X}) = \phi(\mathbf{X} \cdot \boldsymbol{\beta}) \quad (3)$$

The effect of a given risk factor is assessed by predicting the probability of diarrhea at each level of that risk factor, keeping all other variables constant. For example, the effect of having excreta in the yard is estimated by comparing the predicted probability of diarrhea when this variable is set to zero with the predicted probability when the variable is set to one.

The difference between these predicted probabilities is a measure of the excess risk associated with having excreta in the yard. Similarly, the ratio of these predicted probabilities is a measure of the relative risk. Such risk differences and risk ratios are computed for each individual. The mean risk difference and the mean risk ratio are used as the effect estimates for the study population.

Approximate confidence intervals for the effect measures were constructed by simply repeating the simulation using the end points of the 95 percent confidence interval for the coefficient of interest in place of the point estimate. The confidence intervals for the effect measures include the null value precisely when the confidence interval for the parameter estimate includes zero.

RESULTS

Demographic characteristics

There is wide variation in the social, economic, and demographic characteristics of the study population. Almost half of the households (42 percent) include extended family members, and 46 percent have at least two children other than the study infant. Education levels are quite high; more than 75 percent of the parents had completed primary education, another 5 percent had graduated from high school, and almost 10 percent had some postsecondary education. Most of the households (70 percent) were headed by waged or salaried workers; few were engaged in farming or fishing. Household incomes ranged from 0 to 12,500 pesos per week with a median of 200 pesos (approximately $520/year).

Diarrhea in Cebuano infants

The proportion of children experiencing diarrhea in the week preceding the interview increased from slightly more than 7 percent at 2 months of age to 25 percent at 8 months of age (table 1). For the remainder of the year, the prevalence among males remained virtually constant, while the prevalence among females decreased slightly to 22 percent. Over the course of the year, 39 percent of the infants did not experience diarrhea during any of the weeks preceding the six interviews, while 12 percent of the infants were frequently ill, having had diarrhea during three or more of these 1-week periods.

TABLE 1. Seven-day prevalence of diarrhea by child's age and sex, Cebu, Philippines, 1983–1985

Category	Child's age (months)					
	2	4	6	8	10	12
Overall	7.2	12.7	20.4	25.0	24.4	24.1
Females	7.1	12.3	20.1	24.6	22.9	21.9
Males	7.4	13.1	20.6	25.4	25.7	26.0

Excreta disposal

Excreta disposal was not well managed in the study area. Over half of the households used flush or pour-flush toilets, one third of which were located in the house (table 2). However, because Cebu city does not have a sewage system, on-site septic systems are used for disposal. In some cases, effluent from these cesspools and septic tanks was discharged directly into open canals. Twenty-three percent of the households used latrines, and 4 percent used open pits. Slightly more than 20 percent of the households did not use any facility, with individuals defecating in empty lots, on the seashore, or on the banks of rivers and canals.

Toilets and latrines were rarely used to dispose of infants' feces. The majority of mothers (61 percent) reported depositing these stools in places readily accessible to animals or children (e.g., under the house or in a vacant lot). Fecal material was readily observed at more than one third of the households (table 3).

Community sanitation

Those neighborhoods with very dense housing and fecal material readily observable throughout the area were rated as having very poor community sanitation. Eighteen percent of the sample infants resided in these highly contaminated areas.

TABLE 2. Type of excreta disposal facility used, Cebu, Philippines, 1983–1985

Type of excreta disposal facility	Frequency	%
Private facilities		
Cistern toilet (inside)	127	5.4
Water-sealed toilet (inside)	254	10.8
Cistern toilet (outside)	46	2.0
Water-sealed toilet (outside)	655	27.8
Public facilities		
Water-sealed toilet	194	8.2
Latrine	532	22.6
No facility		
Open pit	100	4.3
No facility used (field, canal, seashore)	438	18.6
Other	8	0.3
Unknown	1	<0.1
Total	2,355	100.0

