Cost-effective prevention of diarrheal diseases: A critical review*

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Abstract This paper critically reviews the existing research on the cost-effective prevention and treatment of diarrheal diseases, and identifies research priorities in this area aimed at finding ways to reduce the diarrheal disease burden. In contrast to the empirical knowledge base that exists for traditional child health programs to reduce diarrheal morbidity and mortality, evidence on the relative effectiveness and cost-effectiveness of various environmental health interventions is limited and subject to significant methodological concerns. There is a limited understanding of the determinants of long-term water and sanitation technology adoption and behavior change at the individual level. Even less is known about how collective action problems in water and sanitation infrastructure maintenance can be overcome. An agenda for future research includes evaluating alternative transmission interruption mechanisms, improving understanding of the determinants of individual-level technology adoption in the water and sanitation sector, and assessing the quality of infrastructure maintenance under different management schemes.

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Summary

Diarrheal diseases kill two million children in poor countries each year. This paper critically reviews the existing research on the cost-effective prevention and treatment of diarrheal diseases, and identifies research priorities in this area, particularly for social scientists, aimed at finding ways to reduce the disease burden.

A series of randomized trials has established the impact and cost-effectiveness of several child health interventions, including breastfeeding, vaccination, oral rehydration therapy, and micronutrient supplementation, in preventing and treating diarrheal diseases. The evidence generated by these trials has played a critical role in encouraging the implementation of these interventions on a large scale, resulting in millions of lives saved.

In contrast to the empirical knowledge base that exists for traditional child health programs to reduce diarrheal morbidity and mortality, the evidence on the relative effectiveness and cost-effectiveness of various environmental health interventions, including water and sanitation hardware and hygiene or health education, is limited and subject to significant methodological concerns. Moreover, we have a very limited understanding of the determinants of long-term water and sanitation technology adoption and behavior change at the individual level. Even less is known about how collective action problems in water and sanitation infrastructure maintenance can be overcome.

We identify a tentative agenda for future research, including:
1) Evaluating alternative diarrhea transmission interruption mechanisms—including water and sanitation services as well as hygiene behavior changes—on a comparable basis;
2) Understanding the determinants of individual-level technology adoption in the water and sanitation sector;
3) Assessing the quality of infrastructure maintenance under different management schemes, thus expanding efforts to improve collective action outcomes in this sector.

Methodologically, several design issues will be critical. First, randomized evaluations are needed in order to distinguish the impact of environmental health interventions from potential confounding factors. Second, samples should be of sufficient size to overcome geographic clustering of health outcomes. Third, trials should be designed to allow estimation of the impact of individual interventions as well as packages of interventions.

Research along these lines would provide policymakers with evidence of "what works" in environmental health that is of similar quality to the existing evidence on child health interventions – evidence which in turn can be translated into policy reforms and, ultimately, into saving lives.

1 Introduction

Diarrheal diseases kill around two million children in poor countries each year (WHO 2002b, Kosek *et al.* 2003). There is widespread agreement that massive reductions in diarrheal mortality will be needed to achieve the Millennium Development Goal (General Assembly of the United Nations 2000) of reducing the under-five child mortality rate by two-thirds (World Bank 2003).

Notwithstanding their ongoing burden, a great deal is known about how to prevent and treat diarrheal diseases. As discussed below, a series of randomized trials have established that several child health interventions—including extending breastfeeding, immunization, oral rehydration therapy (ORT), and micronutrient supplementation—are both effective and cost-effective in treating and preventing diarrhea. The evidence from these trials has played a critical role in encouraging the implementation of these interventions on a large scale, saving millions of lives.

Evidence on the effectiveness and cost-effectiveness of environmental health interventions that could prevent diarrheal diseases is much weaker than in the case of child health interventions like vaccines and ORT. While the underlying biological relationships between water and diarrheal disease are well understood, systematic, controlled comparisons of different approaches are lacking. Based on the existing evidence, it is unclear whether the diarrheal disease control priority in poor countries should be to expand the provision of standard child health interventions such as vaccines, ORT, and micronutrient supplementation, or to complement these interventions with water, sanitation, and health behavior change interventions.

Priorities are also unclear within the water sector itself. New research suggests that rapid declines in the U.S. child mortality rate in the early twentieth century were largely a result of improvements in water quality (Cutler and Miller 2005). Similar large-scale investments in piped water infrastructure are infeasible in very poor countries today, leading some argue for prioritizing new point-of-use systems such as chemical disinfectants (which have been shown to be effective in reducing diarrhea incidence); others for digging deep boreholes; and still others for building many cheap shallow wells that allow a more rapid increase in the supply of water (thus allowing people to more frequently wash dishes, clothes, and themselves) but are more easily subject to contamination. Interventions such as improved hand-washing practices or point-of-use water treatment require voluntary behavior change, but there is little evidence on whether such behavior changes persist in the longer run. Rural water facilities can be long-lived if properly serviced, but they often fall into disrepair quickly due to poor maintenance, and while many different approaches to the organization of maintenance have been advocated, there is little hard evidence on their relative effectiveness. Each class of interventions differs in its ability to impact morbidity and/or mortality outcomes, and likely has very different risk and cost profiles as a result of differences in delivery mechanisms, target groups, and cost-recovery opportunities.

This paper critically reviews the existing research on the cost-effective prevention and treatment of diarrheal diseases in rural areas of developing countries.[1] [2] As we

[1] In this paper we restrict our attention to rural areas because water and sanitation coverage rates, a key determinant of diarrheal disease prevalence, are much lower outside of urban areas both globally and in the poorest regions (WHO 2000). World-wide, 94 percent of urban residents have access to improved water sources, and 86 percent have access to improved sanitation. In rural areas, only 71 percent of the population is covered by improved water and 38 percent is covered by improved sanitation. In Africa, urban water and sanitation coverage rates are about double the fraction of the rural population that has access to improved service. Because coverage rates are so different across settings, relevant policy issues also differ across contexts.

discuss, the available research on the relative effectiveness and cost-effectiveness of various hardware and software investments is subject to significant methodological concerns. In light of this limited evidence, we identify outstanding research needs and discuss existing efforts to improve our understanding of the best means of using scarce resources to tackle diarrheal diseases in poor countries. We argue there is a continuing need for randomized impact evaluations that allow for assessment of the effectiveness and cost-effectiveness of environmental health interventions. Such efforts would provide needed evidence to policymakers on "what works" for water sector interventions in developing countries—evidence that in turn can be translated into policy reforms and, ultimately, into saving lives.

