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Interventions for the control of diarrhoeal diseases among young children: improving water supplies and excreta disposal facilities*

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A theoretical model is proposed that relates the level of ingestion of diarrhoea-causing pathogens to the frequency of diarrhoea in the community. The implications of this model are that, in poor communities with inadequate water supply and excreta disposal, reducing the level of enteric pathogen ingestion by a given amount will have a greater impact on diarrhoea mortality rates than on morbidity rates, a greater impact on the incidence rate of severe diarrhoea than on that of mild diarrhoea, and a greater impact on diarrhoea caused by pathogens having high infectious doses than on diarrhoea caused by pathogens of a low infectious dose. The impact of water supply and sanitation on diarrhoea, related infections, nutritional status, and mortality is analysed by reviewing 67 studies from 28 countries. The median reductions in diarrhoea morbidity rates are 22% from all studies and 27% from a few better-designed studies. All studies of the impact on total mortality rates show a median reduction of 21%, while the few better-designed studies give a median reduction of 30%. Improvements in water quality have less of an impact than improvements in water availability or excreta disposal.

Of the several interventions that may reduce diarrhoea morbidity and mortality rates (*38*), the improvement of water supply and excreta disposal facilities has attracted particular interest. These environmental improvements, together with improvements in living standards, played a major role in reducing diarrhoea rates and controlling epidemic typhoid and cholera in Europe and North America between 1860 and 1920. It is anticipated that the improvement of water supply and excreta disposal in poor communities in developing countries today will have a substantial impact on diarrhoea morbidity and mortality rates in those communities. This expectation provides part of the motivation for the International Drinking Water Supply and Sanitation Decade (1981-1990), the aims of which are to increase the rate at which new water supply and excreta disposal facilities are constructed and to maximize the probability that they will be correctly operated, maintained and used.

The potential impacts of improved water supply and excreta disposal on diarrhoea and other water-related diseases in developing countries have been discussed and debated at length over the past decade. White et al. (*86*) provided a conceptual framework for the debate in the context of studies in East Africa; McJunkin (*56*) reviewed the topic extensively; Saunders & Warford (*70*) summarized the water supply impact studies; Feachem et al. (*39*) summarized the excreta disposal impact studies; and Blum & Feachem (*13*) and Esrey & Habicht (*28*) considered the methodological difficulties inherent in attempts to measure the impact of water supply and excreta disposal projects on diarrhoea.

In this review we analyse the effectiveness of water supply and excreta disposal improvements for reducing diarrhoea rates in young children in developing countries. We also examine their impact on diarrhoea-related infections, nutritional status, and mortality. We make no attempt to analyse other impacts of water supply and excreta disposal improvements or to compute an overall cost-benefit ratio for these investments. This paper is the ninth in a series of reviews of potential anti-diarrhoea interventions (*2, 25, 26, 32, 34-36, 38*).[a]

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[a] ASHWORTH, A. & FEACHEM, R. G. *Interventions for the control of diarrhoeal diseases among young children: improving lactation.* Unpublished WHO document CDD/85.2, 1985.

EFFECTIVENESS

For improved water supply or excreta disposal facilities to be an effective diarrhoea control intervention, it must be true that:

either

water supply or excreta disposal improvements can reduce the ingestion by young children of pathogens causing diarrhoea	*hypothesis 1*

and

a reduction in the ingestion of these pathogens by young children can reduce diarrhoea morbidity or mortality rates	*hypothesis 2*

or

water supply or excreta disposal improvements can reduce diarrhoea morbidity or mortality rates among young children	*hypothesis 3*

The effectiveness of improved water supply and excreta disposal would be suggested by a demonstration either of the correctness of hypotheses 1 and 2 or the correctness of hypothesis 3. In some other reviews in this series (for instance, *35, 36*), most of the literature bears on hypotheses 1 and 2, and hypothesis 3 must be handled by theoretical calculations. Here the reverse is the case: there are few data on hypotheses 1 and 2 and an extensive literature on hypothesis 3. The evidence for and against the three hypotheses is examined below.

Hypothesis 1. *Water supply or excreta disposal improvements can reduce the ingestion by young children of pathogens causing diarrhoea.*

There is some evidence to suggest that three types of water and excreta disposal improvements (improved water quality, increased water availability and quantity associated with better hygiene practices, and improved excreta disposal facilities) may reduce the ingestion of pathogens causing diarrhoea (*33*).

All the major infectious agents of diarrhoea are transmitted by the faecal-oral route, and all can be transmitted via contaminated water. For most agents water-borne transmission has been documented. For some agents there is good evidence that, at least in some places at some times, water is a major vehicle of transmission. Notable examples are *Salmonella typhi, Vibrio cholerae*, and *Giardia lamblia* (*39*). Traditional water sources are often highly contaminated with faecal matter. Improved water sources may be free of contamination or considerably less contaminated than unimproved water sources (*30, 77*). Uncontaminated source water may become polluted by the time it is ingested, and water storage in home containers may result in increased contamination depending on storage conditions (*37, 66, 72*).

Increased water availability and quantity, associated with improved hygiene, may reduce faecal contamination of the hands. Proper cleaning of utensils, food, and home environments is also likely to reduce transmission of faecal matter. The transmission of all the main diarrhoea-causing agents is probably influenced to some degree by increased water availability and quantity, but it is *Shigella* transmission that has been particularly associated with poor personal and domestic hygiene (*45, 78*). This may be because of the low infectious dose of *Shigella* relative to other bacterial enteric pathogens, or it may be only because *Shigella* has been most studied. The relationship between personal hygiene and the newly-recognized diarrhoea agents (especially *Campylobacter jejuni*, enterotoxigenic *Escherichia coli*, and rotavirus) should be studied.

