Title: Water and Sanitation: Health and Nutrition Benefits to Children
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In: Child Growth and Nutrition in developing Countries; Priorities for Action
Ed: P. Pinstrup-Andersen, D. Pelletier, A. Aldermann
Publisher: Cornell University Press
Year: 1995
Pages: 153-175

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Water and Sanitation: Health and Nutrition Benefits to Children

Susan E. Burger and Steven A. Esrey

This chapter focuses on the two major pathways through which improvements in domestic water supplies, excreta disposal facilities, and hygiene education are thought to have the most direct potential to benefit the health and nutrition of children: (1) reductions in morbidity- and mortality-producing diseases such as diarrhea, and (2) reductions in water collection time with allocation of that time to child health and nutrition-enhancing activities.

Evaluations of water and sanitation projects have emphasized health impacts measured by reductions in diarrhea, improvements in anthropometric indexes of children, or reductions in total mortality; these effects are assumed to result from a reduction in the transmission of pathogens. This emphasis may be understandable in view of the high prevalence and severity of diarrhea among children under age 5 and its significant contribution to protein-energy malnutrition and death. Water and sanitation projects also have the potential to reduce exposure to pathogens that cause other diseases such as guinea worm, schistosomiasis, ascariasis, and trachoma. These diseases also afflict adults. Therefore, reductions in morbidity have the potential to benefit all members of households and communities, not just children.

The potential health benefits of water and sanitation actually extend

The authors wish to thank the Water and Sanitation for Health Project, the International Center for Research on Women, Katherine Tucker, Barry Popkin, and Joanne Leslie for documents provided and literature suggested, and the staff of the Interlibrary Loan Service at Cornell University for their efforts in tracking down difficult-to-find articles. They also wish to thank Harold Alderman, Per Pinstrup-Andersen, Sandy Cairncross, Jean-Pierre Hab-

Coghill Book Typesetting: Proofed 10-25-1994 07:54, Page 2

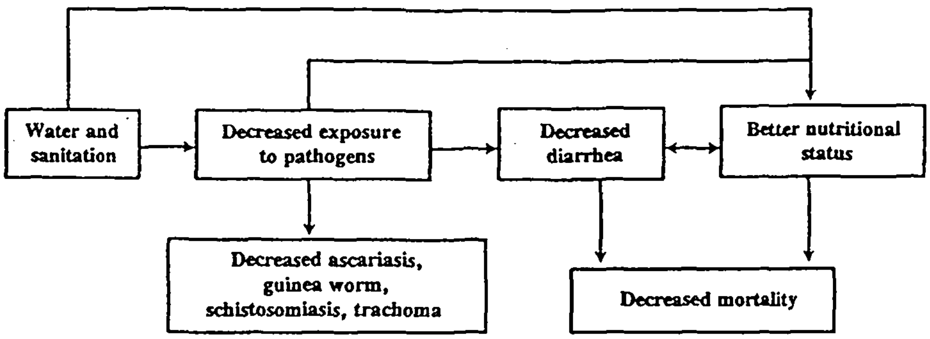
far beyond those resulting from pathogen reduction alone. Accessible domestic water supplies have the potential to augment women's limited resources of time, energy, and income. Time saved by access to water that is closer to the home may be translated into more time spent on food production, income generation, self-improvement, and leisure, all of which may have an indirect impact on child health and nutrition. Allocation of time saved to child care activities such as feeding may have a direct impact on child health and nutrition. The energy saved may be particularly important during periods of low water availability and seasonal increases in agricultural work load, which often coincide with decreased food availability as well as energy stress such as pregnancy and lactation. Thus the easing of the energy-expenditure burden by more accessible water supplies might improve the nutritional status of the mother, the fetus, and the nursling. The increased available water could be used not only for hygienic purposes but also in home gardens, meal or beverage preparation, small animal husbandry, livestock production, and other water-requiring activities that increase food consumption or purchasing ability.

This chapter is limited to evidence for the two pathways described above through which improved water and sanitation may affect child health and nutrition. Each of the theoretical steps through which these pathways might confer benefits to children is examined separately because evidence for all of the intermediate steps is not available in just one study. If each separate step occurs as theorized, the pathway between the water and sanitation interventions and the health or nutrition outcome is considered to be plausible. For example, if evidence from several studies establishes that water supplies brought closer to the home reduce the time spent collecting water, the time saved is used to prepare more food, the preparation of more food results in greater energy intake by children, and that greater energy intake is associated with better growth, *then it is* plausible that water brought closer to homes improves child nutritional status through increased nutrient intake, not just by reduced disease.

In addition, studies that report the conditions under which single or combined water and sanitation interventions have the largest impact are included because such information may be useful for targeting, prioritizing, or combining interventions. Improvements in water supply may influence water quantity, water collection time, water quality, or some combination of the three. Distinctions between the impact of water quantity and quality are discussed in the section on pathogen reduction. Those

icht, Joanne Leslie, and David Pelletier for the thoughtful comments they provided while reviewing earlier drafts of this chapter. The authors take sole responsibility for any errors that remain.

Figure 9.1. Influence of water and sanitation on child health through decreased exposure to pathogens



studies that report on distance traveled or time spent to collect water are discussed in the section on time savings.

Influence of Improved Water and Sanitation on Reductions in Pathogen Exposure and Disease

Evidence That Water and Sanitation Decrease Exposure to Pathogens

Water and sanitation interventions are thought to affect health primarily by reducing exposure to pathogens (Figure 9.1). Diminishing the ingestion of pathogens has the potential to prevent mortality and morbidity from diarrheal illness, an advantage not conferred by oral rehydration therapy, which only prevents the consequences of dehydrating diarrhea once it occurs. Furthermore, improvements in water and sanitation have the potential to reduce other diseases by intervening in their life cycle. Pathogens that lead to infection and disease may be transmitted by several routes including fecal-oral (e.g., all major diarrheal pathogens and *Ascaris*), fecal-cutaneous (e.g., hookworm and *Schistosomes*), cutaneous-oral (e.g., guinea worm), or cutaneous-cutaneous (e.g., trachoma and scabies). Some pathogens need intermediate hosts (e.g., guinea worms and *Schistosomes*) or a period outside the human host (e.g., *Ascaris* and hookworm) for transmission.