This paper is organized as follows. The remainder of Section 1 provides a brief background on water-related diseases and their transmission (1.1), briefly discusses the role of child health interventions (1.2), and reviews some of the methodological problems with the existing literature on environmental health interventions (1.3). Section 2 reviews the available evidence on the effectiveness of source water quality improvements and sanitation investments, and discusses the need for further work examining alternative means of maintaining these "hardware" investments. Section 3 reviews the available evidence on point-of-use water treatment systems as well as two hygiene behavior modification interventions (health education and hand-washing promotion efforts) and discusses the need for further work examining the long-term effectiveness and cost-

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In urban settings, improved service quality and efficiency gains for monopoly service providers are typically more important than in rural areas where the challenge of providing access to dispersed communities remains the key concern (Galiani *et al.* 2002, World Bank 2004a).

[2] There is related work in preparation by the Disease Control Priorities Project at the US National Institutes of Health (*Disease Control Priorities in Developing Countries, 2nd edition*) that will discuss diarrheal diseases (chapter in preparation by Gerald Keusch and Olivier Fontaine) as well as water supply, sanitation, and hygiene promotion (chapter in preparation by Sandy Cairncross and Vivian Valdmanis). Martines *et al.* (1993) also review existing evidence on the relative cost-effectiveness of various interventions to combat diarrhea.

effectiveness of these individual-level behavior change interventions. Section 4 concludes with a discussion of an agenda for future research.

1.1 *Brief background on water-related diseases*

Water destined for human contact that is exposed to the environment is a potential source of diarrheal disease. In particular, surface water in less developed countries is often contaminated with pathogens (including bacteria, viruses, and parasites) due to contact with human and livestock waste. Drinking, handling, cooking, and bathing in such microbiologically unsafe water exposes people, and especially young children, to a wide range of health risks including diarrheal diseases. Moreover, the lack of adequate water of any kind reduces the opportunity to wash dishes, clothes, and people and thus contributes to the spread of disease.

One standard method of classifying the disease burden associated with water summarizes the potential health costs of relying on unsafe water according to pathogen transmission path. In this taxonomy, presented in Table 1, diarrheal diseases—the focus of this paper—are spread through fecal-oral transmission and fall into both the waterborne and water-washed categories (White *et al.* 1972, Feachem 1977, Cairncross 1996, International Institute for Environment and Development 2000).

The health cost of diseases transmitted via the fecal-oral route is tremendous, and falls disproportionately on young children. Diarrheal illnesses accounted for at least eight percent of total lost disability-adjusted life years (DALYs) in developing countries in 1990 (Smith *et al.* 1999) and account for perhaps 20 percent of deaths among children under age five (Kosek *et al.* 2003). Not only can acute diarrhea result in severe dehydration, but persistent diarrhea may predispose children to, and exacerbate, malnutrition (Briend 1990, Schorling *et al*. 1990, Lancet 1991, Guerrant *et al*. 1992). Prospective (though non-randomized) community-based fieldwork in Sub-Saharan Africa summarized by the Child Health Research Project (1998) concludes that diarrhea leads to impaired weight gain, particularly for infants less than one year of age and those not exclusively breast-feeding. Malnutrition is in turn associated with increased risk of death from childhood illnesses (Pelltier *et al.* 1995).[3]

While the biological relationship between diarrheal morbidity water-washed or water-borne pathogens is well understood, the relationship between diarrheal morbidity and various interventions that interrupt pathogen transmission is less clear. This is in part because, as discussed above, individual behavior, collective action, and complementary technologies can mediate infection.

1.2 ***The role of child health interventions***

Randomized trials have established that several child health interventions—including breastfeeding, immunization, oral rehydration therapy (ORT), and micronutrient supplementation—are both effective and cost-effective in treating and preventing diarrhea (for a review see Hill *et al*. 2004). Exclusive breastfeeding of infants is widely accepted as a means of preventing diarrhea in infants up to six months of age and continued breastfeeding for older children also has protective effects (Raisler *et al.* 1999, Perera *et al.* 1999, WHO Collaborative Study Team 2000). For at least two diarrheal diseases (rotavirus and cholera), many in the public health community believe

[3] Perhaps because of the endogenous relationship between diarrhea and malnutrition, some observational studies also suggest that early childhood diarrhea is correlated with reduced fitness and cognitive performance for children age six to nine (Guerrant *et al.* 1999, Berkman *et al.* 2002, Niehaus *et al.* 2002), but have not been able isolate a causal effect of diarrheal morbidity. Impact evaluations of programs providing food supplements to primary school children (Chavez and Martinez 1986, Martorell 1993, Pollitt *et al.* 1993) generally show a positive relationship between improved nutrition and schooling and cognitive outcomes.

vaccines have a valuable role to play in preventing these diseases (Glass *et al.* 2004, WHO 2004). ORT appears to have largely been responsible for significant reductions in diarrheal mortality since 1980 (Miller and Hirschorn 1995, Victora *et al.* 1996 and 2000). Micronutrient supplementation, including both therapeutic and preventative supplementation of zinc as well as therapeutic supplementation of vitamin A, has also been found to have positive impacts on diarrheal disease morbidity and mortality (Grotto 2003, Zinc Investigators' Collaborative Group 1999 and 2000, Black 1998, Ramakrishnan and Martorell 1998, Beaton *et al.* 1993). The evidence generated by rigorous evaluations of such health interventions has played a critical role in encouraging the implementation of these interventions on a large scale, saving millions of lives.

Nonetheless, persistently high diarrheal mortality rates show that there is scope for additional preventative investments. These investments may include expanded access to traditional child health programs, but may also potentially include a further class of environmental health interventions. This is because the marginal cost of expanding the child health interventions to uncovered populations may be high, even though the average cost of the interventions are often relatively low. For example, continuous zinc supplementation can be costly if households must be induced to adopt micronutrient "sprinkles" sachets where fortification is infeasible (Zlotkin 2005, USAID 2004a). There is no vaccine against pathogenic *Escherichia coli*, the most common cause of diarrhea in less-developed countries, and vaccines against rotavirus and cholera will take time to roll out. Expanding use of strictly curative ORT, in itself potentially difficult, will reduce diarrheal mortality, but not disease incidence.

Recommendations about the extent to which further efforts to prevent diarrhea should emphasize environmental health investments including diarrheal disease transmission interruption mechanisms like water and sanitation infrastructure and hygiene behavior change are difficult to make, however. The existing literature cannot be used to confidently estimate the relative cost-effectiveness of environmental health interventions.