All the major infectious agents of diarrhoea are shed by infected persons via the faeces, and therefore hygienic disposal of human excreta plays a role in controlling them. Use of toilets by all members of the community should reduce faecal contamination of houses, yards and gardens, and the neighbourhood. In addition, proper treatment and disposal of human excreta would prevent faecal contamination of fields, crops, and receiving water-bodies, which would in turn further reduce the transmission of faecal pathogens. The hygienic disposal of the faeces of children too young to use the toilet is of the utmost importance, because such children constitute an important reservoir of several agents of diarrhoea (for instance, rotavirus and enterotoxigenic *E. coli*).

Hypothesis 2. *A reduction in the ingestion of these pathogens by young children can reduce diarrhoea morbidity or mortality rates.*

The ingested dose of a pathogen required to cause diarrhoea depends upon the particular properties of the pathogen and upon a number of host factors. The general relationship between ingested dose and proportion of exposed persons contracting diarrhoea

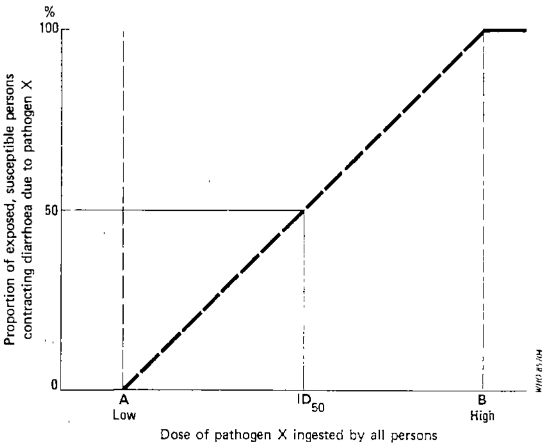

Fig. 1. Dose-response relationship for a group of susceptible persons, all exposed to an equal dose of pathogen X.

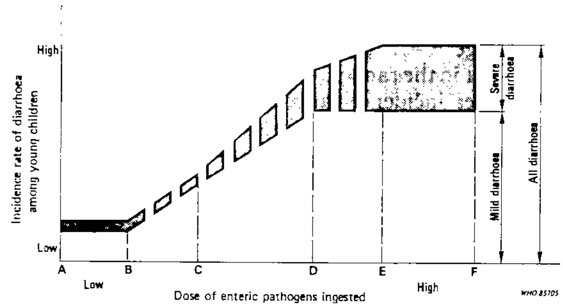

Fig. 2. Dose-response relationship for young children under various levels of exposure to an array of enteric pathogens.

is shown in Fig. 1. In the dose range below A, no one becomes ill.[b] In the dose range above B, all susceptible persons develop diarrhoea. Between A and B lies an intermediate range in which some persons become ill and others do not. The dose at which 50% of challenged persons become ill is known as the median infectious dose (ID_{50}), which is the figure generally reported from volunteer studies. Little is known about the shape of the curve in the intermediate range and, for this reason, a broken line is shown in Fig. 1. Both the shape of the curve and the values of A, B, and the ID_{50} depend upon the particular pathogen, its method of ingestion (in water or in food), and a variety of features of the exposed group of people, such as age and immunity.

Available ID_{50} and other infectious dose data have been recently reviewed for all the major diarrhoea-causing pathogens (*39*). For bacterial agents there is a wide range of ID_{50} values—from around 10^3 for *Shigella* to 10^8–10^{11} for *Vibrio cholerae*. Less is known about the viral and protozoal agents of diarrhoea, although there are grounds for assuming that the ID_{50} values are relatively low ($< 10^2$). Nearly all infectious dose data are derived from studies on volunteers in which the subjects were healthy adults from developed countries. The doses necessary to infect children, particularly malnourished children, may be very different. ID_{50} values also depend on the food or drink with which the pathogens are ingested; therefore, they may differ among countries with differing dietary and child-feeding practices. In addition, in situations where large numbers of persons are exposed to diarrhoea-causing pathogens, the ID_1 or $ID_{0.1}$ values may be of greater epidemiological relevance than the ID_{50} values. More reliance can be placed on the relative ranking of pathogens by ID_{50} than on the absolute dose values obtained from studies on volunteers.

[b] Despite the representation in Fig. 1, it may be that for some pathogens A = 0.

The relationship depicted in Fig. 1 may be generalized to a group of young children having different levels of water supply and excreta disposal services and, consequently, different levels of ingestion of enteric pathogens (Fig. 2). Consider first the incidence rate of mild diarrhoea. At low levels of ingestion (A–B), there remains an appreciable incidence of mild diarrhoea, made up of an irreducible minimum of infectious diarrhoea, plus diarrhoea not due to enteric pathogens. This situation is exemplified by children in wealthy communities in developed countries. When ingestion rises above point B, the incidence rate of mild diarrhoea also rises. At point D saturation is reached, and further increases in the ingestion of pathogens do not result in an increased incidence rate of mild diarrhoea. As in Fig. 1, the shape of the curve between points B and D on the "mild diarrhoea incidence" line in Fig. 2 is unknown, so a broken line is shown. Poor communities in developed and developing countries, with their elevated diarrhoea incidence rates, clearly lie to the right of point B.

The incidence rate of severe diarrhoea, which may be defined by stooling rate, stool volume, duration, degree of dehydration or other measures, is indicated on Fig. 2 by the distance between the two lines (the shaded band). The incidence rate of severe diarrhoea is less than that of mild diarrhoea, but it represents an increasing proportion of the total diarrhoea incidence rate as the ingestion of enteric pathogens rises above the level represented by point C.[c] The incidence rate of severe diarrhoea is shown in Fig. 2 to be constant in the range A–C, to rise in the range C–E, and to be constant in the range E–F. The breakpoints for severe diarrhoea incidence rate (C and E) are offset to the right of the equivalent points for mild diarrhoea incidence rate (B and D), on the assumption that for a single pathogen a higher ingested dose is necessary to produce severe diarrhoea than mild diarrhoea. There is direct experimental confirmation of this for enterotoxigenic *E. coli* (*27*) and for *Vibrio cholerae* (*19*). Indirect evidence is also available for *Salmonella*, for which there is an inverse relationship between dose and incubation period (*12*) and an inverse relationship between incubation period and severity (*10*). Fig. 2 assumes that the ID_{50} for severe symptoms is higher than the ID_{50} for mild symptoms for most enteric pathogens.

