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[OLOGIC EVIDENCE FOR HEALTH BENEFITS FROM)VED WATER AND SANITATION IN DEVELOPING COUNTRIES[1]

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... world's population remains without access to potable water supplies and adequate methods to dispose of human fecal waste (table 1). The cost of providing these services is considerable and depends on the type of facility provided and whether it is installed in rural or urban areas (table 2). The original intent of the International Drinking Water Supply and Sanitation Decade (1981–1990) was to provide global coverage of services (4).

The primary justification for the Decade was to improve the health of people, primarily children, who suffer because of inadequate and contaminated water supplies and poor sanitation. Improvements in water supplies and sanitation facilities are believed to reduce the transmission and ingestion of fecal-oral pathogens, particularly the major infectious agents of diarrhea. A reduction in childhood diarrhea, which afflicts up to one billion children annually (5), should improve growth rates and concomitantly reduce mortality rates. Nondiarrhea-related health outcomes, such as scabies and helminthiasis, may also be related to water and sanitation conditions, respectively.

Over the past 30 years, many studies have addressed the issue of health benefits to be derived from the provision of adequate water supply and sanitation, particularly for young children. Most studies assessing child health impacts of water and sanitation interventions have focused on one of three measurements: diarrheal disease morbidity, nutritional status, or mortality. These investigations have provided contradictory and often confusing results and conclusions, many of which are due to methodological deficiencies.

In the past 10 years, the water (6, 7) and sanitation (8) literature has been reviewed separately and together (3), methodological concerns have been raised (9, 10), and design improvements have been proposed (10, 11). Despite these advances in knowledge, the cost effectiveness of water and sanitation interventions relative to that of other interventions such as oral rehydration (12), breast feeding (13), and immunization (14) needs to be improved.

WATER AND SANITATION INTERVENTIONS AND THEIR BIOLOGIC LINK WITH CHILD HEALTH

In developing countries, three basic types of services could benefit child health: an improvement in the quality of drinking water, an increase in the quantity of water provided and used, and the provision of sanitation facilities for safe disposal of human excreta.

Diarrhea can occur following the ingestion of water contaminated with the infectious agents of diarrhea. Water containing pathogenic bacteria, at doses below those necessary to infect humans, may be used for the preparation of food, at which time the bacteria may incubate and multiply in the food. Viral and protozoal agents of diar-

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TABLE 1

*Percentage of population covered by adequate water supplies and sanitation facilities**

Region	Water supplies				Sanitation			
	Rural		Urban		Rural		Urban	
	1980	1983	1980	1983	1980	1983	1980	1983
Africa	22	29	66	57	20	18	54	55
Asia and the Pacific†	26	44	65	67	11	9	41	48
China‡		40		50				
Latin America and the Caribbean	42	49	78	85	20	20	56	80
Western Asia	41	50	94	95	18	25	80	93
Global totals	27	41	70	71	14	12	49	59

* Data from reference 1.
† Excluding China.
‡ Data from reference 2.

TABLE 2

Per capita and total cost of providing global coverage of water supplies and sanitation facilities by 1990

Facility	Additional people to be serviced 1986–1990 (mill)*	Cost per capita (1982 $US)†	Total remaining Decade costs (1982 mill $US)
Rural			
Water	720	10	7,200
Sanitation	1,140	4	4,560
Urban			
Water	480	11–20	5,280–9,600
Sanitation	760	11–26	8,360–19,760
Total	3,100		25,400–41,120

* Data from reference 1.
† Data from reference 3.

rhea, which do not multiply outside of their hosts, may also be transmitted in this manner; lower doses of these agents than of bacteria are required to infect humans (15–17).

The provision and use of sufficient water, albeit of poor quality, for personal and domestic hygiene could prevent the contamination of food, utensils, and hands and thereby reduce the transmission of the major infectious agents of diarrhea. Increased amounts of water may also promote the feasibility of more frequent food preparation (18), resulting in the consumption of less contaminated food products. Thus, improvements in the quality and quantity of the water supply may reduce food contamination, but the mechanism of action in each case is different, as explained below.

Effective disposal of human excreta should play a role in the control of the major infectious agents of diarrhea, which are eliminated via the feces. Young children, the primary excreters of these agents, do not use toilets. Therefore, the hygienic disposal of their feces is necessary to break the fecal-oral transmission of pathogens. Interruption of this transmission by water and sanitation improvements is probably the major mechanism whereby children's health can be improved.

The three interventions presented above are in descending order of attention. It does not necessarily follow, however, that health benefits from these interventions are in descending order of impact, as discussed below.

EPIDEMIOLOGIC CRITERIA TO JUDGE STUDY RESULTS

This review attempts to evaluate the suitability of methodologies and to assess the conclusions of studies since 1950 that describe the effectiveness of water and sanitation interventions on the incidence of diarrheal disease morbidity, nutritional status, and early childhood mortality. The criteria by which published studies of different types were judged are shown in table 3. Although in theory these criteria are well-established, in practice they are strikingly neglected.