Thus ingestion of contaminated water (diarrheal disease agents and guinea worm), exposure to pathogens through poor personal and domestic hygiene (diarrheal disease agents, *Ascaris, Schistosomes,* and trachoma), or improper disposal of feces (diarrheal disease agents and intestinal parasites) can cause disease. Breaking these routes of transmission would reduce the incidence and severity of several diseases.

Decreased exposure to pathogens is inferred by use of latrines and measured contamination levels on hands and drinking water with feces. Community water supplies are often clean at the point of water collection but become contaminated with feces between collection and ingestion (Rajasekaran et al., 1977; Feachem et al., 1978; Shiffman et al., 1979; Esrey, 1987). Thus improvements in the quality of drinking water may be lost or diminished if the collection point is far from the point of ingestion or if ingestion is sufficiently delayed to allow contamination to occur. Washing hands with or without soap also reduces contamination (Lowbury et al., 1964; Sprunt et al., 1973; Khan, 1982; Aung et al., 1986). Finally, disposal of feces in properly constructed facilities should reduce environmental contamination, but environmental contamination is difficult to measure. People live over a film of contamination, much of it animal in origin.

Diarrheal and intestinal parasitic diseases can result in poor growth through decreased absorption of nutrients and increased requirements, thereby contributing to general protein-energy malnutrition (Martorell et al., 1975; Cole and Parkin, 1977; Guerrant et al., 1983; Rowland et al., 1988) as well as specific nutrient deficiencies such as vitamin A deficiency from *Ascaris* and *Giardia* (Sivakumar and Reddy, 1975; Mahalanbis et al., 1976, 1979) and iron deficiency from hookworm (Holland, 1987) and *Schistosomes* (Stephenson, 1987). This situation may be exacerbated by the reductions in energy intake that can accompany diarrhea (Mata et al., 1977; Hoyle et al., 1980; Martorell et al., 1980; Molla et al., 1983; Esrey et al., 1989).

The contribution of malnutrition as measured by anthropometry has been found to be associated with a longer duration of subsequent diarrhea (Black et al., 1984; Bairagi et al., 1987). Conflicting evidence exists, however, for the relationship between anthropometry and the subsequent incidence of diarrhea (Black et al., 1984; Bairagi et al., 1987; El Samani et al., 1988; Sepúlveda et al., 1988). Regardless of the conflicting evidence for nutritional status and subsequent diarrheal incidence or duration, water and sanitation interventions may both reduce diarrhea and improve nutritional status. Improvements in one are likely to reinforce improvements in the other.

Evidence of Improved Health and Nutritional Status after Decreasing Pathogen Exposure

Decreased exposure to pathogens is inferred best by examining reductions in diseases. Systematic reviews (Esrey et al., 1985; Esrey and Ha-

Table 9.1. Expected reduction in morbidity and mortality from improved water and sanitation

	All studies			Better studies		
Indicator of results	No. of studies	Median (%)	Range (%)	No. of studies	Median (%)	Range (%)
Diarrhea						
morbidity	49	22	0–100	19	26	0–68
mortality	3	65	43–79	—	—	—
Ascariasis	11	28	0–83	4	29	15–83
Guinea worm	7	76	37–98	2	78	75–81
Hookworm	9	4	0–100	—	—	—
Schistosomiasis	4	73	59–87	3	77	59–87
Trachoma	13	50	0–91	7	27	0–79
Child mortality	9	60	0–82	6	55	20–82

Source: Esrey et al., 1991. By permission of the *Bulletin of the World Health Organization.*

bicht, 1985, 1986; Esrey et al., 1991) show that better water and sanitation is associated with decreased diarrheal morbidity, improved nutritional status, lower childhood mortality, and less morbidity from ascariasis, guinea worm, schistosomiasis, and trachoma. Evidence from human volunteer studies indicates a dose-response for diarrheal pathogens (Bille et al., 1964; Blaser and Newman, 1982; Dupont et al., 1971; Cash et al., 1974). Furthermore, the median reduction in diarrhea-specific and overall child mortality rates was found to be greater than the median reduction in morbidity rates following improvements in water and sanitation (Table 9.1). This suggests that as the dose of ingested pathogens is reduced, the severity of disease will decline first, followed by the incidence. Greater reductions in severity compared to prevalence or incidence have also been reported for *Ascaris* (Sahba and Arfaa, 1967; Arfaa et al., 1977), hookworm (Arfaa et al., 1977), and guinea worm (Tayeh and Cairncross, 1989), in which reductions in egg counts or worm load were larger than reductions in prevalence. For example, the magnitude of improvement in health outcome has been shown to increase from no sanitation, to latrines, to toilets (Anker and Knowles, 1980; Haines and Avery, 1982; Esrey, 1993). The evidence for a dose-response indicates that the level of a particular intervention should influence the degree of pathogen transmission and disease reduction.

The number of pathogens transmitted also depends upon the route(s) available and the opportunity for proliferation. Therefore, some interventions may reduce the transmission of pathogens by a greater number, and therefore reduce disease to a greater extent, than others. For instance, proper disposal of contaminated feces may reduce the number of pathogens being transmitted through several routes of exposure such as food, hands, and drinking water. Once in the environment, pathogens may not only survive and disperse but thrive in food or media that is ingested by young children (Barrell and Rowland, 1979; Esrey and Feachem, 1989; Imong et al., 1989). In addition to proper fecal disposal, increasing the quantity of water available may reduce the proliferation of pathogens in contaminated food if more water results in more frequent preparation and feeding, thereby reducing the opportunity for pathogens to multiply sufficiently to cause disease.

