Drinking-water quality, sanitation, and breast-feeding: their interactive effects on infant health

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The promotion of proper infant feeding practices and the improvement of environmental sanitation have been two important strategies in the effort to reduce diarrhoeal morbidity among infants. Breast-feeding protects infants by decreasing their exposure to water- and foodborne pathogens and by improving their resistance to infection; good sanitation isolates faecal material from the human environment, reducing exposures to enteric pathogens. Taken together, breast-feeding and good sanitation form a set of sequential barriers that protect infants from diarrhoeal pathogens. As a result, breast-feeding may be most important if the sanitation barrier is not in place. This issue is explored using data from a prospective study of 2355 urban Filipino infants during the first 6 months of life. Longitudinal multivariate analyses are used to estimate the effects of full breast-feeding and mixed feeding on diarrhoeal disease at different levels of sanitation. Breast-feeding provides significant protection against diarrhoeal disease for infants in all environments. Administration of even small portions of contaminated water supplements to fully breast-fed infants nearly doubles their risk of diarrhoea. Mixed-fed and weaned infants consume much greater quantities of supplemental liquids, and as a result, the protective effect of full breast-feeding is greatest when drinking-water is contaminated. Similarly, full breast-feeding has stronger protective effects among infants living in crowded, highly contaminated settings.

Introduction

Breast-feeding is an extremely effective means of protecting young infants from diarrhoeal disease. Infants who are not breast-fed have a two-to-three times greater risk of diarrhoea than breast-fed infants and a three-to-five times greater risk than those who are exclusively breast-fed (*1–7*). Other studies have documented even stronger protective effects (*8–11*).

There are two mechanisms through which breast-feeding protects infants from enteric infections. First, it reduces or eliminates exposure to food- and waterborne pathogens. Weaning foods and breast-milk substitutes pose a particular risk since bacterial pathogens can readily multiply in these foods if they are stored at ambient temperatures after preparation (*12–19*). Second, mature breast milk contains several compounds, e.g., secretory IgA, which can improve the infant's ability to resist infection (*20–23*). A number of studies have found significant associations between pathogen-specific antibody levels in breast milk and the risk or severity of diarrhoea caused by that pathogen (*24–26*).

Reducing the level of environmental contamination similarly reduces the risk of diarrhoea. Good sanitation protects infants by creating a series of barriers to keep enteric pathogens out of their environment; excreta disposal facilities isolate human wastes; improved water supplies protect drinking-water from faecal contamination; and handwashing and personal hygiene reduce the transmission of enteric pathogens in the home.

As a result, poor sanitation may pose more of a risk to those who are particularly vulnerable, i.e., non-breast-fed infants. Weaning foods and breast-milk substitutes are more likely to be contaminated in areas where water supply, sanitation, and hygiene are lacking. Furthermore, families living under these conditions often have fewer economic resources and thus are less apt to prepare foods freshly for each meal, adequately reheat previously prepared foods, or store foods under refrigeration. Consequently, mixed-fed and weaned infants living in poor sanitary conditions probably face considerably higher exposures to foodborne pathogens than similarly fed infants in less contaminated environments. Thus, exclusive breast-feeding may provide greater protection to infants living in highly contaminated environments.

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Put simply, breast-feeding and sanitation can be thought of as a set of sequential "barriers" protecting the infant from enteric pathogens. Accordingly, the breast-feeding barrier is most important when the sanitation barrier is not in place. Also, the sanitation barrier is most important when the breast-feeding barrier is absent. The hypotheses that are explored in this article follow from this simple model:

— *Hypothesis 1:* The protective effect of breast-feeding is greatest where sanitary conditions are poor.
— *Hypothesis 2:* The protective effect of good sanitary conditions is greatest among those not breast-fed.

Only two published studies have addressed this issue. Using retrospective data gathered from 1262 women in the Malaysian Family Life Survey, Habicht et al. found that any breast-feeding was associated with lower infant mortality and that this protective effect was significantly stronger among households lacking toilet facilities or piped water (*27*). In a similar analysis of the same data, Butz et al. assessed the effect of the duration of breast-feeding on infant mortality at various levels of sanitation (*28*). Exclusive and supplemented breast-feeding had the strongest protective effects when toilets and piped water were absent, and somewhat smaller effects in households that had either of these facilities. Breast-feeding had the smallest protective effect against infant mortality in households that had both piped water and a toilet. These results support hypothesis 1.

In a related study, Clemens et al. examined the relationship between breast-feeding and the risk of severe cholera among Bangladeshi children under 3 years of age (*4*). The protective effect of any breast-feeding against severe cholera infection was stronger for infants living near (presumably contaminated) rivers, compared with those who did not. Similarly, a stronger association was observed among infants whose families did not have a latrine. These results also concur with hypothesis 1, with breast-feeding having a stronger protective effect in poor sanitary conditions; however, the protective effect also appeared to be greater for families who had a tube-well in their compound. The effects of breast-feeding under good or poor sanitary conditions were not statistically different.

In the present study we have used prospective (rather than retrospective) data from a large, representative sample of infants, with detailed information on feeding patterns, environmental sanitation conditions, and diarrhoeal morbidity to address the following questions:

— Is the protective effect of breast-feeding against diarrhoeal morbidity greatest where water quality and sanitary conditions are poor?
— Is the protective effect of improved water quality and sanitary conditions greatest when breast-feeding is not practised?
— What specific aspects of environmental sanitation are particularly important in protecting children who are not breast-fed?

The answers to these questions have profound implications for resource allocation decisions in infant health and environmental sanitation programmes.

Methods

Data collection

Study design and sample. The investigation used data collected by the Cebu Longitudinal Health and Nutrition Survey (CLHNS) in a prospective study of 3080 children living in urban, periurban, and rural areas of metropolitan Cebu city, Philippines. The survey consisted of 14 interviews of mothers conducted during the third trimester of pregnancy, soon after birth, and every 2 months thereafter until the child was 2 years of age. The sample used in the present analysis comes from a 12-month cohort of all births in 17 randomly selected urban and periurban *barangays* (communities). All the women were informed of the purpose of the study, the types of questions they would be asked, and that participation in the study was completely voluntary. Of the 2555 women recruited, 2355 had single, live births between April 1983 and May 1984 and agreed to participate in the study.