A flaw in most studies reported to date is the perception that the individual exposed to water and sanitation improvements is the unit of intervention, when in fact it is the village or some larger unit. Individuals within such a unit are exposed to common factors above and beyond water and sanitation. Thus, health outcomes are

TABLE 3

Criteria necessary to judge the internal validity of water and sanitation health impact evaluations

Positive statistical association reported

- Experimental trials
  - Control for confounding
    - Was randomization properly executed?
    - Was analysis done with
      - Proper unit of intervention?
      - Proper variance term?
    - Was study blinded for
      - Assignment?
      - Assessment? Were other measurement biases controlled?
    - Was randomization confirmed?
  - Analysis for congruity
    - Was intervention confirmed?
    - Were other concomitant and intermediary variables measured and analyzed?
- Observational surveys
  - Control for confounding
    - Were major confounding variables measured?
    - Was there matching by design?
    - Did statistical analysis deal with confounding?
    - Were measurements blinded?
  - Analysis for congruity
    - Were measures of different water and sanitation conditions confirmed?
    - Were other concomitant and intermediary outcomes measured and analyzed?

No statistical association reported

- Experimental and observational studies
  - Adequacy and appropriateness of water and sanitation
    - Could the population benefit from the difference in water and sanitation conditions?
    - Was a difference in conditions confirmed?
  - Adequacy of sample size
    - Was sample size large enough for power of statistical test >0.80?
    - Was appropriate statistical testing done?
  - Control for negative confounding
    - Was randomization carried out (experimental studies)?
    - Was confounding controlled by sampling or analysis (observational surveys)?
    - Were measurement biases controlled (blind assessment)?
  - Analysis for congruity
    - Were other concomitant and intermediary outcomes measured and analyzed?

correlated among individuals within the village or larger unit. Neglecting this correlation in the statistical analyses gives spurious probability statements, which may result in false inferences about the association between the intervention and the outcome. A total of 10 to 20 villages, divided equally into improved and unimproved groups, should allow adequate power to test health differences.

Another common flaw is inadequate attention to assessing the comparability between groups. A design that randomly allocates groups either to receive the intervention or to serve as the control is the ideal and should be utilized when feasible. When random allocation is not possible, stratified sampling and multivariate analyses must be used in cohort studies and matching and multivariate analytic techniques in case-control studies to increase the comparability between groups. Only randomized interventions, however, can control selection bias and permit statistical statements about the probability of confounding between comparison groups. In cohort and case-control studies, the degree to which confounding is controlled depends on insights into various factors and their mechanism of action. Both types of studies must rely on the identification, measurement, and control of these factors.

Another important issue addressed in table 3 is measurement bias. Misclassification of exposure variables and lack of indicator responsiveness may mask benefits, while the systematic bias of interviewers or respondents can produce spurious results.

Of course, it should be confirmed that the expected intervention actually occurred. In addition, measures of congruent outcomes should verify that the intervention was mediated by the expected mechanism. Measures of severity of diarrhea, such as duration, may be more responsive to improvements in water and sanitation than is incidence of diarrhea (3), and indicators of nutritional status may be as responsive as is duration of diarrhea (19).

This review evaluates studies published since 1950 that quantified differences in health outcomes—diarrheal morbidity or specific pathogens, nutritional status, or mortality—between groups that had different water and/or sanitation conditions. In some studies, the data were meager and difficult to obtain. Other studies did not specifically analyze water or sanitation conditions but provided information on these conditions and at least one of the health outcomes.

Epidemiologic Evidence from Selected Studies on Child Health

No study reviewed was considered to be flawless according to the criteria for an experimental study to assess quantitatively the probability of causal association. Some surveys reviewed satisfied more of the criteria necessary to judge the plausibility of the findings than did others. These will be examined in further detail according to one of five categories: water and sanitation, sanitation, water quality and quantity, water quantity, and water quality. Studies that failed to meet a number of criteria in table 3 or for which a serious flaw could be detected are excluded in these discussions. A more complete description of each study can be found elsewhere (10).

Health impacts due to water and sanitation

A few studies examined the combined effect of water and sanitation without separating the effect of one or the other type of intervention (20–27). Six (20, 21, 23–26) of the eight studies reported positive impacts. Some studies (three with and two without positive impacts) are considered to have at least one serious flaw: one failed to control for age (24); two failed to use the correct statistical tests or to control for confounding (20, 21); and two could not detect an improvement in health because the intervention never occurred (22, 27).

Three studies are considered for further detail (23, 25, 26). In two (25, 26), a reduction in diarrhea was associated with improved water and sanitation conditions. A third study (23) reported fewer malnourished children in families with a sewage system and a household bath than in families with latrines and no bath. None of these studies were designed to determine the differential effect of water or sanitation examined below.

Health impacts due to sanitation

Twenty-six studies examined the health impact of sanitation (20, 21, 23, 28–50). Twenty (21, 23, 28–32, 34–41, 45–47, 49, 50) of the 26 studies reported positive impacts. Different levels of sanitation were compared, for example, the presence or absence of adequate sanitation and sanitation and water with water supplies alone. The remaining studies (four with and five without positive impacts) were flawed by obvious regional differences in comparison groups (33, 42, 43, 48) and an inadequate number of replication units (20, 21, 28, 31). Two did not specify the age or age range of the comparison groups (29, 31).