Results of studies that examine the health effect of water and sanitation can be extremely variable (Table 9.1). Impacts range from none to reductions in disease rates well over 50 percent for all health indicators so the average reductions in morbidity and mortality yield less information than understanding the conditions that produce the maximum beneficial impacts. Several reasons exist for this wide range of impacts, including the level and type of intervention, the degree of environmental contamination, and the extent to which the evaluation design and analyses account for sample biases and confounding. The actual success of an intervention depends largely on the degree to which pathogen exposure is reduced. Two questions arise from such an explanation: (1) Is the water or sanitation intervention targeted to eliminate the main route(s) of exposure to pathogens? (2) Is the water or sanitation intervention targeted to population groups whose practices are already reducing their exposure to pathogens? In other words, is the water or sanitation intervention designed to complement or compensate for other conditions that affect the transmission of pathogens? Water and sanitation interventions that complement pathogen-reducing factors would likely result in great improvements in health (Briscoe, 1984) when both are present. On the other hand, water and sanitation interventions that reduce pathogens in the same way as another particular pathogen-reducing factor would likely result in small or no improvements in health when the other factor is present but compensate for the absence of the factor with larger improvements in health.

The best way to examine whether water and sanitation complement or compensate for particular conditions is to evaluate the effects when an intervention occurs in the presence or absence of factors such as breastfeeding or of varying levels of factors such as education. The purpose of examining these varying conditions is to determine whether and where to target specific interventions, whether and in what order to introduce interventions, and whether and how to combine several interventions. Studies in which the effects of water and sanitation across different levels of socioeconomic, cultural, and environmental factors are reported are summarized in Table 9.2 and described below. Studies that compare the impact of combined interventions are also described.

Sanitation

Health impact studies that include analyses of improved excreta disposal among varying socioeconomic or environmental conditions were found for five countries: Malaysia, Fiji, Sri Lanka, Lesotho, and Malawi (see Table 9.2). Flush toilets existed in three locations and latrines in the other two. The other conditions present included breastfeeding and not breastfeeding, high and low income, high and low educational level, greater and lesser water quantity, and good and poor water quality. The analyses conducted in the studies below controlled for factors known to have the potential to confound the outcome of water and sanitation evaluations. This control renders the results more plausible.

Sanitation and Breastfeeding. In Malaysia, the presence of flush toilets was found to have the largest effect on mortality among nonbreastfed infants (Butz et al., 1984). In households with neither flush toilets nor piped water, nonbreastfed infants were five times more likely to die than breastfed infants, but in households with a flush toilet were only two and a half times more likely to die (Habicht et al., 1988). Thus presence of a flush toilet in the home reduced the relative risk of death for nonbreastfed compared to breastfed infants by twofold. Although flush toilets reduced the infant mortality rates among breastfed infants, the effect was much less. This suggests that breastfeeding acts independently of sanitation in reducing the transmission of pathogens and that breastfeeding and flush toilets are compensatory.

Sanitation and Income. In a native Fijian population, the presence of a flush toilet had its largest impact on anthropometry among preschool children in low-income households (Yee, 1984). The mean height-for-age of children in low-income households with a flush toilet was significantly higher than those with a pit toilet or no toilet at all, whereas the magnitude of the difference between those with and without flush toilets was much smaller among children in high-income households (Yee, 1984). A similar relationship was reported for weight-for-age (Yee, 1984). Households in rural areas had lower incomes compared to urban areas. Thus weight-for-age and height-for-age were greater among children in homes with flush toilets than without in rural but not in urban households (Yee, 1984). Because occupation was associated with income, the most marked difference in anthropometry between children in households with and without flush toilets occurred among those whose families earned income from farming, the occupation with the lowest average income (Yee, 1984). These findings suggest that improved sanitation will compensate for poverty and will have its greatest effect among low-income rural populations.

Sanitation and Education. In another analysis of the Malaysian data, the presence of flush toilets was found to have its largest effect on mortal-

Table 9.2. Conditions in which improvements in water and sanitation interventions may maximize child health benefits

Intervention	Joint effect of the intervention and the condition	Condition	Health benefit	Country/years of study *(references)*
I. Sanitation				
flush toilets	compensates for	not breastfeeding	**< IMR**	Malaysia/1976–1977 (Butz et al., 1984; Habicht et al., 1988)
	compensates for	low income	**>W/A & H/A**	Fiji/1981 (Yee, 1984)
	compensates for	illiteracy	**< IMR**	Malaysia/1976–1977 (Esrey and Habicht, 1988)
	complements	literacy	**< IMR**	Sri Lanka/1975 (Meegema, 1980)
latrines	complements	more water usage	**> W & L gain**	Lesotho/1984–1985 (Esrey et al., 1992)
	complements	less contaminated water	**< diarrhea**	Malawi/1985 (Young and Briscoe, 1987)
II. Water				
piped water	compensates for	not breastfeeding	**< IMR**	Malaysia/1976–1977 (Butz et al., 1984; Habicht et al.; 1988)
	compensates for	low income	**< CMR**	Brazil/1970–1976 (Merrick, 1985)
	compensates for	low income	**> W/H**	Fiji/1981 (Yee, 1984)
	complements	literacy	**< IMR**	Malaysia/1976–1977 (Esrey and Habicht, 1988)
	compensates for	low educational status	**< CMR**	Brazil/1970–1976 (Merrick, 1985)
more quantity	compensates for	large family size	**< diarrhea**	Haiti/1976–1977 (Thacker et al., 1980)
	complements	frequent maternal bathing	**> W & L gain**	Lesotho/1984–1985 (Esrey, 1987)
better quality	complements	high income	**< diarrhea**	Philippines/1977–1985 (Magnani et al., 1984)

Note: The table should be read as follows:

The *intervention in column (1) complements or compensates* **for as indicated** in column (2) for the condition (or intervention) in column (3) with the resulting health benefit in column (4). The first entry could be **read as follows:** flush toilets compensated for the lack of breastfeeding by reducing the *infant mortality rate* (Health benefit); < and > *correspond to* **reduction** *or increases.* IMR = infant mortality rate; CMR = child mortality rate; W/A = weight-for-age; H/A = height-for-age; W/H = weight-for-height; **W + L gain** = growth in weight and length.

ity among infants of illiterate mothers (Esrey and Habicht, 1988). Literacy was a more sensitive indicator of mortality than education. The magnitude of the effect for toilets was greater than for literacy when the effect of two was compared. Conversely, in Sri Lanka, the presence of a flush toilet had a larger (but not significant) impact on the mortality among infants of literate than illiterate mothers (Meegema, 1980). The analyses conducted with Malaysian data controlled for potentially confounding factors including breastfeeding, whereas the analyses reported in the Sri Lankan study did not. These contrasting results make it difficult to predict impacts from improved sanitation among populations with different educational levels. They also suggest that changes in hygiene behavior associated with improved sanitation will influence health impacts. Thus it is difficult to know if improved sanitation and knowledge of proper sanitation complement each other or each compensates for the lack of the other.

Sanitation and Water Quantity. In rural Lesotho, child growth was found to be greater among households that had both a latrine and increased their water usage than among those that only increased their water usage, only had a latrine, or neither. This was true whether or not improved water supplies had been installed in the village (Esrey et al., 1992). These results were more pronounced among infants than among older preschool children. Because proper excreta disposal complemented the use of adequate water, the two should be promoted together as an effective means of reducing pathogen exposure.

Sanitation and Water Quality. A study of the impact of sanitation and water quality was conducted in rural areas of Malawi (Young and Briscoe, 1987). The risk of diarrhea in children under five years of age was 20 percent less among those whose families had both a piped water system and a latrine than among those whose families had neither. Although these results were not statistically significant because of the small sample size, the trend was clear. There was little difference in the quantity of water used by those with and without a piped water supply, but the fecal coliform count was significantly lower both at the source and in the home for water collected from the piped water supply than from other sources (Young and Briscoe, 1987). These findings suggest that improved sanitation will enhance the effect of piped water in reducing exposure to pathogens, but this relationship needs to be replicated in other areas with larger samples. In addition, the effect of improved water quality and latrines together should be compared separately to the effect of improved water quality alone, to the effect of latrines alone, and to the effect of neither to determine whether the effect of both interventions together is greater than the separate effect of each.

Water

Studies that include analyses of the impact of improved water supplies by varying socioeconomic or environmental conditions were found for three countries: Malaysia, Fiji, and Brazil. None of these studies includes explicit evidence for whether households with piped water used a greater quantity or better quality of water than those without.

Water and Breastfeeding. Presence of piped water in Malaysia significantly reduced the mortality rates among nonbreastfed infants seven to twelve months of age (Butz et al., 1984). The lower risk of death cannot, however, be attributed to piped water alone because the vast majority of households in which piped water was present also had flush toilets. The magnitude of the impact of piped water among households with flush toilets was less than that of flush toilets alone (Habicht et al., 1988), possibly because many households with sanitation did not have piped water, whereas few households with piped water were without sanitation. Nevertheless, these findings suggest that, among breastfed infants, piped water will complement sanitation in reducing transmission of pathogens because an effect of piped water was found even when toilets were present.

Water and Income. In an urban area of Brazil, piped water in the home was associated with reduced mortality among preschool children (Merrick, 1985). The biggest reduction in child mortality occurred when piped water was available to low-income households (Merrick, 1985). As access to water increased over time, the significance of the association between income and reductions in child mortality disappeared (Merrick, 1985). This finding suggests that access to piped water reduced the differential impact of income on childhood mortality. A similar relationship between piped water and income was observed in Fiji for the impact on weight-for-height (wasting) among preschool children (Yee, 1984) suggesting that piped water can reduce exposure to pathogens to a greater extent among the poor than among the better-off. Whether the effect of piped water among low-income groups can be achieved without adequate sanitation is not known, but the results from the studies discussed above indicate that the addition of proper sanitation would maximize the health impact.

Water and Education. In Malaysia, the presence of piped water was found to reduce mortality among infants of literate mothers more than among infants of illiterate mothers (Esrey and Habicht, 1988). The analyses control for the effects of breastfeeding described above.

In contrast, analyses of data from urban Brazil show the opposite trend. The effect of piped water on mortality reduction was greater among children of less-educated mothers than among children of better-educated mothers (Merrick, 1985). These contrasting results make it difficult to predict impacts from improved water supplies among populations with different educational levels. The differences in conditions such as breastfeeding patterns (short duration in Brazil and longer in Malaysia) and age of the subjects in the two study populations could contribute to the discrepancy in results if maternal educational level has a different effect for different degrees of contamination or among different age groups. A more likely explanation may be differences in piped water. Improvements in water quality might have a different impact among children of mothers with different educational levels if education influenced either decontamination of impure water or protection of clean water from recontamination. Water quantity might have a better impact among children of better-educated mothers if education influenced the use of water for hygienic activities when sufficient water is available. The conflicting results make it difficult to know if improved water supplies and education are complementary or compensatory, particularly without identifying whether water quantity increased or water quality improved.

Water and Hygiene Education. Both hand pumps and hygiene education were introduced in a rural area of Bangladesh where levels of education were minimal. Unfortunately, both of these interventions infiltrated the nonintervention areas so it is difficult to determine the extent to which the interventions are responsible for the observed effects. In addition, there is no indication of whether the hand pumps improved water quality or quantity. The differences in the intervention and the nonintervention areas indicate that hygienic practices may complement the use of water from hand pumps. A larger decrease in diarrhea incidence was found among children of mothers who used hygienic practices compared to those who did not, and households in which at least one hygienic activity was practiced were more likely to be those in which several hygienic activities were practiced (Alam et al., 1989b). The incidence of diarrhea among children 6 to 23 months old in the intervention areas did not drop significantly until at least three of the four hygienic activities (use of hand pump water, no feces in yard, handwashing before serving food, and handwashing after defecation) were practiced together (Alam et al., 1989a). In the nonintervention areas, where fewer hand pumps were available, the incidence of diarrhea among six- to twenty-three-month-old children was higher, and hygienic practices had less of an impact than in the intervention areas.