Data for the first 6 months of life were used since during this time the infant's immune system is developing and full breast-feeding is prevalent. Attrition, because of migration out of the area, death, and refusal to participate reduced the sample size to 1963 at the end of 6 months. This loss to follow-up did not appear to result in a selectivity bias (*29, 30*). More information on the survey design and content have been published previously (*30*).

Diarrhoeal disease. At each bimonthly interview the infant's mother or care-giver was asked whether the infant had experienced any episode of diarrhoea in the 7 days prior to the interview day. The local term for diarrhoea used in the questionnaire (*kalibang*) denotes frequent, watery stools. In a separate study on the validity of retrospective morbidity data conducted in the study area, mothers' reports of diarrhoea, based on frequent or loose stools, had a sensitivity of

95–97% and a specificity of 80% compared with diagnoses made at health clinics and hospitals (*31*).

Feeding practices. Infant feeding encompasses a complex set of behaviours, and apparently small differences in behaviour can have a large impact on an infant's exposure to pathogenic organisms and susceptibility to infection. A complete 24-hour dietary recall was taken at each interview, including the amounts of all foods consumed by the child, method of preparation for broad categories of foods, and whether the infant was suckled. For the descriptive statistics, infants were classified at each time period as either exclusively breast-fed, breast-fed and given only non-nutritive liquids (NNL), mixed-fed, or completely weaned, based on the 24-hour recall. Exclusively breast-fed infants received only breast milk. The breast-fed + NNL infants were primarily breast-fed, but also given liquids lacking caloric content, such as teas, brews, and plain water. Mixed-fed infants were those receiving nutritive foods and/or liquids in addition to breast milk. Completely weaned infants did not breast-feed at all. These definitions are generally consistent with other recommendations that have appeared (*32*).[a]

For the bivariate and multivariate analyses, the exclusively breast-fed and breast-fed + NNL infants were combined into a "fully breast-fed" category, indicating that the infants received all nutrition through breast-feeding, and that they were not exposed to potentially contaminated weaning foods. These categories were based on the reported feeding practices 8 days prior to the interview, minimizing the possibility that the reported practice was a result of, rather than a determinant of, diarrhoea in the week before the interview.

In view of the large number of infants in this study, the variety of foods consumed, and the considerable variation in food contamination levels due to microbial multiplication, it was not feasible to test weaning foods directly for bacterial contamination. The effect of consuming contaminated weaning foods is captured primarily by the infant feeding variables: fully breast-fed infants were not exposed to potentially contaminated foods, while the mixed-fed and non-breast-fed infants were exposed. In addition, a variable representing poor food storage practices was constructed, indicating that the child consumed either a breast-milk substitute or a semisolid food that had been stored without refrigeration for more than an hour after preparation. Exposure to waterborne pathogens in non-nutritive liquids was captured by a water quality variable (see below).

[a] *Indicators for assessing breast-feeding practices: report of an informal meeting, 11–21 June 1991, Geneva, Switzerland.* Unpublished document WHO/CDD/SER/91.14. 1991.

Environmental sanitation. The study infants faced a variety of environmental conditions. To capture this complex array of sanitation-related exposure, the following environmental factors were considered: drinking-water quality; access to water; type of excreta disposal facility; presence of excreta in the household's yard; and the sanitation conditions in the household's neighbourhood.

The water sources used by the household were identified during the baseline survey and verified at each bimonthly survey. Between two and five water samples were collected from each drinking-water source over the course of a year; water sources with more variable quality (such as open dug wells) were sampled more frequently. The samples were analysed for the presence of faecal coliforms (FC) using membrane filtration (*33*). A total of 9% of the samples analysed (154/1650) were not used because they exhibited uncharacteristic colonies or heavy background growth. Faecal coliform concentrations were estimated by dividing the number of dark blue colonies observed by the volume of sample filtered.

Several aspects of sanitation were measured in this study. During the baseline survey the household's excreta disposal facility was identified, the yard was inspected for the presence of faecal material, and the respondent was asked whether animals were allowed in the house. To assess the level of community sanitation, an experienced sanitary engineer carried out a series of environmental assessments. The seventeen primary sampling units (*barangays*) were first divided into 41 homogeneous areas, roughly equivalent to neighbourhoods. Each area was rated using structured observations of housing density, type of settlement (e.g., squatter, periurban, etc.), presence of observable faecal material, predominant types of excreta disposal facilities, and drainage. The same individual conducted all assessments, and each area was surveyed twice over the course of the study to check for internal consistency.

Other risk factors. Detailed demographic and socioeconomic data were gathered during the baseline survey, while data on infant growth and the use of preventive health care services were collected at each bimonthy interview. Rainfall data were derived from daily rainfall measurements at 13 stations around the study area.

Model specification

Multivariable models of diarrhoeal disease in children typically include a wide variety of risk factors such as infant feeding practices, water availability and quality, excreta disposal, age, sex, mother's education and household income. While each of these factors may indeed be associated with diarrhoeal disease, the mechanisms through which they affect a child's risk of diarrhoea are quite different. Factors such as drinking-water quality and sanitation are measures of exposure to enteric pathogens, while nutritional status may affect the child's susceptibility to infection.

Socioeconomic factors, in contrast, do not directly affect the risk of diarrhoea, but rather, influence family behaviours which alter the child's exposure to pathogens or susceptibility to infection. For example, in the study population the more educated mothers had a greater tendency to boil their infant's drinking-water, thus reducing their child's exposure to pathogens. Although educational level and water boiling are both associated with diarrhoeal disease, water boiling has a direct effect on the child's exposure to pathogens, while education level has an indirect effect through its influence on the mother's child-care practices. This conceptual model, first proposed by Mosley & Chen (*34*), has been adapted by the Cebu Study Team to investigate the determinants of child health and growth (*29, 30*).