These studies consistently reported an association between improved health and sanitation. Of the studies that compared the relative importance of water and sanitation, most reported that sanitation was a more important determinant of child health than was water (32, 34, 36, 39, 41, 45, 49, 50). This was true for morbidity (36, 41), growth (41, 49), and mortality (32, 39, 45, 50) indicators.

Some studies reported that the level of sanitation available determined the magnitude of the health impact. For instance, a flush toilet produced larger health impacts than did pit latrines (34, 46, 50), which were nevertheless associated with health benefits compared with no sanitation facilities.

Maximizing the health effect due to sanitation is likely to be dependent on a number of risk factors such as breast feeding, income, and literacy. These factors are either directly or indirectly related to the exposure level of pathogens. Some studies addressed this issue by examining the statistical interaction between sanitation and certain risk factors (32, 35, 40, 49).

Breast feeding is associated with the exposure level of pathogens. It is the most appropriate food for young infants because it is nutritious, sterile, may reduce the ingestion of other, often contaminated foods, and confers immunity. Thus, infants not breast-fed from families with adequate sanitation would be expected to benefit more than breast-fed infants from families without adequate sanitation. In a study from Malaysia (32) in which infants were breast-fed, the addition of a toilet did not significantly lower infant mortality rates. When breast feeding was not practiced, the addition of sanitation facilities produced large reductions in infant mortality rates. Partially breast-fed infants had moderate reductions in mortality rates with the addition of toilets.

Income may also influence the exposure level of pathogens. Poor families may not have the means to keep their environment clean. In addition, poor families may reside in crowded, unhygienic housing that facilitates the spread of fecal-oral pathogens. The presence of toilets in such circumstances might be expected to have a large effect by preventing contamination of the environment, which spreads pathogens easily. In a study from Fiji (49), flush toilets were associated with better child nutritional status among the low-income group. This was also true among the high-income group, but to a much lesser extent.

Literate and educated mothers may keep homes cleaner, thereby reducing the exposure level of pathogens. The children of literate mothers would not be expected to benefit as much as the children of illiterate mothers after the installation of sanitation facilities. In another analysis of the Malaysia study (35), the presence or absence of a toilet changed infant mortality rates when mothers were illiterate. Toilets or piped water had no effect on infant mortality rates among children of literate mothers.

A fertility study from Sri Lanka (40) reported the reverse of the above findings from Malaysia. Infant mortality rates fell more when mothers were literate than when mothers were illiterate. This finding does not fit the exposure hypothesis, unless illiterate mothers do not use the new facilities, do not maintain them adequately, or do not properly dispose of their children's feces, in which instances, the sanitation facilities will have a marginal impact at best. Literate mothers may know how to use the new facilities and to dispose of feces as well as refuse. The contrasting results of the Malaysia (35) and Sri Lanka (40) studies suggest that health benefits due to sanitation improvements are dependent on behavioral patterns associated with the intervention. Future research should more fully document hygienic behavior to examine this possibility.

Health impacts due to water quality and quantity

The majority of studies reviewed compared the health status between groups with different types of water supplies (20, 21, 23, 27, 28, 30, 32–34, 38, 39, 42–45, 47, 49–65). Sixteen (20, 21, 23, 32, 38, 39, 47, 49, 51, 52, 55, 57, 60–62, 65) of the 33 studies reported positive impacts. In most, it was difficult to know if the difference in water conditions between groups was due to increased amounts of water, improvements in the quality of water, or both. Therefore, these studies have been grouped together.

In several studies (11 with and 13 without positive impacts), uncontrolled confounding due to age (30, 33, 51, 53, 54, 56, 59, 61, 62), regional differences among comparison groups (42, 43), failure of the intervention to occur (27), participant self-selection (52), and known extraneous risk factors (20, 21, 28, 44, 55, 63) precluded further examination. Since analysis of the sanitation studies revealed that the effect on health due to water is diminished when sanitation is also examined, those studies failing to control for sanitation were also omitted (23, 57, 60, 64, 65).

Several studies fulfilled a sufficient number of the criteria in table 3 to permit detailed examination (32, 34, 38, 39, 45, 47, 49, 50, 58). Some failed to report a health benefit due to improved water supplies (34, 45, 50, 58), while the remainder reported a modest benefit, sometimes for particular, but not for all, age groups (32, 38, 39, 47, 49). In the studies reporting a health benefit, the water supply was piped into or near the home, whereas in those studies reporting no benefit, the improved water supplies were protected wells (34), tubewells (45), and standpipes (50, 58).

The provision of new or improved water supplies does not necessarily correspond to an increase in the use of water. It was reported in East Africa (51) that after providing water closer to the home, the use of increased amounts of water did not result if the traditional water source was less than 1 km from the home. Most studies that separated groups according to distance to the water source failed to address this issue. Without documentation of changes in water use following a water intervention, it is impossible to know if, in fact, an intervention occurred. Furthermore, uncontaminated source water, often the engineering goal, may become polluted during inappropriate transportation and storage (63, 65, 66), leading to the ingestion of contaminated water. This factor may partly explain the inability to demonstrate health impacts following water-related interventions. The positive findings appear below.

In Chile (39), piped water significantly lowered neonatal mortality rates (infants less than one month of age), but this was not found for postneonatal (one to 12 months) or child mortality. Piped water was associated with higher mortality rates among the latter two age groups.