Existing estimates of the relative cost-effectiveness of environmental health interventions and child health programs to combat diarrheal diseases (summarized in Table 2) are largely based on studies that are subject to significant methodological concerns that we review in section 1.3. [4] In addition, important considerations that make environmental health interventions different from child health interventions are typically not taken into consideration in cost-effectiveness analysis (Briscoe 1984, Okun 1988, Varley *et al.* 1998, Meddings *et al.* 2004). As Briscoe (1984) and Okun (1988) emphasize, gains associated with infrastructure provision can extend far beyond mortality and morbidity impacts; women's time may be freed from water transportation duties and thus income-generating activities may be facilitated. In urban and peri-urban areas, improved water supply may also free households from purchasing drinking water from vendors.

[4] For interventions that impact older children and adults, these figures understate the effectiveness of the intervention. Similarly, for interventions that affect diseases other than diarrhea (like measles), these numbers again understate effectiveness because we report impacts on diarrhea only.

1.3 *Methodological concerns with the existing literature on environmental health interventions*

In this section, we review several methodological concerns associated with the existing literature on water, sanitation, and hygiene education/behavior change. The shortcomings of much of the research include a lack of a plausible comparison group (1.3.1), clustered sampling and reduced power of statistical tests (1.3.2), the inability to estimate separate impacts of individual interventions (1.3.3), and inadequate means of accounting for externalities (1.3.4). We will refer back to these methodological issues throughout this paper when reviewing the research on various classes of interventions.

1.3.1 Lack of a plausible comparison group

A central shortcoming of the existing literature is its reliance on retrospective, non-randomized approaches (for example, comparing outcomes in villages with wells to outcomes in other nearby villages without wells). Such comparisons are problematic because villages with and without wells may differ along other dimensions that also affect the incidence of diarrheal disease. For instance, a village may have a well because it is better organized or wealthier. These attributes may themselves make residents healthier, whether or not they have a village well, so disentangling the "well effect" from the "wealth effect" is in practice difficult, if not impossible. Controlling for all the important differences between villages in multivariate regression analysis may be difficult, if not impossible. Retrospective strategies are especially suspect in this context due to the considerable variation in diarrhea from year to year, as well as the possibility of underlying trends that may differ across even small geographic regions.

1.3.2 Clustered sampling and reduced power of statistical tests

When a comparison group is included, studies often compare outcomes between households in a small number of treatment villages or communities and those in a small number of comparison villages or communities. Because households within a community are likely to be similar to each other, this clustered sampling reduces the power of statistical tests to determine the existence and size of the treatment effect. The intra-cluster correlation of outcome measures is critical to assessing the statistical power of treatment effects estimated in clustered samples, yet most studies fail to report this statistic, making it difficult to draw inferences.

To capture the variance in outcome variables across space and time, many localities must be included in both the treatment and comparison groups. While the exact number of clusters required for a study depends on context-specific estimates of the intra-cluster correlation of outcome variables, Esrey (1996) suggests that at least twenty clusters should be included in both treatment and comparison samples for moderate reductions in diarrhea incidence to be detectable with a reasonable degree of power. In practice, widely cited studies often are based on two or three treatment clusters and a similar number of comparison clusters. For example, two of the most widely cited studies on the impact of source water quality improvements (Aziz *et al.* 1990, Huttly *et al.* 1987) each include only five villages in total.

1.3.3 Inability to estimate separate impacts of individual interventions

The relative effectiveness of several interventions (*e.g*. latrine construction, borehole well construction, and hygiene education) cannot be separately estimated when these services are provided together, as has often been the case. In a similar manner, when evaluating the impact of well construction it is difficult to estimate separate the simultaneous effects of improved water quality at the source and increased water quantity.

From a policy perspective, it is important to be able to distinguish the relative effectiveness of interventions since providing a full package may be prohibitively expensive or difficult (as suggested by the difficulty that Huttley *et al.* [1987] experienced in attempting to roll out a hygiene education effort simultaneously with well construction).[5]

1.3.4 Inadequate means of accounting for externalities

The estimation of the treatment effect may be complicated by the presence of externalities, but studies often fail to account for this possibility. It may be that households near comparison springs, latrines, or wells experience health benefits as a result of the intervention because improved service has reduced diarrhea prevalence in a geographic region. If this is the case, a simple "intention to treat" estimation strategy will underestimate the impact of the intervention. There may also be health externalities among households near the same treatment facility. If this is the case then a "treatment on the treated" estimation strategy is inappropriate (Angrist *et al.* 1996). For example, proximity to a treatment well may affect health through the improved disease environment rather than solely by increasing the probability that the individual will consume better quality water from a protected well. Similar concerns arise regarding community-level hygiene education. Miguel and Kremer (2004) show that cross-cluster

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[5] A related concern is that well and latrine location may be difficult to randomize because of social or political concerns. Research strategies in which data is collected at hospitals can run into the similar problems, in that it may be difficult to select data collection centers randomly. See Daniels *et al.* (1990) and Meddings *et al.* (2004) for examples of this approach in case-control settings.

externalities like those that may arise in such cases can be accounted for in estimation by controlling for whether and to what extent individuals assigned to comparison communities live near treatment wells (*i.e.* near areas where the disease environment may improve).

Further research that measures the externalities associated with water and sanitation service provision is needed. Valuing externalities will allow for more accurate comparison of the relative cost-effectiveness of infrastructure investments as compared to interventions that provide strictly private benefits or have more limited impacts on the disease environment. Externalities are particularly important in this context because the average cost of curative approaches to diarrheal disease treatment may be very low and it is often difficult to justify large-scale investments in preventative measures on the basis of existing, admittedly incomplete, cost-effectiveness estimates (Hutton 2001).

2 Source water quality improvements and sanitation provision

In this section, we review the existing epidemiological evidence on the effectiveness of source water quality improvements (2.1) and sanitation provision (2.2) in the prevention of diarrheal diseases. In Section 2.3, we discuss the need for work examining infrastructure maintenance schemes for these types of "hardware" interventions.

These transmission interruption mechanisms reduce the probability that surface water will become contaminated with fecal matter. Source water quality improvements (*e.g.* well construction or spring protection) allow households access to water sources that are less likely to have been contaminated by fecal matter as a result of environmental exposure.[6] Some source water quality improvements may also increase the supply of water, thus allowing people to more frequently wash dishes, clothes, and themselves. Latrine provision and use removes fecal matter from the environment, reducing the chances of surface water contamination due to run-off.