In this model, diarrhoea was specified as a function of factors that directly affect a child's risk of diarrhoea, i.e., exposure to pathogens and susceptibility to infection. Diarrhoea was measured by a dichotomous variable indicating that according to the mother the child experienced an episode of diarrhoea in the 7 days prior to the interview. Breast-feeding practices were measured by two dummy variables, indicating that the infant was fully breast-fed or mixed-fed. Non-breast-fed infants were used as the comparison group. Exposure to contaminated drinking-water was measured using $\log_{10}$(daily dose of faecal coliforms). The dose for each child was estimated by multiplying the predicted concentration of faecal coliforms in their water source 2 weeks before the interview by the amount of water the child consumed. This dose was adjusted for water boiling since this eliminates the risk posed by contaminated drinking-water (*35*). The level of water service was used as a proxy for water use and water-related hygiene. Having water piped into the house has been shown to increase dramatically the amount used. Lack of a water connection was used as a measure of low water usage and poorer household hygiene.

Families may face exposures directly related to the use of excreta disposal facilities. In a random subsample of the study households, private excreta disposal facilities were kept cleaner than public facilities (J. DeClerque, unpublished data, 1985). Thus, private facilities may pose less of a risk to the users than public facilities or informal defecation areas such as vacant lots or the banks of drainage canals. A dummy variable was used to indicate that the household did not have a private excreta disposal facility.

The presence of faecal material in the yard was used as an overall indicator of household sanitation practices. Such material may be from adults or children who do not use toilet facilities or from domestic animals whose faeces may contain enteric pathogens capable of infecting humans (*12*). The presence of animals in a house and the number of other children in the household were used as measures of exposure in the home.

The purpose of an excreta disposal facility is to isolate human wastes so that any pathogens in them cannot infect others. A child whose family uses a toilet or latrine is less likely to come into contact with faecal material than one whose family defecates indiscriminately in areas near the house. However, even children from households with good excreta disposal practices may face considerable exposure if their neighbours defecate indiscriminately. Thus a child's exposure to faecal material is affected not only by his/her family's excreta disposal practices, but also by the practices of the community as a whole. We refer to this aspect of excreta disposal as community sanitation. A measure of exposure to faecal material due to poor community sanitation was developed from the neighbourhood environmental assessments. Of the 41 areas surveyed, 11 were high-density neighbourhoods where excreta were commonly observed. The infants residing in these areas were considered to be exposed to poor community sanitation.

A number of other factors were controlled in this analysis and are discussed in detail elsewhere (*29, 30*). These include the consumption of foods stored without refrigeration, the infant's weight at the previous interview, expressed in units of standard deviations from the sample mean, the use of preventive health care services during the previous 2 months, age and age-squared terms to account for otherwise unmeasured factors that vary with time (e.g., the development of the infant's immune system), the gender of the infant, and the number of days when it rained over the previous 2 weeks.

Estimation methods

A number of concerns motivated the development of the estimation methods used in this study. First, it was important to ensure that the timing of events was consistent with biological plausibility. We therefore used precise lags of each time-dependent exposure variable, so that the measure of exposure precedes the onset of diarrhoea.

A second concern was the potential effect of unobserved factors. While a large number of exposure and susceptibility factors are included in the model, there are other factors that may directly affect an infant's risk of diarrhoea. For example, children differ in their inherent ability to resist infection. Similarly, there may be small yet important differences in child-care practices that are not represented by the available data. Many of these factors are difficult, if not impossible, to observe. Such unmeasured differences between children are referred to as unobserved heterogeneity.

Biases may occur if the unobserved factors associated with the infant's risk of diarrhoea are also associated with the exposure factors under study. Several of the important risk factors considered in this model are directly affected by the mother's behaviours, such as how she feeds her child and what source of drinking-water she uses. Furthermore, these behaviours may be influenced by the mother's perception of the child's risk of diarrhoea. For example, if the mother perceives her infant to be "sickly", or to be facing some particular health threat, she may be more apt to prolong exclusive breast-feeding. If her perceptions are correct, then her child-care practices may be associated with some of the unobserved factors affecting the infant's risk of diarrhoea. As a result, the exposure factor (breast-feeding) could be correlated with unobserved factors that are themselves risk factors for diarrhoea. In this way, unobserved heterogeneity may confound the relationship between breast-feeding and diarrhoea, leading to a biased estimate of the protective effects of breast-feeding (*36*).

In multivariable models, confounding is controlled by including potential confounders in the model. Since in the present case the potential confounders were not observed, they cannot be explicitly included. An alternative approach is the use of instrumental variables (*37*). In the conceptual model presented above, socioeconomic factors were postulated to affect diarrhoea through their influence on health-related behaviours. In the instrumental variable approach, a statistical model is constructed for each of the health-related behaviours, describing that behaviour as a function of its socioeconomic determinants. For example, breast-feeding is modelled as a function of the parent's education, household income and assets, prices of infant foods and cooking fuel, and demographic factors. These models are then used to generate a predicted value for the particular behaviour for each of the households.

The predicted values for the behavioural risk factors are used to represent these factors in the diarrhoea model. Since these predicted values are simply combinations of socioeconomic factors, they should not be associated with the unobserved factors that affect the mother's behaviours or the infant's risk of diarrhoea. As such, when the predicted values are used in the diarrhoea model, the resulting effect estimates will be unbiased (consistent) estimates of the true effect (*37*). A more detailed description of the creation and use of instrumental variables has appeared elsewhere (*29, 30*).

A "random effects" probit model was used to describe the probability of diarrhoea as a function of the risk factors discussed above. This model specifies that the error term is made up of two components, a standard disturbance that is uncorrelated between children and time periods, and an error term that is different for each child but does not vary with time. This error term represents the unobserved heterogeneity, i.e., the unobserved factors specific to each child that affect his/her risk of diarrhoea. Interaction terms and stratified models were used to estimate the effects of breast-feeding for different levels of sanitation. The parameters were estimated using a maximum likelihood procedure (*38*). Simulations were used to assess the risk of diarrhoea associated with different feeding patterns under good and poor environmental conditions.