Water Quality versus Quantity

Improved water supplies (i.e., more water or cleaner drinking water) may decrease exposure to pathogens. Previous reviews of water and sanitation interventions concluded that water quantity appeared to be more effective than water quality in contaminated environments and that water quality might not have an effect until most major routes of contamination were eliminated (Esrey and Habicht, 1986; Esrey et al., 1991). Studies that explicitly document whether improvement in the water supply was owing to water quality or quantity are discussed below.

Water Quantity and Crowding. During a drought-induced water shortage in urban areas of Haiti with high unemployment and low educational attainment, less water usage was associated with more illness and malnutrition in preschool children (Thacker et al., 1980). The effect of less water usage on rates of diarrhea and other illnesses was larger among children of families with more than four members than among children of smaller families. These findings suggest that the amount of water may be more critical for larger families, among whom person-to-person transmission is more likely, than for smaller families.

Water Quantity and Maternal Bathing. The combination of increased water usage with frequent maternal bathing, a proxy for better hygiene practices, was associated with better child growth in Lesotho (Esrey, 1987). Although the presence of either factor alone had a positive association with growth, only when both factors occurred together was the greatest growth evident. The same characteristics that lead to frequent maternal bathing may also lead to other hygienic behaviors that benefit child health. These findings suggest that if water is available and better hygiene is practiced, pathogen transmission can be reduced and health benefits can be achieved. Which behaviors are most responsible for the better growth of children cannot be determined from the data available.

Water Quality and Income Level. In urban areas of the Philippines, water quality was associated with low diarrhea rates only among children in high-income households (Magnani et al., 1984). Sanitation facilities and better hygiene practices were also associated with less diarrhea and better nutritional status, but these factors were controlled for in the analysis of water quality by income. If the quality of water was most beneficial to high-income households, it may be because pathogens are transmitted less frequently through routes other than drinking water in these households. When water quality is improved and transmission from other routes is already reduced by other means, then improving drinking water may effectively reduce transmission of pathogens. Conversely, if other routes of transmission are not broken, then improvements in drinking water may have little impact. These results suggest that improvements in drinking water quality complement improvements in sanitation and usage of more water but cannot compensate for the lack of either one.

General Trends

The above relationships indicate that improved sanitation has the largest impact in contaminated environments where breastfeeding is curtailed and income is low. The effect of sanitation among breastfed infants is less, although still present. Sanitation appears to compensate for a low level of each factor. For instance, income-related discrepancies in child health indicators appear to diminish or even disappear when improved sanitation is introduced.

The effect of sanitation at different levels of education and literacy is less straightforward. Education may influence the degree of contamination before the introduction of the intervention, as well as the adoption of the intervention. This might explain why the better educated or literate benefited more in some studies and the less educated or illiterate benefited more in others. If better-educated mothers practice better hygiene than less-educated mothers, then children of less-educated mothers would live in a more contaminated environment and would stand to benefit more from improved sanitation than children of better-educated mothers. But if less-educated mothers are not as willing to use improved sanitary facilities, then the health and nutrition of their children will not improve. This may be one explanation for the discrepancy between the effects of education and sanitation in Malaysia and Sri Lanka. The literate in Malaysia may have practiced more hygienic methods of excreta disposal than the illiterate before the introduction of latrines, and the literate in Sri Lanka may have adopted the use of latrines more readily than the illiterate.

It appears that latrines and piped water together have a greater impact than either one alone. The effects of piped water interventions on improved health are more difficult to interpret than for sanitation because the effects could be caused by improved water quality, increased quantity, or both. The impact of improved water supplies in contaminated environments may be muted because, in many cases, proper sanitation does not exist, thereby permitting pathogen exposure to continue through other routes. These other routes may contribute substantially to pathogen exposure and disease. Nevertheless, piped water and sanitation benefit similar population groups. Piped water appears protective in areas of poverty and where breastfeeding is curtailed or not prevalent. Thus piped water can reduce the differences in health and nutrition between socioeconomic groups when installed in contaminated areas and in areas lacking other means to reduce pathogen transmission.

As with sanitation, the effect of piped water in areas where levels of education differ is not straightforward. Education could influence the degree of prior contamination, the use of the improved water supply, or the adoption of behaviors that maintain or enhance the improvements in the water supply. It is theoretically possible that improved water quality would benefit the less educated more than the better educated because the latter group already takes measures to decontaminate impure water.

If the better educated already know how to use more water for hygienic purposes when it is available, then increased quantity of water would do the reverse; it would benefit the better educated more than the less educated.

According to this line of reasoning, the larger effect of piped water among infants of the literate in Malaysia may have been due to more water, whereas the larger effect of piped water among children of the less educated in Brazil might have been due to better water. If the effect of piped water in Brazil among children of less-educated mothers was due to improved water quality, however, one would have expected to see a greater reduction in mortality among children of high-income households, congruent with the greater reduction in diarrhea among children of high-income households in the Philippines, where the improvement in water quality was measured. Instead, children of low-income households benefited *more* from piped water in Brazil.

It is also possible that improved water quality would benefit the better educated more than the less educated because the latter group takes measures to protect the improved drinking water from recontamination. This would be consistent with an improvement in water quality in Malaysia. If both water quality and water quantity improved together, positive effects among all children would be expected although the mechanism for better health may not be known. The effects of increased water quantity could be enhanced through better hygiene practices, but this may be confounded by increased time savings, which was not examined in any of these studies. Verification or refutation of these speculative explanations for the apparent connection between educational level and the impact of improved water supplies depends upon actual observation and quantification of hygienic behaviors, as well as identification of whether water quality or quantity improved.