2.1 *Source water quality improvements*

Lack of access to improved water and sanitation services is strongly correlated with poverty. People living in poor rural regions are the most likely to rely on poor-quality water—defined as microbiologically unsafe water contaminated with disease-causing organisms (WHO 2002a). Among individuals living in rural areas of developing countries, about 30 percent (or approximately 926 million people) lack a safe and accessible water supply as defined by the World Health Organization (WHO 2000). The un-served population is most likely to live in Sub-Saharan Africa and South Asia, where 256 million people and 595 million people, respectively, lack access to safe drinking water.[7] [8]

A large body of epidemiological literature investigates the impact of improved water supply and sanitation service provision (often as part of a package of interventions that includes hygiene education) on health outcomes (reviews include Blum and Feachem

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[6] Spring protection clears and seals off the eye, or source, of a spring so that water flows through a pipe rather than seeping from the ground. This is a widely-used technology in Sub-Saharan Africa (Mwami 1995, Lenehan and Martin 1997, UNEP 1998), though it is unsuitable for semi-arid regions (UNEP 1998). While service remains dependent on groundwater levels and groundwater quality, spring protection is intended to protect surface water from contamination.

[7] These numbers likely understate the proportion of the population actually consuming water of poor quality (WHO 2002a) since the WHO definition of an accessible water supply includes water sources some distance from the home. Reasonable access is defined by the WHO as a source sufficient to supply 20 liters per person per day and no further than one kilometer from the dwelling. However, water at this distance must be transported to the home and stored before drinking, increasing the risk of contamination prior to consumption.

[8] Taking expected population growth into account, achieving the Millennium Development Goal of halving the proportion of the population without access to safe water and sanitation by 2015 (General Assembly of the United Nations 2000) in rural Africa would require providing 400 million people with improved water supplies and 200 million people with improved sanitation over the next decade (WHO 2002a).

1983, Esrey *et al.* 1985, Esrey and Habicht 1986, Esrey *et al.* 1991, Rosen and Vincent 1999, and Fewtrell *et al.* 2005). Critically, much of this research is hampered by important methodological problems, including the issues we discussed in Section 1.3.

Many studies of water infrastructure provision in developing countries lack a plausible comparison group and thus, without a credible counterfactual, cannot isolate a causal treatment effect from service provision. We are aware of two studies that rely on quasi-experimental designs (Huttly *et al.* 1987 [in Bangladesh] Aziz *et al.* 1990, Blum *et al*. 1990 [in Nigeria]), but from the published papers neither study appears to have used random assignment to treatment status. The studies are both hampered by small village-level sample sizes (both studies include only five villages in total).

To our knowledge, only one paper adequately accounts for externalities when assessing the impacts of water and sanitation investments. Watson (forthcoming) exploits the fact that a series of water and sanitation interventions introduced on Native American reservations in the United States from 1960-1998 were largely uncorrelated with other factors affecting infant health, and largely exogenous to local community characteristics after accounting for county and year fixed effects. This research suggests a 10 percent increase in the fraction of homes with improved water and sanitation service reduced Native American infant mortality by four percent. The improved disease environment reduced infant mortality rates among local residents not living on the reservation as well—a fact Watson uses as a means to measure the significant externalities associated with the program.

2.2 *Sanitation service provision*

The appropriate disposal of feces is another method to reduce the incidence of fecal-oral disease. As in the case of drinking water, sanitation service provision is of most concern in Sub-Saharan Africa and Asia. In each of these regions, nearly one-half of the rural population does not have access to sanitation services (WHO 2000).

Relatively few evaluations of latrine provision alone have been published. As discussed in Section 1.3, sanitation service provision is usually evaluated as part of a package of interventions including water service provision and/or hygiene education.

We have identified one randomized control trial of latrine provision, which measures the relative effectiveness of latrines and insecticide spraying for trachoma control (Emerson *et al*. 2004). In this study, with a large sample and over 20 clusters of households, latrine provision did not significantly reduce trachoma incidence. Latrine provision may have affected other water-related diseases, but according to the published paper these outcomes appear not to have been measured. Several case-control studies, which compare health outcomes among children presenting at hospital or clinics with diarrhea to children with similar observable characteristics but presenting with other illnesses (such as upper respiratory infections), have found that access to latrines reduces acute diarrhea incidence (Daniels *et al.* 1990, Meddings *et al.* 2004). This research strategy is vulnerable to the same methodological critique as cross-sectional regression analyses; namely, cases that are similar across observable characteristics may differ systematically along dimensions that are difficult to measure (see Section 1.3).

Two influential papers (Esrey 1996, Esrey *et al.* 1991) are frequently cited in the literature as evidence for the relative importance of sanitation investments and hygiene education over the provision of improved water quality (*e.g*. USAID 1996, Vaz and Jha 2001, World Bank 2002). In a review including the Bangladesh and Nigeria interventions discussed previously, as well as twenty-three other studies deemed by the authors to be relatively rigorous, Esrey *et al.* (1991) attempt to separate the relative impact of water supply, sanitation, and hygiene education interventions on diarrheal morbidity. They conclude that the median reduction in diarrheal morbidity from either sanitation supply or hygiene education provision is nearly twice the median reduction from an investment in water quality alone or an investment in water quantity and water quality together. Using multivariate regression analysis of household infrastructure status and diarrhea prevalence from several countries, Esrey (1996) reaches a similar conclusion; benefits of improved water quality occur only in the presence of improved sanitation, and only when a water source within the home is present.

We believe further research before the conclusions of Esrey and his colleagues about the relative importance of water and sanitation investments can be accepted. As a result of the observational nature of Esrey's (1996) data, these results are subject to omitted variable bias of unknown magnitude (see Section 1.3).[9] Esrey *et al*.'s (1991) meta-analysis that reports that sanitation investments and hygiene education are more effective interventions than water quality improvements also does not convincingly resolve this research question. While the analysis focuses on what the authors deem to be rigorous studies, it appears that none of the studies has a truly randomized control trial design. Drawing conclusions about whether water quality or quantity is more important when

[9] We also agree with Rosen and Vincent (1999) who suggest several other shortcomings of this research. The data used by Esrey includes few African households. In addition, the cross-country data cannot distinguish between working and broken taps. Finally, Esrey's conclusions may not be warranted because many of the correlations he uses to draw inferences are statistically insignificant.