The model put forward in Fig. 2 is tentative and grossly simplified. It may be more applicable to young children than to a whole community. The complex role of immunity is not specifically addressed in the model and, for certain pathogens, the improvement of hygienic conditions may lead to an increase in diarrhoea incidence rates in older age groups. A more complete modelling of the interrelationships between hygiene levels and diarrhoea incidence is difficult because of the wide differences in epidemiology and immunology among the major diarrhoea-causing agents. This simplified model provides some theoretical basis for the explanation of a number of observed features of childhood diarrhoea. We hope that it may stimulate others to conduct studies to define more precisely the complex reality.

The implications of Fig. 2 for diarrhoea control by reducing pathogen ingestion are as follows. If pathogen ingestion is reduced within the range F–E, the incidence rates of mild or severe diarrhoea may not change. In the range E–D, severe diarrhoea rates may fall, but mild diarrhoea rates may not. Because severe cases usually represent a small proportion of all cases, surveillance of all cases may fail to detect a fall in incidence rate in this range. For instance, if a water supply and excreta disposal project reduced the dose of ingested pathogens from E to D, Fig. 2 suggests that the incidence rate of severe diarrhoea might fall by about 44% but the incidence rate of all diarrhoea by only about 12%. Many diarrhoeal disease studies are unable to detect a 12% fall in total incidence rate or to show it to be statistically significant. In the range D–E an impact is more likely to be documented if data on the incidence rate of severe diarrhoea (however defined) are collected. Measures of diarrhoea or total mortality are also more likely to detect an impact in this range (see below).

In the range D–C in Fig. 2, both mild and severe diarrhoea incidence rates are falling, and a change may be detected by surveillance of all cases. Severity, child growth, or mortality parameters are also likely to change in this range. In the range C–B, only the incidence rate of mild cases is declining but, since most cases are mild, surveillance of all cases may detect an impact. In the range B–A, reductions in pathogen ingestion have no effect on diarrhoea of any type.

This discussion of the implications of the model presented in Fig. 2 may be restated in two other ways. First, since it is severe episodes that lead in some instances to death, the mild diarrhoea incidence rate in Fig. 2 may be replaced by the total diarrhoea incidence rate and the severe diarrhoea incidence rate by the diarrhoea mortality rate. Diarrhoea mortality rates may therefore be a more responsive indicator in the range D–E or ranges overlapping with the range D–E than diarrhoea morbidity rates. Diarrhoea mortality rates will not, however, be a good measure of impact in areas where oral rehydration therapy is widely available and averts most deaths from dehydration. Second, since there are putative differences in ID_{50} values, not only between degrees of severity of diarrhoea caused by a single pathogen, but also among different pathogens, the mild diarrhoea incidence rate may be replaced by the incidence rate of etiologies having low ID_{50} values, and the severe diarrhoea incidence rate by the incidence rate of etiologies having high ID_{50} values.[d] This model is consistent with known facts, in that developed countries, which may lie in the range A–C, have a small proportion of cholera and enterotoxigenic *E. coli* diarrhoea (high ID_{50}), a high proportion of rotavirus diarrhoea (low ID_{50}), and an intermediate proportion of shigellosis (intermediate ID_{50}).[e]

It must be emphasized that the model presented in Fig. 2 is hypothetical and grossly simplified. It is, however, consistent with several established facts and, as discussed below, it is helpful in explaining some of the variation in the recorded impacts of water supply and excreta disposal projects on diarrhoeal diseases. A somewhat similar model has been previously published (*73*).

[c] The highest ratios of severe diarrhoea to all diarrhoea have been recorded in some epidemics, which may be associated with exceptionally high average doses of pathogens ingested by an exposed population.

[d] It is not implied here that pathogens having relatively low ID_{50} values cause relatively mild diarrhoea and vice versa. This is clearly untrue in the cases of rotavirus and *Shigella*, both of which have relatively low ID_{50} values but cause relatively severe diarrhoea.

[e] This analysis probably only applies to the anthroponotic agents mentioned here. For the zoonotic diarrhoea agents, such as *Salmonella* and *Campylobacter*, most transmission in developed countries is from infected animals to man via contaminated food products, and so levels of pathogen ingestion depend more on farming methods, food handling practices, and diet than on domestic water supply and human excreta disposal facilities.

Hypothesis 3. *Water supply or excreta disposal improvements can reduce diarrhoea morbidity or mortality rates among young children.*

Numerous attempts have been made to measure the impact on health of improved water supply or sanitation. We selected for review those 67 studies from 28 countries[f] that measured health impact in terms of diarrhoea morbidity, *Shigella* infection or disease, cholera, *Entamoeba histolytica* infection, *Giardia lamblia* infection, nutritional anthropometry, diarrhoea mortality, or total mortality. These studies are grouped in Table 1 according to the health impact indicator measured and ordered alphabetically by country within each group.

The data abstracted from the studies listed in Table 1 are summarized in Tables 2–5. All the studies in Table 1 display methodological deficiencies (*13*, *28*) although some studies were better than others. The total number of studies is large (67), but only a few are reported in sufficient detail to allow an objective assessment of their methodological and analytical

[f] Studies were identified from previous reviews, supplemental enquiries to workers in the field, computer searches in five languages, and from unpublished papers presented at the International Seminar on Measuring the Health Impact of Water and Sanitation Programmes, Cox's Bazaar, Bangladesh, 21–25 November 1983 (sponsored by the International Centre for Diarrhoeal Diseases Research, Bangladesh, and the Ross Institute, London).