TABLE 3. Presence of excreta around the house, Cebu, Philippines, 1983–1985

Observation categories	Frequency	%
Heavy excreta visible	178	7.6
Some excreta visible	600	25.5
Very little excreta visible	335	14.2
No excreta visible	1,219	51.8
No observation made	23	1.0
Total	2,355	100.1

While the households in these areas had fewer assets (table 4), education levels were similar. Approximately the same proportion of study households in these two areas used some type of excreta disposal facility; however, a smaller proportion of households in the poor sanitation areas had private excreta disposal facilities. Within the areas of very poor community sanitation, there was significant variability in the level of contamination around individual households; 38 percent of the sample households in these neighborhoods did not have fecal material visible in their yards.

Exposure to contaminated water

Almost all of the households had access to an improved water supply; 56 percent were served by boreholes and 29 percent by the municipal piped supply. The remaining households relied on open dug wells (5 percent) and dug wells fitted with pumps (5 percent). Boreholes and the piped supply usually provided high-quality water—more than 75 percent of the samples taken from these sources produced no fecal coliform colonies. About 10 percent of these samples, however, were quite contaminated, containing more than 100 FCs/100 ml. Dug wells had much higher levels of contamination; only 16 percent of the dug wells produced water with less than 10 FCs/100 ml, and about two thirds of the wells had counts >100 FCs/100 ml.

TABLE 4. Comparison of households in communities with good and very poor sanitation, Cebu, Philippines, 1983–1985

	Very poor community sanitation (18%)		Good community sanitation (82%)	
	Mean	SD*	Mean	SD
Household assets (pesos $\times 10^{-3}$)	7.8	20.1	13.9	55.3
Mother's education (years)	7.6	3.2	7.6	3.3
Private excreta disposal facility	0.35		0.48	
In-house water connection	0.11		0.08	
Fecal material visible outside house	0.62		0.27	

* SD, standard deviation.

More than 75 percent of the infants 2 months of age were given water as part of food or brews. Average total consumption doubled over the first year from 363 ml/day at 2 months of age to 647 ml/day at 12 months. Boiling the infant's water was quite common in this population. More than 90 percent of the mothers reported boiling the water given to their 2-month-old infants, and half still boiled water when their children were 1 year old. As a result, only a small proportion of these infants were exposed to large doses of fecal coliforms (table 5). A slightly greater proportion of children in the good sanitation areas were exposed to contaminated drinking water (19 vs. 12 percent) due to the higher levels of contamination found in the dug wells.

Water availability

Water was readily available to virtually all households. Ten percent of the households had in-house connections to the piped supply or to a borehole fitted with an electric pump, and another 48 percent had a source within 1 minute of their respective houses. Only 3 percent of the families had to walk more than 5 minutes to fetch water.

Effects of water supply and sanitation on diarrhea

The results of the diarrhea models are presented in table 6. The first, a "main effects" model, does not allow for interactions among the environmental variables. The results show that the prevalence of diarrhea is significantly greater where drinking water is contaminated, the household does not have a private excreta disposal facility, there is excreta in the yard, community sanitation is very poor, children are not fully breast-fed, and there has been substantial recent rainfall. The only result that initially seems counterin-

TABLE 5. Distribution of daily FC* doses, adjusted for water boiling, by level of community sanitation, Cebu, Philippines, 1983–1985

Daily FC dose	Very poor community sanitation		Good community sanitation		Overall	
	No.	%	No.	%	No.	%
<1	2,179	92.0	9,029	93.7	11,208	93.4
1–10	130	5.5	500	5.2	630	5.3
>10–100	56	2.4	99	1.0	155	1.3
>100	3	0.1	4	0.0	7	0.1
Total†	2,368	100.0	9,632	99.9	12,000	100.1

* FC, fecal coliform.
† Based on one observation for each child at each time period.