wells are provided (as is the case in the most rigorous studies reviewed) is difficult because well provision simultaneously improves water quality and reduces the distance to a water source.[10] In addition, while households closer to pumps may use more water and have better health outcomes, the location of pumps is not random. Well location may be determined by where more powerful households live, for example, and this could affect health outcomes through other channels, thus confounding interpretation of results. Nor does the quasi-experimental work in Bangladesh and Nigeria convincingly show that sanitation service is more effective than the provision of new water supplies. In Bangladesh, diarrhea fell in the treatment group after the provision of boreholes but prior to the provision of latrines, without significant additional reduction after the provision of both interventions (Aziz *et al.* 1990). In Nigeria, delays in the latrine construction component of the project lead the authors to conclude the weight-for-height improvements they observed largely reflect the effects of well construction (Huttly *et al.* 1987). Finally, Fewtrell *et al*. (2005) present a more recent meta-analysis that finds that water quality improvements provided via point-of use technologies may be at least as effective as sanitation and hygiene improvements. This evidence is based on rigorous randomized control trials, as we discuss further below. However, this recent review confirms the continuing dearth of credible evidence on the effectiveness and cost-effectiveness of hardware investments.[11]

[10] This is equally true for other studies that examine the impact of borehole or tap construction (Mason *et al.* 1986, Linkskog *et al.* 1987, El Kholy *et al.* 1989).

[11] While it is difficult to draw conclusions about the benefits of hardware investments to improve water quality improvements from existing micro-epidemiological studies, other evidence suggests that the benefits are very large. Cutler and Miller (2005) use exogenous variation in the timing and location of water filtration and chlorination technology adoption across U.S. cities in the 19th Century to identify the contribution of improved water quality to the epidemiological transition in American cities. They find that clean water was responsible for about one-half of the observed mortality decline in cities, and nearly two-thirds of the child mortality reduction.

2.3 *The maintenance of water and sanitation infrastructure investments*

Water and sanitation infrastructure require management and upkeep in order to realize the benefits of these investments over a long time horizon. In this section, we review the available evidence on various infrastructure management schemes, cost-sharing efforts, and on the involvement of women in the management of public good provision.

Infrastructure maintenance has historically been a major problem in developing countries and in the rural water sector in particular. For instance, a quarter of India's water infrastructure is believed to be in need of repair (Ray 2004). The *World Development Report* (World Bank 2004b) estimates that more than one-third of existing rural water infrastructure in South Asia is not functional. Miguel and Gugerty (forthcoming) report that in western Kenya, nearly 50 percent of borehole wells dug in the 1980s, and subsequently maintained using a community-based maintenance model, had fallen into disrepair by 2000. Difficulties with maintaining water infrastructure, particularly in rural areas, reduce the cost-effectiveness of these interventions relative to other measures that prevent diarrhea. The challenge of identifying institutional structures that will make such investments financially sustainable is an important area of ongoing research.

2.3.1 Community-level infrastructure management schemes

A standard model for maintaining donor-funded infrastructure projects in developing countries is to establish user groups responsible for project maintenance and management. This institutional design is expected to result in improved financial sustainability. Giving communities direct control or ownership over key project decisions is intended to improve the quality of public services, while reducing the need for on-going donor funding or involvement.[12]

Despite donor interest in community-based development schemes, there is little convincing empirical evidence that local user-committee management of local public goods such as improved drinking water sources results in either greater financial sustainability or better quality service, relative to on-going centralized public funding. In a recent comprehensive review of the literature on community-based development projects, Mansuri and Rao (2004) note that existing research examining "successful" community-based projects does not compare these projects to centralized mechanisms for service delivery or infrastructure maintenance. This makes it difficult to determine whether alternative project designs would have had different results.[13] The limited available empirical evidence suggests the impact of the community-based development approach on infrastructure maintenance is mixed at best.[14]

A potential alternative to community-managed local public goods that deserves more research is the cost-effectiveness of technologies that allow households or small groups (either newly-organized or pre-existing groups) of households to self-supply water services. For example, pumps that provide both drinking and irrigation water to a few

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[12] Other goals may also be important, as community-based development may be expected to empower poor people or strengthen local governance.

[13] There may well be a strong interaction between the technical difficulty of maintaining a particular infrastructure and the functioning of community based maintenance groups. For example, the task of maintaining a spring is very different from maintaining a hand pump. Keeping springs clean may require many small actions by a number of people in a community, while maintaining a hand pump often requires financing for spare parts, technical knowledge to make repairs, and special equipment to lift the pump out of the ground before it can be repaired.

[14] Isham and Kahkonen (1999) find that in their study of water projects in 44 Indonesian villages "the existence of [local] water committees had either no effect or a negative effect on service performance," though greater community participation in the design of community-based water projects did improve water supply and health outcomes somewhat. On the other hand, Khwaja (2003) finds that community-managed projects in Pakistan, including irrigation and drinking water investments, performed better than projects implemented by the government without community participation. However, he also finds that project-specific factors, such as the quality of the outside facilitator, may have a larger impact on project success than community characteristics.

households may provide sufficient private income benefits such that free-riding problems can be overcome. Randomized impact evaluations that compare the cost-effectiveness of self-supply schemes to infrastructure services that serve a larger community are needed.

2.3.2 Cost-sharing

Similar to efforts to promote community-based management of infrastructure in rural areas of developing countries, cost-sharing with user fees has been widely advocated as necessary for the sustainability of public health services in many less developed countries. However, it remains unclear precisely how user fees have affected the utilization of health services in many countries (McPake 1993; Gertler and van der Gaag 1990). Several studies provide suggestive evidence that continued support (financial and otherwise) may be necessary for effective infrastructure investments and public service delivery (Katz and Sara 1998, Kleemeier 2000, Dayton-Johnson 2000, Newman *et al*. 2002, Kremer and Miguel 2004). Certainly, further research on this question is needed that transparently compares the counterfactual of subsidized public service provision to community-based management schemes.

2.3.3 Involving women in the management of environmental public goods

Some of the sociology literature has predicted that increasing the involvement of women on user committees will improve the management of collectively-owned natural resources because women's social networks provide prior experience with collective action (Agarawal 2000). In addition, since women are major users of these goods, their involvement with the creation and thus their compliance with rules may be especially important (Zwarteveen and Meinzen-Dick 2001).

However, the evidence to date on the impact of women's involvement in public good management is limited. Efforts using laboratory experiments to assess whether women supply differing levels of public goods or are more cooperative than men (Nowell and Tinkler 1994, Eckel and Grossman 1998, Solow and Kirkwood 2002) seem to be sensitive to the form of the experiment performed. Much of the empirical field evidence on this question is hampered by concerns about reverse causality (*e.g.* Dollar *et al.* 2001). It is difficult to determine whether the inclusion of women causes a particular outcome to occur, whether the fact that an outcome occurs encourages the participation and inclusion of women, or whether some other factors are driving these results. This problem affects both retrospective analyses (*e.g.* Prokopy 2004) and case studies (INSTAW-UN 1990, Wijk-Sijbesma 1998, Gross *et al.* 2001), neither of which is able to establish a causal relationship between women's participation and observed outcomes.