Table 1. Studies on the impact of water supply or excreta disposal on diarrhoea morbidity and mortality, enteric infections, total mortality, and nutritional status reviewed in this paper

Indicator	Country	Reference
Diarrhoea morbidity	Bangladesh	*22, 54, 74,*[a]
	Chile	*24*
	Colombia	*51, 88*
	Costa Rica	*62*
	Egypt	*82*
	Ethiopia	*40*
	Gambia	See below[b]
	Guatemala	*16, 72*
	Haiti	*79*
	India	*53, 66, 67, 81*
	Iran (Islamic Rep. of)	*82*
	Kenya	*86,*[c]
	Lesotho	*37*
	Mozambique	See below[d]
	Sri Lanka	*82*
	Saint Lucia	*44,*[g]
	Sudan	*6, 82*
	United Kingdom	*17*
	USA	*8, 15, 55, 64, 69, 71, 84*
	Venezuela	*82, 87*
	Zambia	*4*
Cholera	Bangladesh	*22, 46, 49, 50, 54, 76, 77*
	Philippines	*3*
Entamoeba histolytica infection	Costa Rica	*62*
	Egypt	*20*
	India	*59, 66*
	Kenya	See below[c]
	Libyan Arab Jamahiriya	*41*
	USA	*15, 29, 57*

Table 1: *continued on next page*

Table 1: *continued*

Indicator	Country	Reference
Giardia lamblia infection	Costa Rica	*62*
	Egypt	*20*
	India	*66*
	Kenya	See below[c]
	Libyan Arab Jamahiriya	*41*
	USA	*29*
Shigella infection or disease	Bangladesh	*22, 48, 65,*[a]
	Costa Rica	*62*
	Egypt	*82*
	Guatemala	*7*
	India	*66*
	Iran (Islamic Rep. of)	*82*
	Libyan Arab Jamahiriya	*41*
	Panama	*52*
	Sri Lanka	*82*
	Sudan	*82*
	USA	*45, 55, 71, 78, 84*
	Venezuela	*82*
Nutritional status	Bangladesh	See below[d]
	Colombia	*21*
	Fiji	See below[e]
	Nigeria	*80*
	Philippines	See below[f]
	Saint Lucia	See below[g]
Diarrhoea mortality	Brazil	*83*
	India	*89*
Total mortality	Brazil	*61*
	Costa Rica	*43*
	Egypt	*85*
	Guatemala	*1*
	Malaysia	*18*
	Sri Lanka	*60, 63*
	Sudan	*6*

[a] RAHAMAN, M. M. *The Teknaf Health Impact Study: methods and results.* Paper presented at the International Workshop on Measuring the Health Impacts of Water Supply and Sanitation Programmes, Cox's Bazaar, Bangladesh, 21–25 November 1983.

[b] PICKERING, H. *The role of anthropologists in studying diarrhoea epidemiology: a case study from The Gambia.* Paper presented at the International Workshop on Measuring the Health Impacts of Water and Sanitation Programmes, Cox's Bazaar, Bangladesh, 21–25 November 1983.

[c] FENWICK, K. W. H. The short-term effects of a pilot environmental health project in rural Africa: the Zaina scheme re-assessed after four years. (undated manuscript).

[d] 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, 21–25 November 1983.

[e] YEE, V. S. *Household level correlates of child nutritional status in Fiji.* MPS thesis. Division of Nutritional Sciences, Cornell University, Ithaca, New York, 1984.

[f] MAGNANI, R. J. & TOURKIN, S. C. *Impact of improved urban water supplies in the Philippines: methods and results.* Paper presented at the International Workshop on Measuring the Health Impacts of Water and Sanitation Programmes, Cox's Bazaar, Bangladesh, 21–25 November 1983.

[g] HENRY, F. J. *Health impact of water and sanitation interventions in St. Lucia.* Paper presented at the International Workshop on Measuring the Health Impacts of Water Supply and Sanitation Programmes, Cox's Bazaar, Bangladesh, 21–25 November 1983.

strength. First, therefore, we analysed the pooled data from all the studies to try to draw a consensus from the many different attempts that have been made in many countries to measure the health impacts of water supply and excreta disposal investments. Second, we examined the results of a few selected studies of superior quality in more detail to compare their findings with those from all 67 studies.

The studies listed in Table 1 report impacts on diarrhoea incidence rates and prevalence rates, which are different measures of morbidity due to diarrhoea. If a water supply or excreta disposal project did not affect the mean duration of diarrhoea episodes, the percentage reductions in incidence rates and prevalence rates would be equal. If, on the other hand, the intervention reduced both incidence rates and duration, then the percentage reduction in prevalence rate would be greater than that in incidence rate. In Tables 2–4 reductions in incidence and prevalence rates are combined under the heading of diarrhoea morbidity rate reduction.

Impact on diarrhoea morbidity. The median reduction in diarrhoea morbidity rate is 22% (Table 2). The magnitude of this reduction may vary depending on a number of factors: age of study population, type of service compared, general living conditions of the area studied, and etiology of diarrhoea. Each of these factors is examined below.

The impact of water supply and excreta disposal improvements on diarrhoea is probably age-specific.

Table 2. Percentage reductions in diarrhoeal morbidity rates attributed to water supply or excreta disposal improvements

Type of intervention	Number of results[a]	Percentage reduction	
		Median	Range
All interventions	53	22	0–100
Improvements in water quality	9	16	0–90
Improvements in water availability,	17	25	0–100
Improvements in water quality and availability	8	37	0–82
Improvements in excreta disposal	10	22	0–48

[a] There are 53 results in total but only 44 attributed to specific interventions. The remaining 9 results are for other interventions or combinations of interventions having less than 3 results, and include interventions in fly control and health education together with water supply or excreta disposal.