In Malaysia (38), piped water into the home significantly lowered child mortality rates, but this was not investigated for infants. In another study sample from Malaysia (32), the main effect of piped water was beneficial only for infants less than one month of age. Analysis for interaction revealed that piped water was beneficial to infants seven to 12 months of age when they did not breast-feed. This was not the case for infants eight to 28 days and two to six months of age.

Water-related improvements usually encompass an increase in the availability of water as well as better water quality. For instance, piped supplies or bore holes brought closer to households usually contain some element of both types of improvements. Therefore, it is nearly impossible to ascribe the reported benefits from these studies to either the quality or the quantity of water.

Health impacts due to water quantity

Several studies examined the issue of increased amounts of water (18, 36, 41, 47, 67–78), specifically and independently of water quality. All but one (18) of these 16 studies reported positive impacts. Those studies (11 with and none without positive impacts) that were confounded by age (67–69, 75–77) and seasonality differences (70) will not be examined here. The remainder satisfied a number of criteria to warrant further investigation (18, 36, 41, 47, 71–74, 78). These studies reported better health status among the children whose families used more water than among children whose families used less water, but in some instances, the differences were small or significant only for selected age groups.

In Ethiopia (36), children less than two years of age from families with higher water usage per person had less diarrhea than children of the same age group from families with lower water usage per person. This effect was greatest when no latrine was present in the household. Thus, when exposure was high, increased use of water (>10 liters per capita per day) reduced diarrhea rates among children. In this study, the amount of water used per person was more important than the source of water used.

In Panama (78), children under five years of age on one island whose families averaged 7.1 liters of water per capita per day had less diarrhea from all causes than children of similar ages from another island whose family's water usage averaged 2.3 liters per capita per day. Rotavirus infection was also lower in the group using more water, but no difference in Norwalk virus infection was reported.

In the Philippines (41), more children from families who averaged less than 6 liters per capita per day were significantly malnourished than the number of children from families who averaged 6–20 or more than 20 liters per capita per day. This trend was also detected for diarrhea rates, but the relationship was not statistically significant. Perhaps more important than the amount of water used per person were the behavioral factors associated with water. In this study, washing of hands after toilet use was associated with less diarrhea.

Hands have been documented to be contaminated with pathogenic agents of diarrhea (79–81), but efforts to promote hand washing can reduce contamination (82, 83). Reduction in diarrhea may also be expected when hand washing is increased (84–86). Thus, increased use of water for improved domestic hygienic practices (e.g., hand washing) may reduce diarrhea.

In a study from the United States (73), the nearness of a water source influenced *Shigella* rates, but the source itself, open dug well or city water, did not. Although no mention was made of the total amount of water used per person, this finding suggests that water availability is more important than water quality for reducing shigellosis.

In another US study (47), water inside the houses was associated with lower child diarrhea rates than was water outside the houses. In both comparison groups, privies were available and were used. Furthermore, although the distance to the source was not indicated, diarrheal morbidity rates were highest for the group whose water was obtained off the premises.

In a study from India (71), the increased quantities of water used per person were positively associated with measures of nutritional status for those children over 36 months of age, but not for those 36 months of age or less. In this sample, use of water was categorized into four groups, <6, 6–9, 10–13, and >13 liters per capita per day, which indicates a low level of water usage. The relative homogeneity of water use and the control of other water-related behavioral patterns in the analyses (e.g., child bathing and washing of clothes) may have precluded finding differences among the young children.

In a study in drought-stricken Mozambique (18), the amount of water used per person was low, but a comparison of two groups, one using an average of 8 and the other 14 liters per capita per day, revealed more diarrhea among the group using an average of 8 liters per capita per day. The difference in diarrhea rates was not statistically significant. Another interesting finding in this paper was that the provision of more water, albeit small amounts, allowed women to prepare food more frequently. Thus, reductions in diarrhea may have been mediated through consumption of less contaminated food. If growth of children had been measured, one might have found it to be improved because of the consumption of more food.

During a period of water shortage in Haiti (74), children from families using less than 19 liters per capita per day were compared with children whose families used more than 19 liters per capita per day. Overall, diarrhea rates were less in the group using more water, but the results were not statistically significant. In families comprising more than four people, diarrhea rates for children were significantly less in the group using over 19 liters per capita per day.

Health impacts due to water quality

Twelve studies examined the health impacts of pure versus contaminated water supplies (30, 36, 41, 61, 66, 71, 73, 87–91). Nine (30, 36, 41, 61, 71, 88–91) of the 12 studies reported positive impacts, but in several, the impacts were found only for certain age groups. In these studies, the quantity or availability of water may be presumed to be similar in the comparison groups. Five studies satisfied a sufficient number of criteria in table 3 to warrant further investigation (36, 41, 71, 73, 91). Certain studies (five with and two without positive impacts) were excluded based on the following criteria: possible confounding due to age (61, 87, 88) or other factors (30, 89), participant self-selection (88), and inappropriate measures of health outcome (66, 90).

Of the studies considered, one found no association between the quality of drinking water and diarrhea (73), and another found a weak association with child nutritional status, but not with diarrhea (41). A third study reported water quality to be associated with growth among children 18 months of age or less, but not children 19–36 months of age (71). A fourth study reported an inverse correlation between diarrhea and residual chlorine, but only when residual chlorine levels were above 0.5 parts per million (91).