Chattopadhyay and Duflo (2004) are able to identify a causal relationship between women's participation and project outcomes in their study of a randomized policy change in India that increased the role of women in policy decision-making. They show that village councils headed by women were more likely to invest in public infrastructure for drinking water, and, more generally, that councils dominated by a particular gender were more likely to invest in goods important to that gender. These results suggest that, if women tend to value water resources more than men, placing them in charge of environmental public health infrastructure may be a cost-effective policy for donors and governments.[15] Additional evidence on these questions in other settings is needed.

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[15] Of course, the composition of user committees may vary in ways that are not as easily observable as gender composition, but that are important for determining the success of coordination and collective action for public goods management. Theories of social capital (Putnam 1993, Coleman 1990) argue that the trust, norms,

3 Individual-level behavior change

Concerns about the effectiveness of source water quality improvements have led to research exploring several types of individual-level investments that could reduce the diarrheal disease burden. Point-of-use water treatment systems (3.1) are intended to reduce pathogen loads resulting from environmental exposure prior to consumption, rather than at the source. Drawing on research contending that if communities are to benefit from improved water and sanitation technology they must understand the causes of diarrheal diseases and the behaviors facilitating their transmission, health education/promotion (3.2) and hand-washing promotion (3.3) "software" efforts have also been studied. We review the available evidence on these hygiene behavior modifications, and discuss (3.4) the need for further work investigating how these interventions may be implemented.

3.1 *Point-of-use water treatment*

A key reason to be concerned about the cost effectiveness of water supply improvements at the source is the possibility of water contamination during storage and transportation (Esrey *et al.* 1991, Wright *et al*. 2004). Point-of use water treatment can address these issues. These systems include storage containers with narrow mouths, secure lids, and dispensing spigots, which eliminate contact between hands and stored water and help to prevent contamination, as well as chemical disinfectants, which may be simple household bleach or other products such as flocculent disinfectants. These chemical products kill pathogenic bacteria when added to microbacteriologically-

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and networks created by participation in social organizations can facilitate collective action in local communities.

contaminated water; however, although these products may make the water cleaner they may also negatively affect the taste of the water.

Evidence from randomized evaluations assessing the health impacts of interventions to improve water quality at the point of use suggests this may be a promising way to reduce diarrheal morbidity (Semenza *et al.* 1998, Quick *et al.* 1999, Quick *et al.* 2002, Sobsey *et al.* 2003, Reller *et al.* 2003, Clasen *et al*. 2004). Randomized impact evaluations of point-of-use water treatment systems suggest that, with a rate of technology uptake on the order of 70 percent (over the very short run and with frequent contact with field workers), large statistically significant reductions in diarrheal incidence on the order of 20 to 30 percent are observed at the household level even after taking intra-household correlation into account (Quick *et al.* 1999, Reller *et al.* 2003).[16] [17]

The next step will be to examine the cost-effectiveness and sustainability of these interventions. Little is known about whether people will be willing to permanently adopt systems that affect the taste of water, slow the rate at which water can be consumed (for example, due to filtration), or require that traditional storage containers be abandoned.

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[16] Despite these large reported gains however, many of these same studies also find the observed reductions in diarrheal morbidity associated with the intervention are concentrated among children under age one, and among children over age five. Surprisingly, the age group with the highest diarrheal morbidity that is, children between ages one and five, may be least affected by this intervention (Quick *et al.* 1999, Reller *et al.* 2003, Sobsey *et al.* 2003). However, in two cases larger gains from point-of-use water treatment are identified in children under age five. In Uzbekistan, diarrhea incidence in children under five fell by 85 percent after the provision of a chlorine-stock solution and a narrow-necked storage container. Clasen *et al.* (2004) provided hygiene education to households that received the treatment systems, but argue this limited education effort was superfluous as households in this area of Uzbekistan already had uniformly high levels of hygiene practices. In rural Bolivia Clasen *et al.* (2004) identified reductions in diarrhea incidence of about 83 percent in children under age five with a sample size of 30 children in 50 households. In this case, the treatment system provided to households was a ceramic water filter that left the taste of water unchanged, rather than a disinfectant and a container as in the Uzbekistan study. Uptake appears to have been on the order of 70 percent, suggesting that improved compliance with treatment relative to the studies that supplied disinfectant cannot explain the observed result. It is unclear why the large gains identified in these two studies for the most vulnerable group have not been found in other contexts.

[17] A few randomized trial studies report evidence on solar disinfection of water in homes that support these research findings by identifying large benefits for young children. In a Kenyan Maasai community researchers identified large health benefits for children under age six from the exposure of drinking water to sunlight (Conroy *et al.* 1999, 2001).

Willingness to pay for these systems has not been investigated on any meaningful scale using a randomized approach. Household willingness to use these treatment systems on a consistent basis, and ultimately to pay for them, remains to be verified (Makutsa *et al*. 2001). As we discuss in Section 5, research investigating these issues is a critical open area for future work. Research is also needed to compare the impacts of this intervention to investments that improve source water quality alone.

3.2 *Health education and health promotion*

The literature evaluating health education programs[18] in developing countries suffers from important methodological weaknesses similar to those that discussed previously in the context of water and sanitation interventions.[19] Loevinsohn (1990) and Cave and Curtis (1999) survey this research and conclude that methodological improvements are needed (see also Fewtrell et al. [2005]). Cave and Curtis (1999) are able to identify only five studies since 1987 in which sample sizes exceeded 60 individuals or two clusters and in which randomized or quasi-randomized designs were used (Haggerty *et al.* 1994, Lloyd *et al.* 1994, Pant *et al.* 1996, Tayeh *et al.* 1996, and Elder *et al.* 1998).

Among studies that do use a randomized design, several have found positive effects of health education. For example, Haggerty *et al.* (1994) find an 11 percent reduction in the risk of reporting diarrhea as a result of an education program randomly administered to a sample of 2,000 children from 18 communities in rural Zaire (now Democratic

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[18] Health education programs may target one particular hygiene behavior, or a set of inter-related behaviors. One well-known education program is the Participatory Hygiene and Sanitation Transformation Series (PHAST) education methodology. This widely-used program, developed by WHO, United Nations Development Program, and the World Bank Water and Sanitation Program, emphasizes increasing awareness of the causes of diarrhea, the reasons that diarrhea is dangerous, and strategies for treatment and prevention (Wood *et al*. 1998).