TABLE 6. Parameter estimates† and *t*-statistics from diarrhea model, 2–12 months of age, Cebu, Philippines, 1983–1985

Variable	Main effects		Water quality/sanitation interactions					
	Model 1		Model 2		Model 3		Model 4	
	β	*t*	β	*t*	β	*t*	β	*t*
Water quality (log_{10} FC‡ dose)	0.13	2.6***	0.19	3.3***	0.10	1.3	0.17	2.4***
No private excreta disposal	0.37	3.3***	0.37	3.3***	0.38	3.4***	0.36	3.3***
Excreta in yard	0.26	2.7***	0.25	2.5***	0.26	2.7***	0.28	2.7***
Very poor community sanitation	0.18	4.3***	0.20	4.8***	0.18	4.3***	0.17	4.2***
Water quality interacted with								
Very poor community sanitation			−0.21	−2.1**				
No private excreta disposal					−0.15	−0.5		
Excreta in yard							−0.20	−0.9
No in-house water connection	0.08	1.2	0.08	1.2	0.08	1.2	0.08	1.2
Animals in house	0.03	1.2	0.03	1.1	0.04	1.2	0.04	1.2
Number of children	−0.10	−2.1**	−0.10	−2.1**	−0.10	−2.1**	−0.10	−2.1**
Crowding (persons/room)	0.00	0.4	0.00	0.4	0.00	0.4	0.00	0.4
Fully breast-fed	−0.49	−2.3**	−0.48	−2.2**	−0.50	−2.3	−0.48	−2.3**
Mixed-fed	−0.12	−0.8	−0.11	−0.7	−0.12	−0.8	−0.12	−0.8
Preventive health care use	−0.11	−0.6	−0.08	−0.4	−0.11	−0.6	−0.11	−0.6
Lagged weight (SD‡)	−0.00	−0.1	−0.00	−0.1	−0.00	−0.1	−0.00	−0.1
Child's age (weeks)	0.05	6.9***	0.05	6.9***	0.05	6.9***	0.05	6.9***
Child's age squared	−0.00	−6.0***	−0.00	−6.0***	−0.00	−6.0***	−0.00	−6.0***
Male child	0.07	1.8*	0.07	1.8*	0.07	1.8*	0.07	1.8*
Days of rain in last 2 weeks	0.02	4.1***	0.02	4.1***	0.02	4.1***	0.02	4.1***
Intercept	−1.63	−6.9***	−1.65	−7.0***	−1.62	−6.9***	−1.64	−6.9***
Log likelihood	5,378.6		5,375.3		5,378.2		5,378.6	

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
† Parameter estimates from a probit model cannot be directly interpreted in terms of epidemiologic measures of effect (see Materials and Methods).
‡ FC, fecal coliform; SD, standard deviation.

tuitive is that diarrhea is less prevalent in households with more children. On further consideration, however, the greater risk associated with a larger number of children in the home might be offset because this variable could be measuring the mother's experience and her ability to protect her children from illness.

Subsequent models (2–4 in table 6) incorporate a variety of interactions between the environmental variables. Model 2 shows that the interaction between water quality and very poor community sanitation is highly significant. The coefficient is negative and almost equal in magnitude to the water quality coefficient (0.21 ≈ 0.19). This implies, first, that among the infants living in highly contaminated areas, changes in water quality have little effect on the risk of diarrhea (0.19−0.21 ≈ 0) and, second, that in areas with better community sanitation, water quality is strongly associated ($\beta = 0.19$, $t = 3.3$) with diarrhea. In fact, the effect of water quality estimated in the interaction model is nearly 50 percent greater than estimated in the main effects model (0.19 vs. 0.13).

Model 3 shows that the interaction of water quality with the "no private excreta disposal" variable is negative, suggesting that water quality has a greater effect on diarrhea in households having private excreta disposal facilities. Similarly, model 4 shows that the interaction between water quality and excreta in the yard is negative, suggesting that water quality would have less of an impact in households with excreta in their yard. In these two cases, however, the interaction terms are not statistically significant. It should be noted that the effects of the noninteracted factors remain stable across the four different models.