Since diarrhea is multifactorial in origin, drinking water constitutes only one of many sources of pathogen transmission when exposure is high. In areas in which environmental fecal contamination is high, little or no health impact would be expected. For instance, water quality studies in Lesotho (66) and Guatemala (63) failed to detect reductions in diarrhea following water quality improvements. This failure could have been due to non-water-related factors, but these areas can be considered to have high levels of environmental contamination. In Lesotho, only 10 per cent of the population had adequate sanitation facilities; in Guatemala, the corresponding figure was 20 per cent. Thus, the proportion of diarrhea due to drinking water alone may have been too small for improvements in the quality of drinking water to produce a measurable health benefit. This appears to be borne out in the following studies.

Although no main effect of water quality was found in the Philippines (41), the quality of the drinking water was associated with low diarrhea rates for children in the high-income group, but not for those in the low-income group in urban areas. High-income urban dwellers would be expected to have a level of pathogen exposure lower than that of their low-income counterparts.

In an urban area in Colombia, water quality, as measured by residual chlorine levels, was inversely associated with clinic-reported diarrhea rates over a five-year period (91). Colombia has virtually 100 per cent coverage of adequate water and sanitation facilities in urban areas, indicating a low level of exposure.

Conclusions

Improved studies are needed to estimate the health impacts of water and sanitation interventions. Despite the lack of adequate studies, one can infer from the current literature beneficial health impacts following improvements in water and sanitation. The impacts are dependent on the type of intervention, the level of pathogen exposure in the area, and the presence or absence of certain risk factors. This knowledge can be used to target areas most in need of selective interventions, thereby increasing the cost effectiveness of water and sanitation interventions.

Excreta disposal appears to consistently play a more important role in determining children's health in developing areas than do water supplies, especially where the prevalence of diarrhea is high. This effect was seen for all types of outcomes: morbidity, child growth, and mortality. If one considers that the installation of sanitation facilities per capita is cheaper (table 2) and produces larger health impacts than does improving water supplies in rural areas, improving sanitation may be a more cost-effective intervention.

Increasing the use of water for improved domestic hygienic practices should nevertheless remain a priority. Providing increased amounts of water, however, does not necessarily result in the use of that extra water. Concurrent education to promote hand washing and cleaning of the home environment is also necessary. The amount of daily water per person necessary for improved domestic hygiene is not known. Some of the studies suggest that when water use is low, small increases result in health benefits, but the health benefits resulting from an increase in the amount of water used above 20 liters per capita per day are not known. Estimates on the amount of water to be provided daily per person have varied from a low of 15 liters per capita per day in refugee camps (92) to a high of about 50 liters per capita per day (7). A target range of 20–40 liters per capita per day has been advocated by the United States Agency for International Development (93). Achieving such high estimates may not be necessary and may be costly. Nevertheless, targeting areas where water use is low should be considered with simultaneous encouragement of hygienic use of the extra water.

The emphasis on water quality may be questioned in light of the above findings, except in certain more economically advantageous areas that have high coverage of sanitation facilities. First, water quantity appears to be more important than water quality. Since diarrhea is multifactorial in origin and the hygienic use of water, when sufficient water is available, can reduce environmental contamination, water quality may contribute a small proportion of all diarrhea among young children in contaminated environments.

Second, the feasibility of providing clean water to meet standards (94) and recommendations (95) has been questioned (96). If these recent water quality recommendations are to be met, much greater efforts than those made in the past will have to take place to provide uncontaminated drinking water. The above findings indicate that this may become a priority only after improvements in sanitation and water quantity have been achieved.

Thus, it is important to consider levels of environmental contamination when setting priorities for the type of water and sanitation intervention and for targeting areas most in need. A number of factors, such as the curtailment of breast feeding, that are protective in the absence of adequate water and sanitation conditions should also be taken into account. Areas where these protective factors are lacking should receive priority. Finally, water and sanitation interventions can markedly improve the health of children, and tailoring the intervention to the particular setting maximizes the health benefit.