Hygiene education appears to enhance the adoption of activities that improve the use and, hence, the impact of piped water. This seems to support the complementarity of improvements in water supply and hygienic behaviors but does not identify whether this is because of improved water quality or increased water quantity, and the specific hygiene practices are difficult to identify.

Although the separate effects of water quantity and quality are difficult to measure, the use of more water appears to have larger impacts than improvements in the quality of drinking water. The impact of increased water quantity may be greater in more contaminated environments, such as among children living in crowded households, than in less contaminated environments. Larger families could influence the need for more water and better hygiene because of increased exposure to pathogens through person-to-person contact, particularly if they have less housing space per child or if mothers or larger families have less time to spend per child. An increase in the quantity of water used may also partially or completely explain the larger effects of piped water among children of low-income households and among nonbreastfed infants, and a failure to increase water usage may explain the lack of positive results in other studies. The effect of water quantity on pathogen reduction may also depend on the adoption of hygienic activities permitted by the increased use of water. This theory is consistent with the findings in Lesotho. Thus, increasing water usage appears to compensate for the lack of some pathogen-reducing measures in highly contaminated environments but in conjunction with other pathogen-reducing measures that depend on sufficient water.

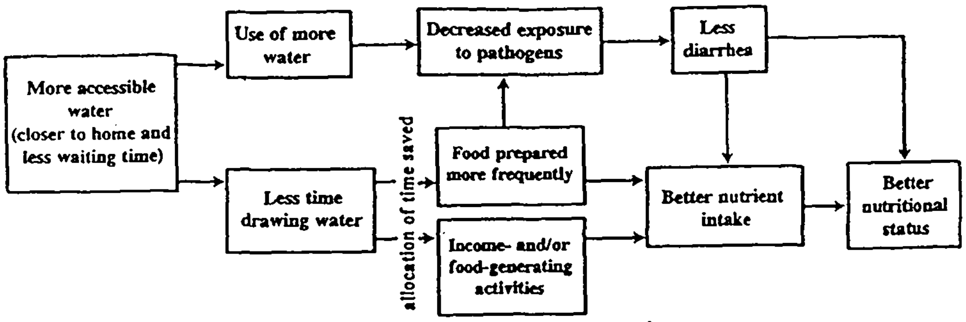
Improved water quality appears to complement other interventions, and the effects may be realized only in environments where contamination from other sources is low, as observed among children of high-income households in the Philippines. Contamination would likely be less among high-income households because these families have reduced their exposure to pathogens by better housing, sanitation, and hygienic practices. If improved water quality does not compensate for lack of pathogen reduction through other routes, then many water projects need to include improved sanitation and more water for better hygiene. Conclusive judgments of whether the largest impacts of piped water are due to water quality or quantity cannot be made until these differences are quantified and examined across different sites. Furthermore, hygienic behavior associated with these interventions needs to be understood.

Influence of Improved Water Supplies on Time Savings and Improved Child Health

In reviewing the role of women in water collection, van Wijk-Sijbesma (1985) concludes that water collection is probably one of the most time-consuming domestic chores. Although women occasionally get help from men and children in collecting water, nearly all the burden of this duty falls on women. If collection times were reduced by the provision of more readily accessible water supplies, then the potential to improve child health could be realized by converting this time into other beneficial activities (Figure 9.2).

Time saved from more readily accessible water could be spent on new activities, or the time spent on existing activities could be extended. In either case, child health could benefit by improving nutrient intake, de-

Figure 9.2. Influence of improved water supplies on child health through time savings



creasing the exposure to pathogens, or both. For instance, more frequent food preparation in an environment where refrigerators are a luxury may diminish food contamination, thereby reducing disease; and where bulky foods are common it may permit the child to eat more frequently, thereby increasing the total energy intake. This is just one of many time-consuming child care activities that may enhance child health and nutritional status.

Time Spent Collecting Water

The total time spent collecting water varies widely throughout the world, from virtually no time, where taps are in the home, to an estimated twelve hours per day (Russell, 1979). The time spent collecting water depends upon means of transportation, the terrain, the distance, the waiting time, the consumption rate, the number of consumers in the household, and the number of people available to collect water (Curtis, 1986). Seasonal and climatic changes can also substantially influence the time required for water collection. For example, in Ethiopia, round-trip collection time in the lowlands took thirty to sixty minutes in the rainy season but over three hours in the dry season; in the highlands, the median time per round trip was less than thirty minutes regardless of season (Kebede, 1978). In Nigeria, water collection times increased by nearly two hours from the wet to dry season (Akintola et al., 1980).

Evidence of Time Saved from Improvements in Water Supplies

The amount of time saved from collecting water from improved sources has been reported to range from zero to over an extreme of eleven hours in a rural village in the Sudan (Russell, 1979). Time savings in dry regions of Malawi, as a result of installation of gravity-piped water systems, was estimated to be more than thirty minutes per day (Warner et al., 1986). In the Peruvian Andes, installation of gravity-piped water systems with household connections resulted in time savings of about three hours per day (Haratani et al., 1981). In urban Philippines, the provision of piped water also reduced water collection times (Magnani et al., 1984).

Basing estimates on self-reported time savings may have biased these studies toward a higher than actual time savings, particularly if the respondents were aware of the purpose and wanted to fulfill the expectations of the interviewer. Actual time spent on water collection has been observed. In Lesotho, the difference in time between collecting water from improved sources and from unimproved sources was thirty minutes per woman per day in the lowlands and, in the highlands, where water was more readily available from springs, eighteen minutes per woman per day (Feachem et al., 1978). In Mozambique, comparison of time budgets from two villages, one in which a standpipe had been installed in the center of the village and one in which the standpipe was located in a neighboring village four kilometers away, indicate that in the village with the standpipe women spent about an hour and three quarters less per day collecting water (Cairncross and Cliff, 1987).