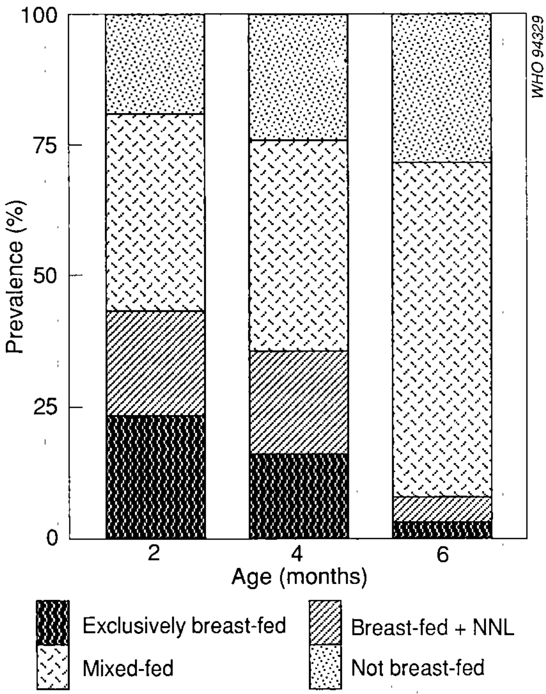
Results

Feeding practices, sanitation and diarrhoeal disease in Cebu

Breast-feeding and exposure to potentially contaminated foods. Infant feeding practices in urban Cebu are typical of those in many developing areas. Very few mothers follow the recommended practice of exclusive breast-feeding for the first 4–6 months. By 2 months of age, 38% of the infants were mixed-fed and 19% were completely weaned (Fig. 1). Another 20% received non-nutritive liquids in addition to breast milk. The proportion of infants who were fully breast-fed dropped to less than 10% by the end of the first 6 months (*39*).

Breast-milk substitutes and semisolid foods seem to pose the greatest risk of bacterial multiplication (*13, 15, 18*). During the first 6 months of life virtually all of the weaned children were given breast-milk substitutes, and these foods accounted for a major part of the infant's diet (88% of the total weight consumed at 2 months; 75% at 6 months). About half of the mixed-fed infants consumed breast-milk substitutes at 2 months of age, and the amounts consumed were, on average, less than half that of the weaned group. Approximately a quarter of those given the substitutes were exposed to milk products that had been stored without refrigeration for over an hour. By 4 months of age, semisolid foods were

Fig. 1. **Feeding practices, by age, among the study infants** (NNL = non-nutritive liquids).



being given to almost half of the mixed-fed and weaned infants, and improper storage was common.

Environmental sanitation. Unlike the situation in many developing countries, water was readily available to almost all the study households. While only 10% of the households had an in-house water connection, less than 3% had to walk more than 5 minutes to fetch water. Furthermore, the quality of the drinking-water available to the majority of households was moderately good to very good. Over half of the households (56%) used deep boreholes fitted with hand pumps or electric pumps, and 29% used a municipal piped supply serving most of the urban areas. Faecal coliform concentrations in these supplies were quite low (geometric mean level = 0.01 colony-forming units (CFU) per 100 ml). The remaining 10% of the households used hand-dug wells, which were frequently contaminated (geometric mean level = 195 CFU per 100 ml).

In contrast to the availability of water, there was no sewerage in any of the study areas. While 54% of the households used flush or pour-flush toilets, very few households had adequate means for disposing of the wastewater, which was commonly discharged into cesspools or open drainage canals. A total of 23% of the households used latrines, and the remaining 23% did not use any facility, defecating into open pits, empty lots, or on the seashore. Toilets and latrines were rarely used to dispose of infants' faeces; the majority of mothers (61%) reported depositing stools under the house, in a vacant lot, or in other places readily accessible to animals or children. Overall, faecal material was readily observed at more than one-third of the households. A total of 30% of the households were rated as being in areas of poor community sanitation, i.e., neighbourhoods with high housing density where excreta were frequently observed.

Infant feeding and sanitation. Many aspects of environmental sanitation and infant feeding were influenced by the same set of underlying socioeconomic factors. For example, household income was inversely related to the duration of breast-feeding and directly related to having an in-house water connection or a private excreta disposal facility. As a result, mothers in households with the highest levels of water supply and sanitation were more likely to wean their children early (Table 1). At 2 months of age, twice as many infants from households with a private excreta disposal facility or in-house water connections were fully weaned compared with households lacking these facilities, and only about half as many were exclusively breast-fed. In contrast, there was little association between feeding practices and the other environmental factors.

Diarrhoeal morbidity and breast-feeding. The proportion of children who experienced diarrhoea in the week preceding the interview rose from 7.2% to 20.4% over the first 6 months (Table 2). There was a clear relationship between feeding practices and diarrhoeal disease (Fig. 2). At 2 months of age the prevalence of diarrhoea among the non-breast-fed infants was nearly three times greater than that among the breast-fed infants. At 2–4 months of age there was a substantial increase in diarrhoeal prevalence among the breast-fed infants, while there was a very sharp rise among the mixed-fed and non-breast-fed aged 4–6 months. After 6 months of age there was little difference in diarrhoeal prevalence between the mixed-fed and non-breast-fed groups.