[19] As an additional complication, measuring behavior change can be both costly and difficult. For example, in Congo, Manun'Ebo et al. (1997) investigate the relationship between reported feces-handling behavior and observed feces-handling behavior and find that agreement was little better than might be expected by chance.

Republic of the Congo). In urban Bangladesh, Stanton and Clemens (1987) identify a 25 percent reduction in diarrhea incidence six months after a hygiene education program was randomly administered to 1,900 families in 51 communities.

However, the relative cost-effectiveness of education relative to other interventions remains uncertain and may differ systematically across groups. Pant *et al.* (1996) divide a random sample of 40,000 children from 75 locations in Nepal into two randomly-assigned groups and provide one group with Vitamin A supplements and the other with nutrition education. They find that the risk of child mortality declined by equal amounts in the two groups but that the education program was more costly to deliver. In addition, they also find that education was the least cost-effective when maternal literacy was low. This study points to the need for further work that directly compares alternative interventions to each other.

3.3 *Handwashing*

Hands are a common vector for the transmission of fecal-oral diseases (Curtis *et al.* 2000). Hand-washing with soap after defecation, after cleaning children, and before and after cooking can block this diarrheal disease transmission path.

A recent survey of the literature (Curtis and Cairncross 2003) evaluating the effect of hand-washing with soap on diarrhea risk in developing countries (and in daycare settings in developed countries) identified only two randomized control trials with more than two communities in their samples (Khan 1982, Han and Hlaing 1989).[20] Each of

[20] Low hand-washing rates in U.S. elementary schools have prompted interest in the use of instant hand sanitizers (which do not require water) in classrooms as an alternative means of breaking disease transmission. A review of the evidence on the efficacy of sanitizers (Meadows and LeSaux 2004) identified only one (clustered) randomized control trial of this technology to date. That trial found that sanitizers can effectively

these studies have relatively large sample sizes randomly divided into treatment and control groups and measure compliance by observing or weighing provided bars of soap as well as by tracking diarrhea cases. We also identified an additional recent randomized impact evaluation of a hand-washing promotion program in Karachi, Pakistan (Luby *et al.* 2004a, 2004b).

Each of these randomized impact evaluations reports large positive effects of hand washing and soap provision programs on diarrhea incidence. Khan (1982) reports that either the provision of soap and water storage containers or the provision of soap alone, along with an initial exhortation to increase the frequency of hand washing, reduced individual-level *shigella* reinfection by 67 percent in Bangladesh. However, this result does not account for intra-household clustering, thus overestimating the statistical significance of the effect of the intervention. Han and Hlaing (1989) report a 40 percent reduction in dysentery incidence among children under age two (though no reduction in incidence for older children) following hand washing education and the provision of soap to a random sample of mothers in Rangoon (Yangon). Luby *et al.* (2004a) report similar results. In their study, infants and malnourished children under age five living in treatment households had 39 percent fewer days of diarrhea compared to the control group after one year of treatment and observation. Gains roughly doubled after a second year of service provision as relatively poor households increased their compliance (Luby *et al.* 2004b).

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reduce absenteeism as a result of illness (White *et al.* 2001). Based solely on that study, it is unclear whether sanitizers may be suitable for a developing country context.

3.4 *The implementation of "software" interventions*

The effectiveness of various software interventions as actually implemented in practice and over time is a critical determinant of the relative cost-effectiveness of each intervention. The health benefits of this class of interventions rely on individual-level decisions to adopt and consistently adhere to certain behaviors. The studies reviewed in this section suggest several unresolved questions about the efficacy of individual-level behavior change efforts in practice.

First, the cost-effectiveness of handwashing and soap provision programs is uncertain. Weekly or daily reminders, which Luby *et al.* (2004b) identify as critical for adoption by the poorest households as compared to richer households (and upon which all of these studies rely), are prohibitively expensive to provide on a large-scale basis. The cost-effectiveness of point-of-use water treatment systems also needs further study; to our knowledge no evaluation has been published that compares health gains in groups that have been charged different amounts (or no fee) for treatment systems.

Second, existing research has not established that technology adoption persists in the long term. For instance, Khan (1982) tracks his subjects for only 10 days, and the other studies, while longer-term, rely on daily or weekly visits for observational data and reinforcement of treatment. We have little evidence from this research that hand-washing behaviors will persist after fieldworkers are gone, and evidence on the persistence of other hygiene behavior modifications is mixed. Some follow-up studies taking place several years after soap provision and hygiene behavior change efforts find that the behavior change can persist (Wilson and Chandler 1993, Shordt and Cairncross in press). However, as the initial interventions studied were not randomized, these finding is somewhat difficult to interpret. On the other hand, a follow-up study performed five years after the quasi-randomized intervention in Bangladesh that we described in section 2.1 suggests that the hygiene education effort there may have been relatively ineffective as five years later treatment households did not exhibit better hygiene behaviors than control households (Hoque *et al.* 1996).

In order to identify cost-effective means of facilitating long-term behavior change and technology adoption, additional research is needed that compares alternative messages and alternative message delivery avenues in several cultural contexts. For example, randomized evaluations are needed that compare health education messages directed towards women that emphasize family health versus children's well-being in particular. The usefulness of positive and negative messages should also be explored.

In some contexts, and for some behaviors, households may not be the most cost-effective entry point for message dissemination. Evaluations are needed that examine the relative effectiveness and cost-effectiveness community-level hygiene education efforts (along the lines of PHAST) that target women with other designs that might include programs that work through maternity clinics (potentially providing incentives for women to take-up antenatal services) or school-based programs. It is possible, for example, that providing soap, hand washing facilities, and messages about the importance of hand washing after defecation in primary schools may be an effective and relatively cost-effective means of promoting long-term behavior change.

Research that identifies how social learning occurs about hygiene behavior and water treatment is also needed. For example, we know little about whom opinion leaders are for water-related matters, and identifying these individuals and encouraging their adoption of treatment systems or hygiene behaviors may be critical to encouraging wider community adoption. Research might examine whether encouraging women's groups to use water treatment systems is particularly effective as a means of increasing uptake, for example, as this could be a means of targeting mothers of young children. Such targeted dissemination to women could be compared to targeted dissemination to political leaders (likely men) and wider service provision.

Service pricing decisions may have implications for both short-run cost effectiveness calculations and long-term adoption rates. The implications of cost-recovery efforts for uptake of point-of-use treatment systems in particular is little understood. Social learning effects may make it desirable to offer technologies for free initially to at least some populations. On the other hand, some argue that offering a service free of charge, even temporarily, may make people reluctant to pay for it later. The effects of pricing on service use and uptake needs further study.