If recipients continue using traditional water supplies even when these are improved, there is no time savings. Traditional supplies might be preferred because factors such as the distance, reliability, waiting time at taps, adequacy for all the household needs, frequency of water collection trips, and willingness of other household members to assist in water collection have not improved or have worsened with the introduction of so-called improved water supplies. In Ethiopia, Kenya, Tanzania, and Zimbabwe, waiting time at an unreliable improved water supply canceled out any time saved in reduced travel (van Wijk-Sijbesma, 1985). Time may not be saved if water does not meet all the household needs, as illustrated in India, where an improved water supply was used only for drinking and cooking so trips to and from the traditional wells continued (van Wijk-Sijbesma, 1985). Improved water supplies no closer than traditional sources did not result in time savings in Malawi (Warner et al., 1986; Msukwa and Kandoole, 1981). If the distance from traditional sources constrains the total amount of water collected (White et al., 1972), even bringing the improved water sources closer may not result in greater time saved. When closer water supplies were provided in Kenya, women made more frequent trips to collect water without reducing the time spent collecting water (Whiting and Krystall, n.d.). Of course, more frequent trips to collect water results in increased use of water, which is in itself beneficial. Although time savings did not accrue to women in Kenya, Guatemala, and Mexico because assistance from other family members declined when improved water sources were introduced (van Wijk-Sijbesma, 1985), the increased time savings to other family members may have its own merit; for instance, young girls may spend more time attending school, baby-sitting, and assisting in food preparation.

Allocation of Time Savings from Improved Water Supplies

Time saved from bringing water supplies closer to people's homes has been reported to result in more time spent on food processing in Ghana (Harkness, 1983), in Mozambique (Cairncross and Cliff, 1987), in the Philippines (Magnani et al., 1984), and in the Sudan (Russell, 1979). The additional time spent on food-processing activities, such as grinding grains, may have increased the availability of food in the home, but such a result was not reported. In Ghana (Harkness, 1983) and Mozambique (Cairncross and Cliff, 1987), more time was spent cooking. Food-preparation activities, such as cooking, could increase the frequency of feeding or the amount eaten at each meal, but frequency and amounts were not measured in these studies. In the highlands of Peru, women reported using more water for food processing (Haratani et al., 1981). Because time saved can be allocated to more water collection, it is difficult to know if the increased time spent in food preparation was owing to time savings, more water, or some combination of the two.

The time savings resulting from more accessible water may lead to increased food-production or income-generating activities. The additional food produced from time savings can either be used for home consumption or sale. Because water use may increase from improvements in water supplies, it is often difficult to identify whether more time or more water or both is responsible for increases in these activities. Villagers reported that water and time gains were used for livestock watering or tending in Thailand (Dworkin et al., 1980), Peru (Haratani et al., 1981), and Malawi (Msukwa and Kandoole, 1981); for home gardening in Thailand (Dworkin et al., 1980), Peru (Haratani et al., 1981), Panama (Meehan et al., 1982), Malawi (Msukwa and Kandoole, 1981), and the Philippines (Magnani et al., 1984); and for agricultural work in Ghana (Harkness, 1983). In the Philippines, the installation of improved water supplies not only increased gardening for home consumption, but the water was also used for raising poultry and pigs (Magnani et al., 1984). In Sudan (Russell, 1979), beer brewing was increased. Village women brew and sell beer in villages (Esrey, personal observation), earning needed cash for families living on incomes that are marginal at best. Other increases in potentially income-generating activities included adobe making in Peru (Haratani et al., 1981) and brick making in Malawi (Msukwa and Kandoole, 1981). In the Philippines, the percentage of households that sold both prepared and unprepared food increased after the introduction of an improved water supply, and more households in areas where the water supply was improved sold prepared and unprepared food than did households in the control areas (Magnani et al., 1984). Teachers in Malawi (Msukwa and Kandoole, 1981) and villagers in Thailand (Dworkin et al., 1980) mentioned handicrafts, and women in Panama (Meehan et al., 1982) and Peru (Haratani et al., 1981) mentioned sewing and weaving as other benefits of improved water supplies.

Constraints to food-producing and income-generating activities include legislative restrictions against water usage for nondomestic purposes, lack of sufficient resources to exploit the time and income gains, and seasonal droughts. In Malawi, Panama, and Peru, official restrictions were placed on the uses of the improved water sources. Although one-fifth of the respondents in Malawi claimed no economic benefits from improved water supplies because decision makers prohibited the use of tap water for purposes other than drinking and cooking water, more respondents used the additional water available at the traditional sources for more purposes (Msukwa and Kandoole, 1981). In Panama and Peru, villagers reported that they used the additional water for nondomestic purposes despite the restrictions (Haratani et al., 1981; Meehan et al., 1982). Dry-season gardening, one anticipated benefit of an improved water supply project in Ghana, did not increase, possibly because no inputs, such as training, seeds, or fertilizer, were provided, nor were women encouraged to exploit this new resource (Harkness, 1983). In Burkina Faso, an integrated attempt to provide labor-saving devices, such as grinding mills, accessible wells, and carts, to increase the women's available time was hampered because the wells tended to dry up in the season when water was most difficult to obtain (McSweeney and Freedman, 1980).

Influence of Time Savings on Child Health

Child care activities that directly improve the health of children clearly require time. The amount of time spent on these activities is difficult to ascertain because it is often not counted as such when other activities are carried out simultaneously and is, therefore, underreported (Popkin and Doan, 1989; Leslie, 1989a). The benefit of allocating the time savings to different activities is likely to vary. For instance, the time spent breastfeeding or feeding children more frequently is likely to have more benefit than time spent sweeping the house. Thus it is important to determine how the time is allocated among the various activities that could be classified as child care. Empirical evidence for the amount of time spent on specific activities that are likely to result in health benefits to the child is almost nonexistent (Leslie, 1989a). Furthermore, alternative means for providing for a child may offset certain infrequently practiced activities. For instance, maternal employment in Panama was positively associated with higher calorie intake of children, despite the potentially detrimental effects of decreased time spent by mothers on the home production activities of cooking and serving food, child care, and housework (Tucker and Sanjur, 1988).