References

1. United Nations. Progress in the attainment of the goals of the International Drinking Water Supply and Sanitation Decade. A/40/108 E.1985/49. New York, 1985.
2. International Bank for Reconstruction and Development. China: the health sector. Washington, DC: World Bank, 1984.
3. Esrey SA, Feachem RG, Hughes J. Interventions for the control of diarrhoeal disease among young children: improving water supplies and excreta disposal facilities. Bull WHO 1985;63:757-72.
4. United Nations. Report of the United Nations water conference, Mar del Plata, March 14-25. Document E/CONF 70/29. New York, 1977.
5. Snyder JD, Merson MH. The magnitude of the global problem of acute diarrhoeal disease: a review of active surveillance data. Bull WHO 1982;60:605-13.
6. Saunders RJ, Warford JJ. Village water supply: economics and policy in the developing world. Baltimore: The Johns Hopkins University Press, 1976.
7. McJunkin FE. Water and human health. National Demonstration Water Project, Washington, DC: United States Agency for International Development, 1982.
8. Feachem RG, Bradley DJ, Garelick HW, et al. Sanitation and disease: health aspects of excreta and waste water management. New York: John Wiley & Sons, 1983.
9. Blum D, Feachem RG. Measuring the impact of water supply and sanitation investments on diarrhoeal diseases: problems of methodology. Int J Epidemiol 1983;12:357-65.
10. Esrey SA, Habicht J-P. The impact of improved water supplies and excreta disposal facilities on diarrheal morbidity, growth, and mortality among children. In: Esrey SA, Habicht J-P, Butz WP, eds. A methodology to review public health interventions: results from nutrition supplementation and water and sanitation projects. Ithaca, NY: Cornell International Nutrition Monograph Series no. 15, 1985.
11. Briscoe J, Feachem RG, Rahaman MM. Measuring the impact of water supply and sanitation facilities on diarrhoea morbidity: prospects for case-control methods. Geneva: World Health Organization, WHO/CWS/85.3, 1985.
12. Oberle MW, Merson MH, Islam MS, et al. Diarrheal disease in Bangladesh: epidemiology, mortality averted and costs at a rural treatment center. Int J Epidemiol 1980;9:341-8.
13. Feachem RG, Koblinsky MA. Interventions for the control of diarrhoeal diseases among young children: promotion of breastfeeding. Bull WHO 1984;62:271-91.
14. Feachem RG, Koblinsky MA. Interventions for the control of diarrhoeal diseases among young children: measles immunization. Bull WHO 1983;61:641-52.
15. Rendtorff RC. The experimental transmission of human intestinal protozoan parasites. I. *Endamoeba coli* cysts given in capsules. Am J Hyg 1954;59:196-208.
16. Rendtorff RC. The experimental transmission of human intestinal protozoan parasites. II. *Giardia lamblia* cysts given in capsules. Am J Hyg 1954;59:209-20.
17. Kapikian AZ, Wyatt RG, Levine MM, et al. Oral administration of human rotavirus to volunteers: induction of illness and correlates of resistance. J Infect Dis 1983;147:95-106.
18. Cairncross S, Cliff J. Water and health in Mueda, Mozambique. Paper presented at the International Workshop on Measuring the Health Impacts of Water and Sanitation Programmes. Cox's Bazaar, Bangladesh, November 21-25, 1983.
19. Esrey SA, McCulloch CE, Habicht J-P. Comparing the responsiveness of diarrheal rates with child growth in judging the health impact of improved water and sanitation. Paper presented at the International Congress on Tropical Medicine and Malaria in Calgary, Canada, September 16-21, 1984.
20. Henry FJ. Environmental sanitation infection and nutritional status of infants in rural St. Lucia, West Indies. Trans R Soc Trop Med Hyg 1981;75:507-13.
21. Azurin JC, Alvero M. Field evaluation of environmental sanitation measures against cholera. Bull WHO 1974;51:19-26.
22. Chandler AC. A comparison of helminthic and protozoan infection in two Egyptian villages two years after the installation of sanitary improvements in one of them. Am J Trop Med Hyg 1954;3:59-73.
23. Christiansen N, Mona JO, Herrera MG. Family social characteristics related to physical growth of young children. Br J Prev Soc Med 1975;29:121-30.
24. Khan M, Curlin GT. Urban cholera study, 1974 and 1975. Dacca: International Center for Diarrhoeal Disease Research, Bangladesh, Scientific Report no. 7, 1977.
25. Koopman JS. Diarrhea and school toilet hygiene in Cali, Colombia. Am J Epidemiol 1978;107:412-20.
26. Rahaman MM, Aziz KMS, Hasan Z, et al. The Teknaf health impact study: methods and results. Paper presented at the International Workshop on Measuring the Health Impacts of Water and Sanitation Programmes. Cox's Bazaar, Bangladesh, November 21-25, 1983.
27. Weir JM. An evaluation of health and sanitation in Egyptian villages. J Egypt Public Health Assoc 1952;27:55-114.
28. Bruch HA, Ascoli W, Scrimshaw NS, et al. Studies of diarrheal disease in Central America. V. Environmental factors in the origin and transmission