Different age groups have different pre-intervention diarrhoea rates, different risk factors, and different tendencies to utilize new water supply or excreta disposal facilities. However, no consistent difference by age in the magnitude of the impact was apparent (data not shown). This suggests that all ages will benefit from improvements, despite the fact that young children do not use latrines.

The type of water supply or excreta disposal service provided is likely to influence the size of the impact. Improvements in water quality had less of an impact on diarrhoea rates than did improvements in water availability or excreta disposal (Table 2). Impacts from water quality plus availability were greater than from either of these improvements separately or from improvements in excreta disposal. The magnitudes of the reductions due to individual service components shown in Table 2 are probably overestimates because situations labelled, for instance, as water quality improvement may well have contained some element of water availability improvement. Data on the impact of water quality improvement, with both water availability and excreta disposal controlled, are not available. This factor may also lead to an underestimate of the magnitude of the differences among the impacts of the different types of service improvement analysed in Table 2.

The magnitude of the impact is likely to be influenced not only by the type of service installed but also by the level of service both before and after the intervention and the living conditions of the study area. All studies of diarrhoea morbidity (Table 1) were therefore divided according to the magnitude of the difference between pre-intervention and post-intervention levels of service (big difference or small difference)[g] and according to the adult literacy rate of the country in which the study was conducted (< 40%, 40–75%, > 75%). Adult literacy is used here as a proxy for pre-intervention levels of hygiene and faecal contamination; in other words, to define the pre-intervention point on the horizontal axis of Fig. 2. Current adult literacy figures are used, assuming that the relative ranking of countries, according to adult literacy, has not changed over the past 30 years. The impacts of studies, categorized by adult literacy rate and magnitude of service improvement, are shown in Table 3.

Impacts attributed to large service-level improvements are consistently higher than impacts attributed

[g] A study was considered to have investigated a large service improvement if one or more of the following comparisons was made: in-house water vs. public water source, piped water vs. unpiped water, water near and plentiful vs. water scarce or far, any toilet vs. no toilet, flush toilet vs. other toilet, or studies in which more than one service component was improved (water quality and water availability, water quality and excreta disposal, water availability and excreta disposal, water quality and water availability and excreta disposal).

Table 3. Percentage reductions in diarrhoea morbidity rates attributed to water supply or excreta disposal improvements by adult literacy rate of the country and magnitude of service improvement

Adult literacy rate[a] (%)	Small service improvements[b]		Large service improvements[b]	
	No. of results	Median (%)	No. of results	Median (%)
< 40	11	18	7	46
40–75	4	20	8	39
> 75	10	16	13	32

[a] Data on adult literacy, by country, from *World development report, 1983* (Washington, World Bank).

[b] See footnote *g*, page 762.

to small service-level improvements (Table 3). If a large service-level improvement is made, the percentage reduction in diarrhoea morbidity rates achieved is inversely related to the pre-intervention level of hygiene (Table 3). The greatest impact is achieved when the pre-intervention hygiene level is worst. For small improvements in service level, impacts appear less dependent upon the pre-intervention hygiene level. These conclusions are consistent with the hypothetical model depicted in Fig. 2 and suggest that the impact of water and sanitation improvements depends in part on the presence and interaction of other risk factors.

Impact on specific infections. When impact on total diarrhoea morbidity is broken down by etiology, it is likely, as discussed above, that different specific diarrhoeas will be reduced by different amounts. Table 4 presents data on impacts on cholera, *Shigella* infection or disease, and infection by *Ent. histolytica* and *G. lamblia*. Since the distinction between the severe and mild diarrhoea bands in Fig. 2 is merely one of infectious dose (ID), in ranges including D–E, any reduction in pathogen ingestion will produce a greater percentage reduction in the incidence rate of the high ID etiologies than the low ID etiologies. Thus the impact of a water supply and excreta disposal improvement (in ranges including D–E) on specific etiologies may be in the following descending order of magnitude: cholera, enterotoxigenic *E. coli*, *Shigella*, the protozoa, rotavirus. The relative impacts on *Shigella* and the protozoa are supported by the data in Table 4. The anomalous cholera data are discussed elsewhere (*31*).

Data on the impact of water supply and excreta disposal projects on enterotoxigenic *E. coli* and rotavirus incidences are not yet available, but it is anticipated that the impact on enterotoxigenic *E. coli* will be considerable and on rotavirus negligible. The latter prediction is indirectly supported by data showing that the incidence rate of rotavirus diarrhoea among children under 2 years of age is 0.3–0.4 episodes per child per year in both Bangladesh (*11*) and Winnipeg, Canada (*42*).

Impact on nutritional anthropometry. If water supply and excreta disposal improvements reduce diarrhoea incidence rates or duration among young children, then nutritional anthropometric indicators should also improve because of the inverse relationship between time spent with diarrhoea and child growth (*58, 68*). Six studies that investigated the relationship between water supply or excreta disposal improvements and nutritional status are summarized in Table 5. All six studies reported an association between improved water supply or excreta disposal and improved nutritional status. In two studies, in Fiji and the Philippines, attempts to control for extraneous risk factors reduced the differences between the control and intervention groups, but some of these differences were nonetheless found to be statistically significant.

Impact on mortality. Only two studies were located that reported the impact of water supply or excreta disposal improvements on diarrhoea mortality rates (Table 1); a 41% median reduction in diarrhoea mortality rate was calculated from them. Both studies were concerned with the impact of improved water supplies in urban areas, and in neither was the study method well described. A further eight studies reported impacts of water supply or excreta disposal improvements on mortality from all causes (Table 1), and they indicated a 21% (range, 0–81%) median reduction in mortality rate.