Further research on the use of social marketing to increase or maintain adoption rates in this sector also would be fruitful. Social marketing can substitute for or complement educational programs, and applies marketing techniques to design and implement programs promoting socially beneficial behavior change. This approach is growing in both popularity and use within the public health community and elsewhere (Grier and Bryant 2005).

4 Conclusion and recommendations

Randomized control trials have established that vaccination, ORT, breastfeeding, and micronutrient supplementation are effective in reducing the burden of diarrhea, and that these are cost-effective investments. This evidence base has led to widespread implementation of these interventions, in turn saving millions of lives. The continuing toll of diarrhea makes it clear that further investments to prevent this disease are needed. Yet we have scant evidence and only tenuous consensus on the impact and cost-effectiveness of various environmental health interventions that might complement existing child health programs.

We have tentatively identified three broad areas for future work to address this shortcoming of the existing literature: First, research is needed that evaluates alternative environmental health interventions on a comparable basis across several settings. By properly assessing the life of infrastructure investments and accounting for externalities, researchers' goal should be to determine the extent to which environmental health projects can cost-effectively complement the medical interventions currently included in child health programs. Work is needed to rigorously assess the relative effectiveness of investments in improving water quality and increasing water quantity and to determine the extent to which contamination in water transport and hygiene practices may reduce the benefits of water quality improvements at the source. This will allow researchers to trace the chain of transmission from water source to health outcomes more accurately than is currently possible.

Second, future studies should expand efforts to understand the determinants of individual level technology adoption (including social learning) and increase technology uptake in this context. Additional information is needed about households' willingness to permanently adopt point-of-use water treatment systems, and to modify hygiene behaviors on a consistent basis. The implications of cost-recovery efforts, alternative message designs, and alternative means of product introduction for adoption should be explored. Follow-up studies should be planned when initial evaluations are designed to determine whether behavior change persists over the longer term.

Third, future research should also expand efforts to assess the quality of infrastructure maintenance under different management schemes, again using a randomized impact evaluation methodology. In particular, research is needed that compares community-based maintenance schemes with centralized mechanisms of service delivery, and that estimates which approach is the most cost-effective way to achieve financially sustainable rural water and sanitation supply. A recent *World Development Report* (World Bank 2004b) cites local governments, regional utilities, and independent providers, in addition to local community groups, as possible institutional channels for supporting community-based water systems. Research designs might directly compare the success of several of these models in infrastructure maintenance.

Several key methodological points should also be integrated into future work. First, to the greatest extent possible, projects should be designed as randomized evaluations. Randomized evaluations allow researchers to credibly estimate the impacts a particular intervention, unlike many existing non-experimental studies that are likely to suffer from omitted variable bias. By comparing results from randomized evaluations to those that would be found in cross-sectional regression, researchers will also be able to identify and better understand the biases in cross-sectional regressions. Prospective randomized evaluations also allow for the collection of the data necessary to derive cost-effectiveness estimates. A fruitful area for future work would be to examine the longer-term impacts of some of the earlier, well-executed randomized trials discussed in this review.

Second, great effort should be made to significantly expand sample sizes beyond those seen in most existing studies. Larger sample sizes allow researchers to take intra-cluster correlation into account in statistical analysis and to detect moderate treatment effects with a reasonable degree of power.

Finally, projects should be designed so as to allow for the estimation of the impact of individual interventions, rather than to only estimate the impact of packages of interventions. For example, there is a need for credible information on the complementarities and possibilities for substitution between hardware and software interventions. Evidence is also needed comparing the impacts of water quality improvements across households with different levels of sanitation, thus allowing researchers to rigorously assess the claim that improved water quality is only effective after sanitation has been improved.

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Tables

Table 1: Transmission routes of water-related diseases

Classification	*Transmission route*	*Examples*
Waterborne	• Pathogens are ingested in drinking water	• Diarrheal diseases • Enteric fevers, such as typhoid • Hepatitis A
Water-washed	• Result from having insufficient water for bathing and hygiene purposes • Pathogens are incidentally ingested in the course of other activities	• Diarrheal diseases • Trachoma • Scabies
Water-based	• Caused by repeated physical contact with contaminated water, transmission occurs via an aquatic invertebrate host	• Guinea worm • Schistosomiasis
Water-related insect vector	• Transmission occurs via an insect vector which breeds in or near water	• Malaria (parasite) and yellow fever (virus)

Sources: White *et al.* (1972), Feachem *et al.* (1983), Cairncross and Valdmanis (2004).

Table 2: The cost-effectiveness of interventions to combat diarrheal diseases

Intervention	*Reference*	*Notes*	*Cost per child diarrhea death averted (1999$)*	*Cost per child diarrhea case averted (1999$)*
Standard child health interventions				
Vitamin A supplementation	USAID Micronutrient Program (2004b)	Data from Ghana, Nepal, and Zambia	236[a]	
Vitamin A supplementation	Loevinsohn *et al.* (1997)	Data from the Philippines	68-257 [a]	
Breastfeeding promotion	Martines *et al.* (1993)	Synthesis of several studies	1,000	71
Improved weaning practices	Martines *et al.* (1993)	Synthesis of several studies	1,681	
Hypothetical rotavirus vaccine	Martines *et al.* (1993)	Synthesis of several studies	221-2,215	8
Cholera immunization	Martines *et al.* (1993)	Synthesis of several studies	3,164	273
ORS	Robberstad *et al.* (2003)	Data from Tanzania	3,213	
ORS and zinc supplementation	Robberstad *et al.* (2003)	Data from Tanzania	2,098	
ORS	Varley *et al.* (1998)	Synthesis of several studies	871	
Environmental health interventions				
Latrine rehabilitation and provision	Meddings *et al.* (2004) [b]	Data from Afghanistan	2,144	
Hypothetical hardware only	Varley *et al.* (1998)[c]	Simulation model	41,689	176
Hypothetical hardware and software	Varley *et al.* (1998)	Simulation model	14,960	64
Hypothetical software only	Varley *et al.* (1998)	Simulation model	1,599	7
Hygiene education and promotion	Martines *et al.* (1993)	Synthesis of several studies		16

Notes:
(a) Randomized control trial estimates that include deaths averted from measles.
(b) Case-control study using data collected in hospitals.
(c) Varley *et al.* (1998) model provision of tubewells and taps to a peri-urban community. Costs in rural areas would be higher.