The mean diarrhoeal prevalence among the infants aged 2–6 months of age is shown in Table 3 for each feeding group stratified by four sanitation variables. For each feeding category, infants living under "poor" sanitary conditions had higher prevalences of diarrhoea, with one exception — fully breast-fed infants in areas of poor community sanitation had about the same prevalence of diarrhoea as

Table 1: **Feeding patterns of the study infants, by sanitation factors, at 2 and 6 months of age**

	Private excreta disposal (%)		In-house water connection (%)		Excreta in yard (%)		Poor community sanitation (%)	
Feeding practice at:[a]	Yes	No	Yes	No	Yes	No	Yes	No
2 months of age								
Exclusively BF	16.5	28.7	13.4	24.3	24.9	22.0	24.8	22.5
BF + NNL	18.1	22.0	14.2	20.9	21.6	19.4	22.3	19.3
Mixed-fed	40.7	35.7	35.8	38.2	34.8	39.6	33.4	39.8
Weaned	24.8	13.6	36.6	16.6	18.7	19.0	19.5	18.4
6 months of age								
Exclusively BF	1.7	3.5	1.4	2.9	3.3	2.4	2.2	3.0
BF + NNL	3.0	6.2	2.4	5.0	5.2	4.6	5.0	4.7
Mixed-fed	59.1	67.8	42.3	66.4	64.0	63.5	62.6	64.4
Weaned	36.2	22.4	53.9	25.7	27.5	29.5	30.2	27.9

[a] BF = breast-fed; BF + NNL = breast-fed and given non-nutritive liquids.

those in good sanitation areas. Among weaned infants, diarrhoeal prevalence in each of the poor sanitation strata was consistently high (ranging from 19.5% to 21.5%). Infants from households with in-house water connections had the lowest prevalence of diarrhoea.

Statistical model results

Main effects model. In the multivariable model, both breast-feeding and environmental sanitation were important determinants of diarrhoeal disease during the first 6 months (Table 4, model 1). The protective effect of full breast-feeding relative to no breast-feeding was large and statistically significant. Mixed-feeding had a somewhat smaller, yet statistically significant effect.

Poor environmental conditions were strongly associated with the risk of diarrhoeal disease. Consumption of contaminated water significantly increased the risk of diarrhoea, independently of the type of feeding. In addition, three sanitation variables were significantly associated with diarrhoeal disease. Lack of a private excreta disposal facility and the presence of excreta in the yard had the strongest effects; lack of in-house water was somewhat less important. Poor community sanitation was only marginally significant, and this coefficient was small relative to the other sanitation factors. Other measures of household sanitation, (i.e., having animals in the house and inadequate food storage practices) were not associated with the risk of diarrhoea.

Table 2: **Prevalence of diarrhoea in the 7 days preceding the study interview, by the child's age, sex, and feeding practice**

	% prevalence among infants aged:		
	2 months	4 months	6 months
Overall	7.2	12.7	20.4
Females	7.1	12.3	20.1
Males	7.4	13.1	20.6
Exclusively breast-fed	4.6	13.0	13.2
Breast-fed + NNL[a]	6.2	11.3	10.4
Mixed-fed	5.6	11.6	19.5
Not breast-fed	14.4	15.9	23.7

[a] NNL = non-nutritive liquids.

Fig. 2. **7-Day prevalence of diarrhoea among the study infants, by feeding practice.**

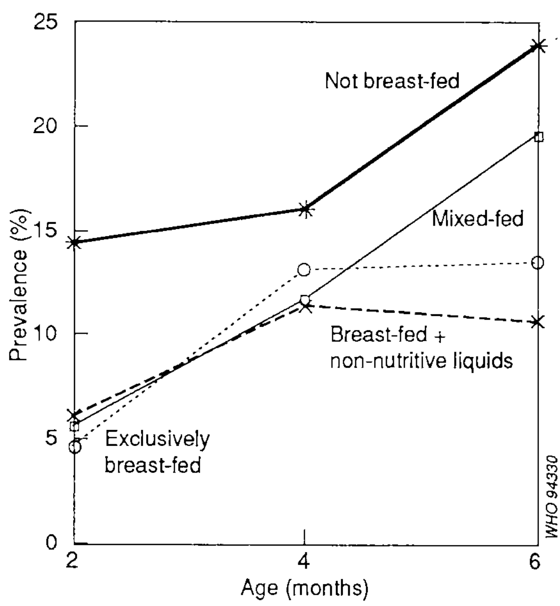


Table 3: **Prevalence of diarrhoea in the 7 days preceding the study interview, and the difference in prevalence relative to fully breast-fed infants aged 2–6 months, by feeding practice and level of sanitation**

	% prevalence of diarrhoea among infants:		
Sanitation variable	Fully breast-fed	Mixed-fed[a]	Not breast-fed[b]
Community sanitation			
Good	8.6	11.6 (3.0)	17.6 (9.0)
Poor	8.1	17.0 (8.9)	20.3 (12.2)
In-house water connection			
Yes	2.0	6.2 (4.2)	13.4 (11.4)
No	8.7	13.6 (4.9)	19.5 (10.8)
Excreta in the yard			
No	7.2	11.6 (4.4)	17.0 (9.8)
Yes	10.5	16.5 (6.0)	21.5 (11.0)
Private excreta disposal			
Yes	6.4	10.2 (3.8)	17.0 (10.6)
No	9.5	15.5 (6.0)	20.5 (11.0)

[a] Figures in parentheses in this column are obtained by subtracting the prevalence of diarrhoea among fully breast-fed infants from that among mixed-fed infants.
[b] Figures in parentheses in this column are obtained by subtracting the prevalence of diarrhoea among fully breast-fed infants from that among infants who were not breast-fed.

Breast-feeding and water contamination. Many of the infants in the study sample were predominantly breast-fed and in addition received NNL supplements. To assess the risk associated with consuming such liquids, the coefficients from the main effects model were used to predict the probability of diarrhoea for each feeding mode at three levels of water quality: no contamination; moderate contamination (10 FC per 100 ml); and high levels of contamination (100 FC per 100 ml). The following mean consumption levels of non-milk liquids for each feeding category were used in this analysis: 39 ml/day for fully breast-fed infants; 119 ml/day for mixed-fed infants; and 209 ml/day for weaned infants. The resulting predicted values are the probabilities that an infant with the given characteristics will experience an episode of diarrhoea over a 7-day period, and represent the average effect for infants aged 2–6 months.

Exclusive breast-feeding and full breast-feeding supplemented with uncontaminated water (breast-fed + NNL) were associated with the lowest risk of diarrhoea (Fig. 3). However, supplementing fully breast-fed infants with even small portions of contaminated water nearly doubled the risk of diarrhoea, from 0.08 to 0.15. Mixed-fed and weaned infants consume much greater quantities of water, and as a result, face much greater risks when their drinking-water is contaminated. Consequently, providing good quality water is most important when the protective effects of breast-feeding are absent.