Table 4. Percentage reductions in morbidity or infection rates of cholera, *Shigella*, *Entamoeba histolytica*, and *Giardia lamblia* attributed to water supply or excreta disposal improvements

Disease or infection	No. of results	Percentage reduction	
		Median (%)	Range (%)
Cholera	11	41	0–91
Shigella	27	48	0–81
Entamoeba histolytica	17	2	0–80
Giardia lamblia	10	0	0–20

Table 5. Improvements in nutritional status attributed to various types of water supply or excreta disposal improvement

Country	Nutritional indicator[a]	Age (months)	Type of intervention[b]	Value of indicator: Control group	Value of indicator: Target group	Reference
Bangladesh	Percentage with H/A > 90% of standard	0–11	Q+A+E	75	76	See below[d]
		12–23	Q+A+E	50	51	
		24–35	Q+A+E	45	48	
	Percentage with W/A > 75% of standard	0–11	Q+A+E	59	63	
		12–23	Q+A+E	44	43	
		24–35	Q+A+E	47	50	
Colombia	Percentage with W/A > 90% of standard	6–30	E	26	47	*21*
		6–30	A	22	51	
	Percentage with H/A > 95% of standard	6–30	E	26	48	
		6–30	A	20	53	
Fiji	Mean percentage of:					See below[e]
	standard W/A					
	urban	0–59	E	102	100	
	rural	0–59	E	95	102	
	standard H/A					
	urban	0–59	E	100	100	
	rural	0–59	E	99	103	
Nigeria	Percentage with:					*80*
	W/A > 75% of standard	6–59	A	50	69	
	H/A > 90% of standard	6–59	A	80	69	
	W/H > 80% of standard	6–59	A	63	90	
Philippines	Percentage with W/A > 75% of standard					See below[f]
	pre-intervention	6–54		74	75	
	post-intervention	6–54	Q+A	71	80	
Saint Lucia	Percentage with W/A > 90% of standard	1–3	A (A+E)	93	92 (86)[c]	See below[g]
		4–6		72	90 (88)	
		7–9		51	78 (76)	
		10–12		44	76 (73)	
		13–15		50	76 (58)	
		16–18		51	74 (57)	
		19–21		53	75 (66)	
		22–24		54	79 (71)	

[a] W/A = weight for age; W/H = weight for height; H/A = height for age.

[b] Q = water quality improvement, A = water availability improvement, E = excreta disposal improvement.

[c] Figures not in parentheses refer to the communities receiving water availability improvements (A). Figures in parentheses refer to communities receiving water availability improvements plus excreta disposal facilities (A + E).

[d] See footnote *a* to Table 1.

[e] See footnote *e* to Table 1.

[f] See footnote *f* to Table 1.

[g] See footnote *g* to Table 1.

Fig. 2 predicts a larger impact on diarrhoea mortality than morbidity over a wide range of conditions. The impact on total mortality will depend on the proportion of all mortality that is due to diarrhoea and the degree to which water supply and excreta disposal improvements affect the causes of death other than diarrhoea. Since water supply and excreta disposal improvements will have little impact on some major causes of death (for instance, respiratory infection, measles, malaria, and neonatal tetanus), it is to be expected that the impact on diarrhoea mortality is considerably greater than the impact on all mortality.

Results from selected studies. For the analyses so far, we have used pooled data from all studies listed in Table 1 to give an overview of all documented experiences on the impacts of water supply and excreta disposal improvements on diarrhoea. It is instructive to compare these findings with the results of a few of the better studies. Criteria for judging the quality of each study have been developed and are reported elsewhere (*28*).

The first finding from this selective analysis was that all studies that reported a negative impact were flawed in one or more major respects. In other words, the better studies consistently reported positive impacts.

The best studies were on total mortality (*18, 43, 60*), and the median impact on total mortality rates reported from these studies was a reduction of 30%. Analysis for statistical interactions revealed a range of reductions in mortality rates of 8–64%, depending on the type of intervention and on the presence of other risk factors, such as poor feeding practices and low literacy rates. For example, in one study (*18*) excreta disposal improvements were reported to have a larger impact on infant mortality rates than water supply, but the magnitudes of these impacts were greatly affected by whether the infants were breast-fed. The impact of the environmental interventions was greater for non-breast-fed infants than for breast-fed infants. Thus, it is likely that non-breast-fed infants were further to the right along the horizontal axis in Fig. 2 than were breast-fed infants. Another study reported that excreta disposal improvements had a greater impact on mortality in families with literate mothers than in families with illiterate mothers (*60*). This may reflect an increased ability of literate mothers to make correct use of the new excreta disposal facilities.

Two studies on nutritional status also examined statistical interactions. In one,[h] excreta disposal was reported to have more impact in rural than in urban areas. In the other,[i] water quality improvements had an impact only among higher income households.

Studies on diarrhoea morbidity were not as well controlled as the mortality studies referred to above. A median reduction in diarrhoea morbidity rates of 27% (range, 0–68%) was found in the studies judged to be most satisfactory (*40, 51, 55, 71*).[j, k, l]

This brief review of selected studies of superior design leads to two conclusions. First, the median reductions in diarrhoea morbidity rates (27%) and total mortality rates (30%) are a little higher than the values found by analysing all studies. Second, the magnitude of the impact depends greatly on the presence of other risk factors. More knowledge of these interactions would enable the appropriate type of intervention to be targeted to families that are likely to benefit the most.

FEASIBILITY

Nearly all developing countries are currently engaged in substantial programmes to improve water supplies in both rural and urban areas. The urban programmes date back, in many cases, to the 1920s or earlier, while many of the rural programmes were initiated in the 1960s. This considerable experience in water supply programmes throughout the world has been copiously documented (e.g., *23*) and is continuously monitored by WHO.[m] Improved water supplies can be provided to almost all people in all developing countries, and the technologies for achieving this are, for the most part, well established. Several problems remain, however, such as poor operation and maintenance, inappropriate choice of technology, inadequate revenue collection, failure to sustain community participation, and high rates of water leakage and wastage.