of acute diarrheal disease in four Guatemalan villages. Am J Trop Med Hyg 1963;12:567–79.
29. McCabe LJ, Haines TW. Diarrheal disease control by improved human excreta disposal. Public Health Rep 1957;72:921–8.
30. Beck MD, Munoz JA, Scrimshaw NS. Studies on diarrhoeal diseases in Central America. I. Preliminary findings on cultural surveys of normal population groups in Guatemala. Am J Trop Med Hyg 1957;6:62–71.
31. Kumar P, Sehgal BS, Singh R. Bore-hole disposal of excreta of children and diarrhoeal morbidity in a rural community. Indian J Environ Health 1970;12:155–9.
32. Butz WP, Habicht J-P, DaVanzo J, et al. Environmental factors in the relationship between breastfeeding and infant mortality: the role of sanitation and water in Malaysia. Am J Epidemiol 1984;119:516–25.
33. Kourany M, Vasquez MA, Mata LJ. Prevalence of pathogenic enteric bacteria in children in 31 Panamanian communities. Am J Trop Med Hyg 1971;20:608–15.
34. Anker R, Knowles JC. An empirical analysis of morbidity differentials in Kenya at the macro and micro levels. Econ Dev Cultural Change 1980;29:165–185.
35. Esrey SA, Habicht J-P. The relationship between literacy and feeding patterns on infant mortality: the interaction with water and sanitation. Washington, DC: Report prepared for USAID, PPC/PDPR/HR, 1983.
36. Freij L, Wall S. Exploring child health and its ecology. Acta Paediatr Scand (Suppl) 1977;267:1–180.
37. Guerrant RL, Kirchhoff LV, Shields DS, et al. Prospective study of diarrheal illnesses in northeastern Brazil: patterns of disease, nutritional impact, etiologies, and risk factors. J Infect Dis 1983;148:986–97.
38. Heller PS. Interactions of childhood mortality and fertility in W. Malaysia: 1947–1970. Center for Research on Economic Development, Michigan. Discussion Paper no. 57, Ann Arbor, MI, 1976.
39. Livingstone-Balbontin M. Socioeconomic and health variables affecting infant and child mortality in Chile, 1970: a regional analysis. Center for Demography and Ecology, University of Wisconsin-Madison, CDE Working Paper 76-2, 1976.
40. Meegama SA. Socio-economic determinants of infant and childhood mortality in Sri Lanka: an analysis of post-war experience. London: World Fertility Survey Report no. 8, 1980.
41. Magnani R, Tourkin S, Hartz M. Evaluation of the provincial water project in the Philippines. International Statistical Program Center, Bureau of the Census, US Dept of Commerce, Washington, DC, 1984.
42. Moore HA, de la Cruz E, Vargas-Mendez O. Diarrheal disease studies in Costa Rica. IV. The influence of sanitation upon the prevalence of intestinal infection and diarrheal disease. Am J Epidemiol 1965;82:162–84.
43. Patel M. Effects of the health services and environmental factors on infant mortality: the case of Sri Lanka. J Epidemiol Community Health 1980;34:76–82.
44. Pickering H. Social and environmental factors associated with diarrhoea and growth in young children: child health in urban Africa. Soc Sci Med 1985;2:121–7.
45. Rahman M, Rahaman MM, Wojtyniak B, et al. Impact of environmental sanitation and crowding of infant mortality in rural Bangladesh. Lancet 1985;2:28–31.
46. Haines MR, Avery RC. Differential infant and child mortality in Costa Rica: 1968–1973. Popul Studies 1982;36:31–43.
47. Schliessman DJ. Diarrhoeal disease and the environment. Bull WHO 1959;21:381–6.
48. Victora CS, Blank N. Epidemiology of infant mortality in Rio Grande de Sol, Brazil. J Trop Med Hyg 1980;83:177–86.
49. Yee V. Household level correlates of child nutritional status in Fiji. Master's Thesis. Ithaca, NY: Cornell University, 1984.
50. Waxler NE, Morrison BM, Sirisena WM, et al. Infant mortality in Sri Lankan households: a causal model. Soc Sci Med 1985;4:381–92.
51. White GF, Bradley DJ, White AU. Drawers of water: domestic water use in East Africa. Chicago, IL: University of Chicago Press, 1972.
52. Rubenstein A, Boyle J, Odoroff CL, et al. Effect of improved sanitary facilities on infant diarrhea in a Hopi village. Public Health Rep 1969;84:1093–7.
53. Bahl MR. Impact of piped water supply on the incidence of typhoid fever and diarrhoeal diseases in Lusaka. Med J Zambia 1976;10:98–9.
54. Curlin GT, Aziz KMA, Khan MR. The influence of drinking tubewell water on diarrhea rates in Matlab Thana, Bangladesh. Dacca: International Centre for Diarrhoeal Disease Research, Bangladesh, Cholera Research Lab Working Paper no. 1, 1977.
55. Fenwick KWH. The short term effects of a pilot environmental health project in rural Africa: the Zaina scheme reassessed after four years. Mimeograph undated.
56. Levine RJ, Khan MR, O'Sauza S, et al. Failure of sanitary wells to protect against cholera and other diarrhoea in Bangladesh. Lancet 1976;2:86–9.
57. Merrick T. The effect of piped water on early childhood mortality in urban Brazil, 1970–1976. Demography 1985;22:1–24.
58. Popkin BM. Time allocation of the mother and child nutrition. Ecol Food Nutr 1980;9:1–14.
59. Raman V, Parhad NM, Deshpande AW, et al. Assessment and control of water quality in a town distribution system with reference to the incidence of gastrointestinal diseases. Prog Water Tech 1978;11:65–71.
60. Skoda JD, Mendis JB, Chia M. A survey in rural Bangladesh on diarrhoeal morbidity, water usage and related factors. Dacca: First Report, UNICEF, 1977.
61. Spira WM, Khan MU, Saeed YA, et al. Microbiological surveillance of intra-neighborhood El Tor cholera transmission in rural Bangladesh. Bull WHO 1980;58:731–40.
62. Van Zijl WJ. Studies on diarrhoeal diseases in seven countries by the WHO diarrhoeal diseases