Similarly, the results can be used to assess the effects of breast-feeding at different levels of water quality. In general, breast-feeding had a strong protective effect; exclusively breast-fed infants had the lowest risk and weaned infants the highest risk. The increase in risk associated with weaning was greatest when drinking-water was highly contaminated. Thus, full breast-feeding will have the strongest protective effect where water quality is poor, i.e., when there is no sanitation barrier to prevent enteric pathogens from entering the water supply.

These results support the two study hypotheses. First, the protective effects of breast-feeding are greatest when drinking-water is contaminated. Second, good water quality has a greater protective effect among infants who are not breast-fed.

Breast-feeding and sanitation. Contamination of infant foods is more likely where sanitary conditions are poor. As a result, eliminating this source of exposure by not giving infants breast-milk substitutes and semisolid foods may be most important under poor sanitary conditions. To assess whether the protective effects of breast-feeding vary with the level of sanitation, the interactions of full breast-feeding with each of the sanitation variables were added sequentially to the main effects model (Table 4, models 2–5). The null hypothesis in each case is that the protective effects of breast-feeding are greatest where sanitary conditions are poor.

Table 4: **Interactions between full breast-feeding with sanitation factors among the study infants aged 2 to 6 months according to the statistical model used** (β and *t* refer to parameter estimate and *t*-statistic, respectively)

	Model 1		Model 2		Model 3		Model 4		Model 5	
Variable	β	*t*	β	*t*	β	*t*	β	*t*	β	*t*
Fully breast-fed	−0.69	−2.5[a]	−0.58	−2.0[a]	−0.66	−2.3[a]	−0.55	−1.6	−0.69	−2.0[a]
Mixed-fed	−0.41	−1.7[b]	−0.42	−1.7[b]	−0.37	−1.5	−0.34	−1.3	−0.41	−1.7[b]
Water quality (log_{10}FC dose)[d]	0.26	2.4[a]	0.26	2.4[a]	0.26	2.4[a]	0.26	2.4[a]	0.25	2.3[a]
No in-house water connection	0.19	1.9[b]	0.19	1.9[b]	0.11	0.9	0.19	1.9[b]	0.19	1.9[b]
No private excreta disposal	0.61	3.6[c]	0.60	3.6[c]	0.60	3.5[c]	0.52	2.4[c]	0.61	3.6[c]
Excreta in yard	0.37	2.7[c]	0.38	2.8[c]	0.38	2.8[c]	0.38	2.8[c]	0.36	1.8[b]
Poor community sanitation	0.08	1.6	0.15	2.2[a]	0.08	1.6	0.08	1.6	0.08	1.6
Full breast-feeding interacted with:[e]										
Poor community sanitation			−0.31	−1.5[b]						
No in-house connection					0.75	1.5				
No private excreta disposal.							0.41	0.7		
Excreta in yard									0.02	0.0
Animals in house	0.06	1.4	0.06	1.4	0.06	1.4	0.06	1.4	0.06	1.4
Poor food storage	0.07	0.3	0.05	0.2	0.06	0.2	0.07	0.3	0.07	0.3
No. of children	−0.11	−1.6[b]	−0.11	−1.6[b]	−0.11	−1.7[b]	−0.12	−1.7[b]	−0.11	−1.6[b]
Preventive health care use	0.52	1.8[b]	0.52	1.8[b]	0.52	1.8[b]	0.49	1.7[b]	0.52	1.8[b]
Lagged weight (SD)	0.02	0.8	0.02	0.8	0.02	0.9	0.02	0.8	0.02	0.8
Child's age (weeks)	0.04	1.7[b]	0.04	1.7[b]	0.04	1.7[b]	0.04	1.8[b]	0.04	1.7[b]
Child's age-squared	−0.00	−0.5	−0.00	−0.5	−0.00	−0.6	−0.00	−0.7	−0.00	−0.5
Male child	0.01	0.2	0.01	0.2	0.01	0.2	0.01	0.2	0.01	0.2
Days of rain	0.02	2.5[a]	0.02	2.5[a]	0.02	2.5[a]	0.02	2.5[a]	0.02	2.5[a]
Intercept	−1.33	−3.7[c]	−1.34	−3.7[c]	−1.35	−3.7[c]	−1.39	−3.7[c]	−1.32	−3.6[c]
No. of observations	6 226		6 226		6 226		6 226		6 226	
Log-likelihood	2 313.8		2 313.2		2 313.2		2 313.2		2 313.8	

[a] $P < 0.05$.
[b] $P < 0.10$.
[c] $P < 0.01$.
[d] FC = faecal coliform.
[e] The null hypothesis is that these interactions are negative. Accordingly, one-sided hypothesis tests were conducted.

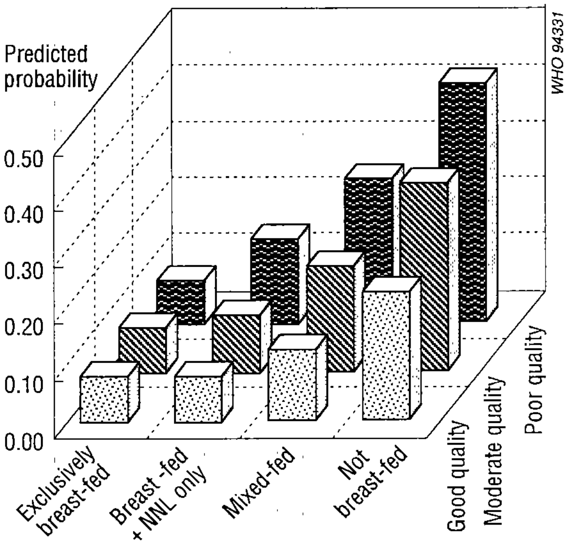
Of the interaction terms, only the poor community sanitation/breast-feeding interaction coefficient was negative and marginally significant (model 2), indicating that, as expected, breast-feeding has a stronger protective effect among infants living in highly contaminated communities. The interaction between no in-house water connection and breast-feeding (model 3) was positive, suggesting that, contrary to our hypothesis, breast-feeding had a stronger protective effect where sanitary conditions were good. The remaining interaction terms were not significant.