All countries have experience in excreta disposal

[h] YEE, V. S. *Household level correlates of child nutritional status in Fiji.* MPS thesis. Division of Nutritional Sciences, Cornell University, Ithaca, New York, 1984.

[i] MAGNANI, R. J. & TOURKIN, S. C. *Impact of improved urban water supplies in the Philippines: methods and results.* Paper presented at the International Workshop on Measuring the Health Impacts of Water and Sanitation Programmes, Cox's Bazaar, Bangladesh, 21-25th November 1983.

[j] 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, 21-25 November 1983.

[k] PICKERING, H. *The role of anthropologists in studying diarrhoea epidemiology: a case study from the Gambia.* Paper presented at the International Workshop on Measuring the Health Impacts of Water and Sanitation Programmes, Cox's Bazaar, Bangladesh, 21-25 November 1983.

[l] RAHAMAN, M. M. *The Teknaf Health Impact Study: methods and results.* Paper presented at the International Workshop on Measuring the Health Impacts of Water Supply and Sanitation Programmes, Cox's Bazaar, Bangladesh, 21-25 November 1983.

[m] See, for example, *World Health Statistics Report*, Vol. 26, No. 11, 1973; *World Health Statistics Report*, Vol. 29, No. 10, 1976; and *The International Drinking Water Supply and Sanitation Decade. Review of national baseline data (as at 31 December 1980)*, Geneva, World Health Organisation, 1984 (WHO Offset Publication No. 85).

programmes in urban areas, in some cases dating back thousands of years. Rural excreta disposal programmes are typically a new phenomenon, and some countries still lack concerted efforts in this sector. Problems commonly encountered in excreta disposal programmes include the inappropriate choice of technology, poor operation and maintenance, inadequate revenue collection, and the lack of perception in many rural communities of the importance of improved excreta disposal practices. Research into the technical, economic, and social aspects of excreta disposal in developing countries (e.g., see *47*) over the past decade has led to some promising new approaches.

COSTS

Despite the extensive experience with water supply and excreta disposal projects throughout the world, the cost data on these projects are often of poor quality and not strictly comparable. Data on operation and maintenance costs, on institutional overhead costs, and on the costs of community mobilization and education, are especially deficient.

Table 6 presents cost data from 87 developing countries. Costs vary widely depending upon the design criteria adopted in different countries and upon the costs of labour and materials. The costs of operation and maintenance (recurrent costs) must be added to the construction costs, and data on these costs are not readily available. One study of excreta disposal in 12 countries estimated that operation and maintenance accounted for between 4% and 52% of the total project costs per year, depending on the technology under consideration (*47*). Several widely used technologies (for instance, sewerage and pour-flush latrines) had operation and maintenance costs that comprised approximately 30% of the total annual project costs. For rural water supplies, data assembled by a UNDP/World Bank project[n] suggest that the same figure, 30%, is a reasonable estimate of the proportion of the total annual costs taken up by operation and maintenance. The 30% figure is adopted in Table 6 for both water supplies and excreta disposal.[o] Reliable data on the costs of software support (such as the promotion of community par-

[n] UNDP project INT/81/026.

[o] The computation of the percentage of total annual costs due to operation and maintenance requires the adoption of a discount rate (or opportunity cost of capital). Choosing the discount rate is partly a matter of judgement, and different economists may advocate different rates for the analysis of the same project. The choice of a high discount rate (say, 20%) will reduce the apparent importance of recurrent costs within total project costs. If a low discount rate (say, 5%) is chosen, perhaps to reflect the scarcity of recurrent funds (*5*), the proportion of total costs that is attributed to operation and maintenance will be greatly increased.

Table 6. Costs for urban and rural water supply and excreta disposal projects

Type of service	Construction cost per capita (1982, US$)[a]	Lifetime (years)[b]	Annual construction cost per capita (1982, US$)[c]	Annual total cost per capita (1982, US$)[d]
Water supply				
Urban				
House connection	116	20	14	20
Public tap	66	20	8	11
Rural[e]	60	20	7	10
Sanitation				
Urban				
Sewerage	174	50	18	26
Other	66	20	8	11
Rural	19	10	3	4

[a] Median values of the costs from 87 developing countries reported to WHO. For further information, see *The International Drinking Water Supply and Sanitation Decade. Review of national baseline data (as at 31 December 1980)*, Geneva, World Health Organization, 1984 (WHO Offset Publication No. 85).

[b] Commonly assumed values.

[c] Assuming an opportunity cost of capital (discount rate) of 10%.

[d] Assuming that construction costs are 70% of the total annual costs (see text).

[e] A variety of technologies are included here, but predominantly public taps and handpumps.

ticipation or hygiene education) and of apportioned institutional overheads have not been located, and so these costs, which are not trivial, have been omitted from the calculations.

Total annual costs per capita are derived in Table 6, assuming that recurrent costs comprise 30% of the total annual costs, that project lifetimes are between 10 and 50 years (depending upon the technology), and that the appropriate discount rate is 10%. The total annual costs per capita in Table 6 may be aggregated to derive the costs of complete water supply and excreta disposal interventions. For instance, a rural water supply and excreta disposal project might cost US$ 14 per capita annually ($10 + $4), whereas a combination of in-house water and sewerage in an urban area might have an annual cost of US$ 46 per capita ($20 + $26).