advisory team. Bull WHO 1966;35:249–61.
63. Shiffman MA, Schneider R, Faigenblum JM, et al. Field studies on water, sanitation and health education in relation to health status in Central America. Prog Water Tech 1978;11:143–50.
64. Wray JD. Direct nutrition intervention and the control of diarrheal diseases in preschool children. Am J Clin Nutr 1978;31:2073–82.
65. Rajasekaran P, Dutt PR, Pisharoti KA. Impact of water supply on the incidence of diarrhoea and shigellosis among children in rural communities in Madurai. Indian J Med Res 1977;66:189–99.
66. Feachem RG, Burns E, Cairncross S, et al. Water health and development. London: Tri-Med Books, 1978.
67. Hollister AC, Beck MD, Gittelsohn RM, et al. Influence of water availability on *Shigella* prevalence in children of farm labor families. Am J Public Health 1955;45:354–62.
68. Burr ML. Diarrhoea and the drought. Public Health 1978;92:86–7.
69. Bannaga SEI, Pickford J. Water-related relationships in Sudan. Eff Water Treat J 1978;18:560–9.
70. El Karim MAA, El Hasan BM, Hussein KK. Social and public health implications of water supply in arid zones in the Sudan. Soc Sci Med 1985;4:393–8.
71. Hebert JR. Effects of water quality and water quantity on nutritional status: findings from a south Indian community. Bull WHO 1985;63:143–55.
72. Sommer A, Woodward WE. The influence of protected water supplies on the spread of classical/Inaba and el tor/Ogawa cholera in rural East Bengal. Lancet 1972;2:985–7.
73. Stewart WH, McCabe LJ, Hemphill EC, et al. The relationship of certain environmental factors to prevalence of *Shigella* infection. IV. Diarrheal disease control studies. Am J Trop Med Hyg 1955;4:718–24.
74. Thacker SB, Music SI, Pollard RA, et al. Acute water shortage and health problems in Haiti. Lancet 1980;1:471–3.
75. Tomkins AM, Drasar BS, Bradley AK, et al. Water supply and nutritional status in rural northern Nigeria. Trans R Soc Trop Med Hyg 1978;72:239–43.
76. Trivedi BK, Gandhi HS, Shukla NK. Bacteriological water quality and incidence of water borne diseases in a rural population. Indian J Med Sci 1971;25:795–801.
77. Watt J, Hollister AC, Beck MD, et al. Diarrheal diseases in Fresno county, California. Am J Public Health 1953;43:728–41.
78. Ryder RW, Reeves WC, Singh N, et al. The childhood health effects of an improved water supply system on a remote Panamanian island. Am J Trop Med Hyg 1985;34:921–4.
79. Hardon A. Food contamination in relation to diarrhoea: a study in a rural village in the Philippines. Amsterdam: Royal Tropical Institute (mimeo) 1984.
80. Mathur R, Reddy V. Bacterial contamination of infant foods. Indian J Med Res 1983;77:342–6.
81. Samadi AR, Huq MI, Ahmed QS. Detection of rotavirus in handwashings of attendants of children with diarrhea. Br Med J 1983;286:188.
82. Lowbury EJL, Lilly HA, Bull JP. Disinfection of hands: removal of transient organisms. Br Med J 1964;2:230–3.
83. Sprunt K, Redman W, Leidy G. Antibacterial effectiveness of routine hand washing. Pediatrics 1973;52:264–71.
84. Black RE, Dykes AC, Anderson KE, et al. Handwashing to prevent diarrhea in day-care centers. Am J Epidemiol 1981;113:445–51.
85. Khan MU. Interruption of shigellosis by hand washing. Trans R Soc Trop Med Hyg 1982; 76:164–8.
86. Torun B. Environmental and educational interventions against diarrhea in Guatemala. In: Chen LC, Scrimshaw NS, eds. Diarrhea and malnutrition: interactions, mechanisms and interventions. New York: Plenum Press 1982:235–66.
87. Ghannoum MA, Moore KE, Al-Dulaimi M, et al. The incidence of water-related diseases in the Brak area, Libya, from 1977 to 1979, before and after the installation of water treatment plants. Zentralbl Bakteriol Mikrobiol Hyg (B) 1981; 173:501–8.
88. Hughes JM, Boyce JM, Levine RJ, et al. Epidemiology of eltor cholera in rural Bangladesh: importance of surface water in transmission. Bull WHO 1982;60:395–404.
89. Petersen NJ, Hines VD. The relation of summertime gastrointestinal illness to the sanitary quality of the water supplies in six Rocky Mountain communities. Am J Hyg 1960;71:314–20.
90. Zaheer M, Prasad BG, Govil KK, et al. A note on urban water supply in Uttar Pradesh. J Indian Med Assoc 1962;38:177–82.
91. Bersh D, Osoria MM. Studies of diarrhoea in Quindo (Colombia): problems related to water treatment. Soc Sci Med 1985;1:31–9.
92. Cuny FC. Development of water supply standards for refugee camps. Dallas, TX: Intertect, 1982.
93. USAID. Domestic water and sanitation, PPC/Policy Paper, Washington, DC, 1982.
94. World Health Organization. International standards for drinking water quality. 2nd ed. Geneva: WHO, 1971.
95. World Health Organization. Guidelines for drinking water quality. Vol 1. Recommendations. Geneva: WHO, 1984.
96. Feachem RG. Bacterial standards for drinking water quality in developing countries. Lancet 1980;2:255–6.