The effects of contaminated drinking water were calculated using the coefficients from model 2 (table 7). As shown, in areas with good community sanitation, the risk of diarrhea increases substantially as the level of contamination increases. Infants consuming 500 ml of water per day (the average for those infants consuming water) with an average contamination level of 20 FCs/100 ml (= 100 FCs/day) face a 69 percent greater risk of diarrhea than infants consuming potable water (relative risk = 1.69, 95 percent confidence interval 1.25 to 2.11). In contrast, the results in table 7 indicate that there is no relation between water quality and the risk of diarrhea in areas with very poor community sanitation.

The coefficients from model 2 were used to estimate the expected health impacts from improving water quality, level of water service, and sanitation (table 8

TABLE 7. Risk differences and risk ratios for diarrheal disease associated with water contamination, by level of community sanitation, Cebu, Philippines, 1983–1985

Daily FC* dose	Community sanitation							
	Good				Very poor			
	Risk difference†	95% CI*	Risk ratio‡	95% CI	Risk difference	95% CI	Risk ratio	95% CI
1	Reference		Reference		Reference		Reference	
10	0.05	0.02 to 0.08	1.32	1.12 to 1.53	−0.01	−0.05 to 0.05	0.97	0.75 to 1.22
100	0.11	0.04 to 0.18	1.69	1.25 to 2.11	−0.01	−0.10 to 0.09	0.94	0.56 to 1.46
1,000	0.17	0.06 to 0.29	2.12	1.39 to 3.00	−0.02	−0.13 to 0.15	0.91	0.39 to 1.73

* CI, confidence interval; FC, fecal coliform.

† Risk difference = (expected proportion with diarrhea at specified FC dose) − (expected proportion with diarrhea for FC dose of 1).

‡ Risk ratio = (expected proportion with diarrhea at specified FC dose) / (expected proportion with diarrhea for FC dose of 1).

TABLE 8. Comparison of the effects of alternative environmental interventions on diarrheal disease in children: mean reductions in the predicted probability of diarrhea, Cebu, Philippines, 1983–1985

Intervention	Reduction in diarrhea for affected families (%)	95% CI*
In-house water connections	12	−7 to 28
Private excreta disposal facilities	42	19 to 60
Removing excreta around the house	30	8 to 45
For families in neighborhoods with good community sanitation, reduce water source FC* concentration from 100 FC/100 ml to:		
10 FC/100 ml	24	11 to 34
1 FC/100 ml	40	20 to 54
For families who use good quality drinking water, improving community sanitation	25	16 to 33

* CI, confidence interval; FC, fecal coliform.

and figure 1). For families who do not have in-house connections, providing such a connection would decrease the prevalence of diarrhea in children of these families by 12 percent. This effect would appear to be relatively small primarily because water was readily available to all houses in the study population.

For families who do not have private or well-maintained excreta disposal facilities, the provision of such facilities is estimated to reduce childhood diarrhea by 42 percent. Similarly, for households with excreta around the house, eliminating the excreta would result in 30 percent less diarrhea among the affected families.

As discussed previously, improving water quality would have no impact on diarrhea for infants living in crowded, highly contaminated neighborhoods. Conversely, improving the level of neighborhood sanitation would have little effect where water quality is poor. Table 8 shows the positive effect of improving water quality where community sanitation is good. Reducing the concentration of fecal coliforms from 100 to 1 per 100 ml would be expected to reduce infantile diarrhea by 40 percent in such families. And for families who use good quality drinking water, the table shows that improving the level of neighborhood sanitation would reduce diarrheal prevalence by 25 percent.

These estimated impacts are broadly consistent with the effects found in literature reviews of the better designed health impact assessments. In these assessments, the median reduction in diarrhea associated with improved water quality was 17 percent, while the median reduction associated with improved sanitation was 36 percent (4).