It is easier to explore and explain these interactions using stratified models. In the first analysis, households were stratified according to whether they had a water connection in their home. Only a small proportion of the sample had such connections, and the model estimated for these households did not produce stable coefficients.

In the second analysis, households were stratified according to whether they were located in areas with good or poor community sanitation. Separate models were successfully estimated for these two groups (Table 5). While full breast-feeding is a significant protective factor in both areas, the magnitude of the effect in the poor sanitation areas (β = 0.98) is about 1.5 times that in the good sanitation areas (β = 0.61). The difference between these coefficients (0.37) is not statistically significant. Similarly, the effect of mixed feeding was greater for infants living in contaminated communities (0.63 versus 0.40), but the mixed-feeding coefficients were not statistically significant ($P < 0.20$).

The parameters estimated from the stratified models were used to predict the probability of diarrhoea associated with each feeding pattern for areas of good and poor community sanitation (Fig. 4). Poor community sanitation increased the risk of diar-

Fig. 3. **Predicted probabilities of diarrhoea among the study infants, by feeding practice and water quality.** (NNL = non-nutritive liquids).



rhoea among the non-breast-fed infants, but had no effect on the fully breast-fed infants. Thus, full breast-feeding can completely mitigate the risk posed by poor community sanitation.

These results can be interpreted in two ways. Improving community sanitation would clearly have a large impact on weaned infants, and virtually no impact on fully breast-fed infants. The protective effect of good sanitation is therefore greater when infants are not breast-fed, i.e., when the breast-feeding barrier is absent.

Alternatively, the results could indicate that breast-feeding has a stronger protective effect when sanitation is poor. Fully breast-fed infants apparently face much lower risks than weaned infants, and the difference in risks is greater for infants who live in neighbourhoods with poor sanitation. Thus the protective effect of breast-feeding is stronger in the highly contaminated neighbourhoods than in those with good sanitation. In other words, when the sanitation barrier is absent, the protection afforded by breast-feeding becomes even more important.

Discussion

The purpose of our analysis was to test the hypothesis that the protective effect of breast-feeding is greatest where sanitary conditions are poor. While the results do not provide an unambiguous answer, several important conclusions can be drawn.

Full breast-feeding provides significant protection against diarrhoeal disease for infants living in all environments during the first 6 months of life. Exclusive breast-feeding is by far the most protective. Adding even small quantities of contaminated water to the infant's diet can double the risk of diarrhoeal disease. Nevertheless, full breast-feeding (i.e., supplementation with only non-nutritive liquids) is much more protective than mixed-feeding, a result supported by the findings of several previous studies (*1, 7–9*). While mixed-fed infants are at a higher risk than fully breast-fed infants, they are still only half as likely to develop diarrhoea as completely weaned infants. This inverse relationship between the level of breast-feeding and the risk of diarrhoea is probably due to two factors: reduced protection from maternal antibodies in breast milk and an increase in exposure to foodborne pathogens.

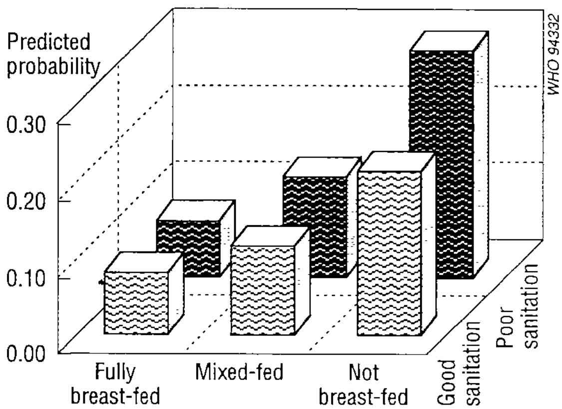
Clearly, under certain circumstances breast-feeding did provide greater protection in poor sanitary conditions. Exclusive breast-feeding had a stronger protective effect when drinking-water was contaminated, and breast-feeding was more protective for infants living in crowded, highly contaminated settings. In contrast, fully breast-fed infants from households lacking water connections or private excreta

Table 5: **Diarrhoea model stratified by community sanitation for infants aged 2–6 months**

	Community sanitation:			
	Good		Poor	
Variable	β	*t*	β	*t*
Fully breast-fed	–0.61	–1.8[a]	–0.98	–1.9[a]
Mixed-fed	–0.40	–1.3	–0.63	–1.4
Water quality (log_{10}FC dose)	0.29	2.3[b]	0.16	0.7
No in-house water connection	0.26	2.0[b]	0.09	0.6
No private excreta disposal	0.42	2.1[b]	1.07	3.4[c]
Excreta in yard	0.39	2.3[b]	0.32	1.3
Animals in house	0.07	1.3	0.04	0.5
Poor food storage	–0.13	–0.4	0.38	0.8
No. of children	–0.07	–0.8	–0.23	–1.8[a]
Preventive health care use	0.24	0.6	0.88	1.9[a]
Lagged weight (SD)	0.02	0.5	0.06	1.0
Child's age (weeks)	0.02	0.8	0.06	1.5
Child's age-squared	0.00	0.1	–0.00	–0.8
Male child	0.09	1.4	–0.20	–1.8[a]
Days of rain	0.03	2.5[b]	0.01	0.8
Intercept	–1.35	–3.1[c]	–0.89	–1.3
No. of observations	4 382		1 844	
Log-likelihood	1 560		745	

[a] $P < 0.10$.
[b] $P < 0.05$.
[c] $P < 0.01$.

Fig. 4. **Predicted probabilities of diarrhoea among the study infants, by feeding practice and level of community sanitation.**



disposal facilities did not derive a higher level of protection from full breast-feeding than infants from households that had these facilities. These results are in agreement with the reported effects of breast-feeding and sanitation on infant mortality (*27, 28*) and cholera morbidity (*4*).