A goal of this series of reviews (*38*) is to derive cost-effectiveness estimates for each intervention. Special difficulties are inherent in applying the cost-effectiveness analysis to interventions having multiple benefits, and water supply and excreta disposal interventions present these difficulties in an extreme form (*9, 14*). In addition to their impact on diarrhoea rates among young children, these interventions may avert diarrhoea in other age groups, reduce the incidence of other infectious diseases, and have a variety of benefits unrelated to health. In view of this, a treatment of the cost-effectiveness of water supply and excreta disposal in relation to other diarrhoea control measures will be left to a later publication.

CONCLUSIONS

The results in Tables 2-4 show that substantial reductions in diarrhoea morbidity and mortality rates can be expected from investments in water supply and excreta disposal. Table 2 suggests that investments that improve both water quality and availability are especially effective. There are no adequate data on the impact of improvements in water quality plus availability together with excreta disposal. Likewise, the available data do not permit an assessment of the advantages of adding a hygiene education component to a project, but analysis of hygiene education alone suggests that it may further enhance the impact (*34*). Taking all this evidence together, and in view of the impact of large service-level improvements shown in Table 3, it is possible that well-designed projects combining water supply, excreta disposal and hygiene education may achieve diarrhoea morbidity rate reductions of 35-50%. It is to be expected that, in any given project, the impact on diarrhoea mortality rates will be larger than that on diarrhoea morbidity rates, except in areas where other interventions, such as oral rehydration programmes, have substantially reduced the risk of death from diarrhoea.

This review highlights some of the deficiencies in our knowledge of the impacts of water supply and excreta disposal on diarrhoea. More studies of these impacts are required, and it is expected that current advances in methodology[p] will enable such studies to be undertaken retrospectively and at reasonable cost. The model discussed under hypothesis 2 suggests that there may be advantages in measuring the impact on severe diarrhoea rather than all diarrhoea. Where etiology-specific studies are being conducted, they are more likely to record impacts on diarrhoea due to agents having high infectious doses than on diarrhoea due to agents having low infectious doses. The most pressing research need is to document the impact on diarrhoea of projects that combine improvements in water quality, water availability and excreta disposal with hygiene education that are functioning satisfactorily and are being utilized by the intended beneficiaries.[q]

[p] BRISCOE, J. ET AL. Measuring the impacts of water supply and sanitation projects on diarrhoea: prospects for case-control methods (in preparation).

[q] *Minimum evaluation procedure (MEP) for water supply and sanitation projects*. Unpublished document WHO/ETS/83.1, 1983.

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RÉSUMÉ

LA LUTTE CONTRE LES MALADIES DIARRHÉIQUES DU JEUNE ENFANT: INTERVENTIONS VISANT À AMÉLIORER L'APPROVISIONNEMENT EN EAU ET L'ÉLIMINATION DES EXCRETA

Cet article est le neuvième d'une série d'analyses consacrées aux mesures possibles pour lutter contre les diarrhées. Dans les pays en développement, l'impact des projets d'approvisionnement en eau et d'évacuation des excreta sur les maladies diarrhéiques a été au centre de très nombreuses discussions et recherches. Quelques observations donnent à penser que des améliorations portant sur la qualité de l'eau, l'approvisionnement en eau, l'hygiène individuelle et l'évacuation des excreta, réduiraient l'ingestion des agents pathogènes à l'origine de diarrhées. On expose ici un modèle théorique qui établit une relation entre la quantité ingérée d'agents pathogènes responsables de diarrhées et la fréquence de ces affections dans la communauté.

Ce modèle montre que, dans des communautés pauvres, mal approvisionnées en eau et où l'évacuation des excreta se fait de façon insalubre, la diminution de la quantité d'agents entéropathogènes ingérée exerce, à valeur égale, un impact plus grand sur les taux de mortalité que sur ceux de morbité. Elle améloire davantage les diarrhées graves que les diarrhées bénignes et plutôt celles dont les agents étiologiques agissent à dose élevée.

Le recensement de 67 études effectuées dans 28 pays permet d'analyser l'impact de l'approvisionnement en eau et de l'évacuation des excreta sur les maladies diarrhéiques, les infections apparentées, l'état nutritionnel et la mortalité. Toutes ces études montrent une diminution médiane de 22% des taux de morbidité associés aux maladies diarrhéiques, la diminution atteignant 27% dans quelques études mieux conçues; pour le taux de mortalité global, la diminution médiane a été de 21%, atteignant 30% dans les quelques études mieux conçues. L'amélioration de la qualité de l'eau importante moins que celle de l'approvisionnement ou de l'évacuation des excreta. Mieux vaut améliorer la qualité de l'eau et l'approvisionnement qu'un seul de ces éléments ou que l'élimination des excreta. Les projets d'approvisionnement en eau et d'évacuation des excreta ont un impact plus important sur la shigellose que sur les infestations à *Entamoeba histolytica* ou à *Giardia lamblia*, mais on ignore quelles peuvent en être les répercussions sur les diarrhées causées par *Escherichia coli* entérotoxigène ou les rotavirus. Les six études portant sur les répercussions de l'approvisionnement en eau ou de l'évacuation des excreta sur l'état nutritionnel ont fait état d'une amélioration.

L'article présente ensuite une analyse des données sur les coûts de construction pour les projets d'approvisionnement en eau et d'assainissement dans 87 pays en développement. Si l'on ajoute les coûts d'exploitation et d'entretien, sans tenir compte des coûts liés à la mobilisation et à l'éducation de la communauté ni des frais généraux institutionnels, on arrive à un total médian de 14-46 dollars E.-U. (prix de 1982) par tête, selon l'importance du service.

Il faudra effectuer davantage d'études concernant l'impact des projects d'approvisionnement en eau et d'évacuation des excreta sur les maladies diarrhéques. En tout premier lieu, on étudiera l'impact de projets combinant une amélioration de la qualité de l'eau, de l'approvisionnement en eau et de l'évacuation des excreta à une éducation en matière d'hygiène, en s'intéressant à des installations qui donnent satisfaction et sont effectivement utilisées par les personnes visées.

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