The evidence cited above suggests that time saved from water and sanitation has been allocated to activities that may improve child health and nutrition. Furthermore, the additional time and availability of water may increase commercial activities, such as preparing food for sale on the street, in markets, or in restaurants, as well as raising livestock or small animals for home consumption or sale. If the woman controls the increased purchasing power from these and other non-food-related commercial activities, even more food may be available to the child.

Conclusions and Recommendations

Water and sanitation interventions clearly improve child health and nutrition by decreasing exposure to pathogens. First, the severity of illness appears to decrease to a greater extent than the incidence rates of disease; the result has been found for diarrhea, ascariasis, and schistosomiasis. Second, rates of decline in diarrheal, infant, and total child mortality are larger than those for morbidity. Third, as the level of a particular intervention improves (i.e., from no sanitation to latrines to toilets) the magnitude of the impact on health also improves (Anker and Knowles, 1980; Haines and Avery, 1982; Esrey, 1993). Thus a dose-response relationship between the level of intervention and the severity of the health outcome is seen for pathogens that can be affected by water and sanitation interventions.

The wide range of impacts reported in the literature suggests that benefits following improvements in water and sanitation depend on the routes through which pathogens are transmitted in a community (Briscoe, 1984). Sanitation, water quality, water quantity, and hygiene affect different transmission routes. Thus water and sanitation interventions can either complement each other and existing efforts, such as education, or compensate for undesirable conditions, such as a lack of breastfeeding, to reduce pathogen transmission. This means that either a single intervention must be targeted to areas where it breaks the transmission of pathogens not dealt with by other means, or a package of interventions must be provided to a community to break transmission from several routes to achieve maximum health impacts.

Interventions can be prioritized as contamination in the environment is diminished. Highly contaminated environments require sanitation and water supplies, which appear to complement each other. In areas where breastfeeding rates and income levels are low or crowding is a problem, both improved sanitation and piped water will likely result in improved health. The relationship between these interventions and education is less straightforward. More information is needed on the differential impact of water quality and quantity among children of parents with different educational levels.

Improvements in water supply save women time in amounts that, like the degree of pathogen reduction, is specific to their socioeconomic, cultural, and environmental conditions. The amount of time saved as a result of more accessible water is likely to be greatest where traditional water is scarce, sources are distant, and travel is difficult. Evidence from several countries indicates that time spent on activities related to food production, processing, and preparation is increased after water is brought closer to the home. Further indirect evidence suggests that nutritional status of children can be improved following water supply interventions, even if disease is not reduced. In the Philippines (Magnani et al., 1984), Lesotho (Esrey, 1987), and Nigeria (Huttly et al., 1990) indicators of nutritional status were influenced by improvements in water supplies, but diarrhea was affected less or not at all.

In addition to improvements in food preparation and processing, women may also increase their income by devoting more time to learning and engaging in income-producing activities. Thus incomes may increase, and the increased purchasing power of women could lead to increased nutrient intake, not only of children but of mothers as well, if more food is bought and consumed.

The potential to use the saved time may be critical to other aspects of child care. For example, women may have more time to give oral rehydration therapy to dehydrated children, to take children to be immunized, to learn new recipes to increase nutrient density, or to participate in a growth-monitoring program. This aspect of time savings from water and sanitation interventions, in particular, needs to be carefully considered to optimize programs to improve child health and nutrition.

Although water and sanitation interventions clearly have numerous benefits and beneficiaries, a better understanding of many issues would improve the maximum impacts obtainable. Five general research areas, if better understood, would contribute to the ability to design such programs.

First, the conditions in which the benefits from improvements in water and sanitation could be maximized should be identified. The various factors that complement and compensate for improvements in sanitation, water quality, water quantity, and better hygiene should be identified. Identifying these factors will enable the initially costly investment to purchase new or improve existing water or sanitary facilities to be targeted to areas where the potential benefits would be greatest.

Second, the mechanisms by which increases in water quantity, improvements in water quality, and increased maternal time reduce pathogen transmission should be examined. Direct measurements are preferred to proxy indicators or estimations. Observations and measurements of specific hygiene practices should identify those practices that reduce transmission the most.

Third, time saving and its use should be investigated more rigorously. One, time should be quantified rather than estimated by travel distance. Two, the conditions that maximize time saving should be examined and quantified. Three, the activities that are undertaken by savings in time should be identified and quantified, and they should be operationalized according to functional categories of nutritional and health benefits rather than general child care activities. Four, the time costs of learning new activities beneficial to child health as well as the time costs of carrying out the activities should be quantified. Five, the decreases in travel time should be correlated with health benefits to determine the optimal location of water supplies. Six, the contribution of saving in time to food-producing and income-generating activities should be measured.

A fourth area of study is the poorly understood interaction between disease transmission, particularly diarrhea, and behavior. Therefore, several areas of study would ensure health benefits following the implementation of water and sanitation facilities. One, the lack of knowledge before implementation may constrain the use of facilities, but little is known about this preintervention knowledge. Two, the influence of knowledge on changes in hygiene practices when new facilities are introduced should be determined. Three, the influence of knowledge on adoption and use of new facilities should be understood. Four, the influence of different levels of knowledge of proper hygiene on disease transmission and behavioral changes should be determined.

Fifth, the links between water and sanitation on the acceptance and use of other interventions is not well appreciated and is poorly understood. These links should be investigated. One, the influence of recent water and sanitation interventions on the acceptance of immunizations, oral rehydration, and growth-monitoring activities should be studied. This acceptance may be through reductions in time to collect water or general acceptance of new interventions. Conversely, the influence of other sectors (e.g., agricultural extension and vitamin A–rich gardens) on the acceptance and use of water and sanitation facilities should also be investigated.