The positive interaction between breast-feeding and no in-house water connection was unexpected. Those households with in-house water connections were the wealthiest, and virtually all of these families also owned a private excreta disposal facility. Moreover, only a relatively small proportion of the infants from these households were fully breast-fed (see Table 1). Thus the interaction between an in-house water connection and full breast-feeding may have captured the protective effects of unmeasured child care and hygiene practices among the small group of wealthy mothers who chose to fully breast-feed their infants.

The policy implications of these findings are clear. Full breast-feeding through the first 4–6 months should be encouraged as a means of protecting young infants in all settings from diarrhoeal disease. Furthermore, exclusive breast-feeding is strongly recommended where potable water is not readily available. Also, breast-feeding appears to provide stronger protective effects to infants in crowded, highly contaminated communities. Contamination of supplemental or weaning foods is more likely under these circumstances. In the Cebu region, as in most low-income countries, early supplementation and weaning were most prevalent in these urban squatter and slum areas. Thus, programmes that promote appropriate infant-feeding practices should consider targeting such communities.

In the present study, both water quality and sanitation were important risk factors for diarrhoea. Consumption of contaminated water, lack of private excreta disposal, and the presence of excreta in the yard were associated with the largest increases in risk. As hypothesized, the protection provided by high-quality drinking-water and good sanitation in the community appear to be greatest for non-breast-fed infants. A high-quality water source is particularly important for mixed-fed and weaned infants since they consume the largest quantities of water. Similarly, good community sanitation would benefit completely weaned infants the most since they face significantly higher risks from living in neighbourhoods with poor sanitary conditions. Such highly contaminated environments may well increase the risk of weaning foods being contaminated. Efforts to reduce diarrhoea should focus on reducing exposures, particularly foodborne exposures, through improvements in the choice of supplemental foods, preparation practices and storage methods, and better personal hygiene. Increasing the availability of water and access to excreta disposal facilities can do much to enable families to improve hygienic conditions in the home and to reduce the level of contamination in the community.

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Résumé

Interaction entre les effets de la qualité de l'eau de boisson, des conditions sanitaires et de l'allaitement au sein sur la santé des nourrissons

Les mesures visant à favoriser une bonne alimentation des nourrissons et l'amélioration des conditions sanitaires sont deux stratégies importantes pour réduire la morbidité diarrhéique chez les

jeunes enfants. L'allaitement au sein protège le nourrisson en lui évitant d'être exposé aux pathogènes présents dans l'eau et la nourriture et en renforçant sa résistance à l'infection; l'amélioration des conditions sanitaires réduit l'exposition aux pathogènes en éliminant les excréments de l'environnement humain. L'allaitement au sein et de bonnes conditions sanitaires constituent donc deux barrières complémentaires contre les pathogènes responsables de la diarrhée. En conséquence, l'allaitement au sein est peut-être encore plus important lorsque les conditions sanitaires laissent à désirer.

Pour vérifier cette hypothèse, on a utilisé les données d'une enquête prospective longitudinale sur la santé et la nutrition menée à Cebu (Philippines). Dans cette étude, 2355 enfants d'un milieu urbain ont été suivis pendant les six premiers mois de la vie. Lors de chaque visite, les épisodes diarrhéiques survenus au cours de la semaine écoulée et le type d'alimentation du nourrisson ont été déterminés en interrogeant la mère. Les conditions environnementales ont été établies par observation directe. On a utilisé un modèle de représentation des effets aléatoires par probits pour estimer les effets de l'allaitement au sein exclusif et d'une alimentation mixte dans différentes conditions sanitaires.

L'allaitement au sein a un effet protecteur marqué contre les maladies diarrhéiques, quel que soit l'environnement. La fréquence des diarrhées était trois fois plus faible chez les enfants nourris exclusivement au sein que chez les enfants sevrés; elle était deux fois plus faible chez les enfants recevant une alimentation mixte. Il existe une forte corrélation entre des conditions d'hygiène médiocres et le risque de maladie diarrhéique. La contamination de l'eau de boisson, l'absence de toilettes privées et la présence d'excréments dans la cour des habitations sont les facteurs qui ont l'effet le plus marqué; l'absence d'adduction d'eau est un peu moins importante à cet égard.

Dans certaines circonstances, l'allaitement au sein offre une plus grande protection lorsque les conditions sanitaires sont mauvaises. Premièrement, l'allaitement au sein exclusif a un effet protecteur plus important lorsque l'eau de boisson est contaminée, car les enfants totalement ou partiellement sevrés consomment des quantités de liquides beaucoup plus importantes. Deuxièmement, l'allaitement au sein offre davantage de protection aux enfants vivant dans un milieu surpeuplé ou fortement contaminé, c'est-à-dire lorsque la "barrière sanitaire" est absente. Par contre, la protection offerte par l'allaitement au sein exclusif est à peu près la même, que le logement possède ou non l'eau courante ou des latrines privées.

Les implications pratiques des résultats de cette étude sont claires. Il faut encourager l'allaitement au sein exclusif pendant les quatre à six premiers mois de la vie, car il protège les nourrissons de la diarrhée, quelle que soit la qualité de l'environnement. En outre, l'allaitement au sein exclusif est fortement recommandé lorsqu'il n'est pas facile de se procurer de l'eau potable. Enfin, les programmes visant à améliorer les habitudes d'alimentation des nourrissons devraient être davantage ciblés sur les communautés surpeuplées vivant dans un milieu fortement contaminé.

L'hypothèse de départ, selon laquelle la protection offerte par une eau de boisson de qualité et de bonnes conditions sanitaires est plus marquée pour les enfants qui ne sont pas nourris au sein, a été confirmée. La qualité de l'eau est particulièrement importante pour les enfants partiellement ou totalement sevrés, car ils en consomment des quantités plus importantes. De même, de bonnes conditions sanitaires dans la communauté sont particulièrement importantes pour les enfants sevrés, car ces derniers sont davantage exposés aux risques liés à un environnement insalubre. Les mesures visant à améliorer l'approvisionnement en eau et l'élimination des excreta peuvent contribuer largement à réduire le niveau de contamination dans la communauté et aider les familles à améliorer les conditions d'hygiène à domicile.

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