DISCUSSION

This study provides powerful confirmation of the importance of environmental determinants of infant diarrhea. In all models (see table 8), water quality, household sanitation, and community sanitation have

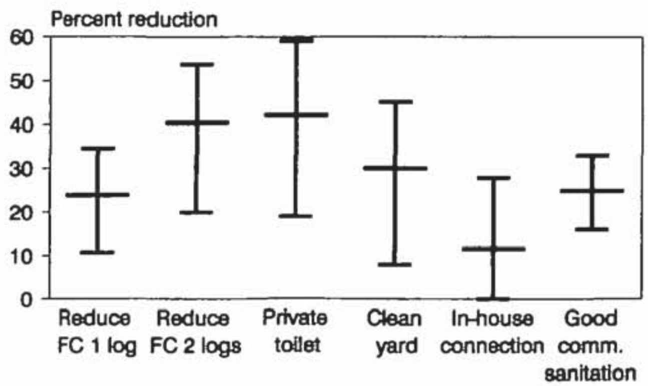

FIGURE 1. Expected reduction in diarrheal prevalence among Cebuano infants for alternative environmental interventions, Cebu, Philippines, 1983–1985.

strong, consistent, and statistically significant effects on diarrhea in infants. The novel aspect of the study, however, is the exploration of interactions among the environmental determinants of diarrhea. Here the findings of the study are both consistent with the predictions of theory and consistent internally. In all cases, the positive impact of improved water quality is greatest for families living under good sanitary conditions. Where the measure of sanitation is at the community level, this relationship is statistically significant. Where the measure is at the household level, the signs of the parameters are as expected but the effects are not statistically significant. The existence and strength of this type of interaction raise three vital policy issues.

First, there is the implication that, where interactions are important, it is impossible to draw any policy conclusions from a study of the health impact of a single intervention (e.g., of improved water quality alone). If a study shows that improving water quality alone has no health impact, does that mean that it is not important to improve water quality? In the presence of strong interactions, the answer is clearly "no," since improving water quality (or any other single risk factor) is a necessary but not sufficient condition for improving health. The conundrum this raises is the following: If the impact study shows that water quality improves health, then this can be used to justify improvements in water quality. If the impact study shows that water quality (alone) does not improve health, then this absence of effect can be attributed to interactions, and improvements in water quality can be argued for with equal force as a "necessary but not sufficient" condition. Since the conclusion from a negative finding is much the same as a conclusion from a positive finding, the finding has little policy relevance.

Second, where interactions are present but not taken into account in an impact study (as is virtually always the case), then too little impact will be attributed to the early intervention (which will pick up only the separate effects) and too much to later interventions (which will pick up the separate *and* joint effects (see 5 for a detailed discussion of this point). In the water and sanitation field, this is particularly important because, with very few exceptions, the "early" intervention is to improve water supply and the "later" intervention is to improve sanitation. The health impacts of sanitation would be overstated accordingly, and the health impacts of water supply would be understated.

Third and finally is the issue of sequencing of interventions. The cost-effective epidemiologic argument would be to first do that intervention for which the separate effect divided by the cost would be the greatest. However, there are insurmountable difficulties in translating this algorithm into practice. Because there are likely to be other interactions involving the potential interventions and contextual factors (e.g., the level of development), it would be necessary to carry out a large number of studies that take account of interactions between interventions in a variety of settings in order to paint a "universal picture" of the impacts of environmental interventions. However, as is obvious from this paper, studies that take these interactions into account are difficult to conduct, require large sample sizes and substantial analytical and financial resources, and are therefore rarely carried out.

In light of these very great conceptual and empirical difficulties, and considering the serious problems faced in financing, operating, and maintaining water and sanitation facilities in developing countries, a rational policymaker would conclude the following: "We know that people in developing countries will not be healthy until they are able to use reasonable amounts of safe, reliable water and until they have adequate excreta disposal facilities. Rather than split hairs about which intervention has the greatest health impact, pay attention to the fundamental issues (elaborated at length elsewhere (28–30)), which are the development of accountable, efficient institutions that can deliver the services people want and value."

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