WATER *and* SANITATION *in* Developing Countries: Including Health *in the* Equation

Millions suffer from preventable illnesses and die every year.

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Improving global access to clean drinking water and safe sanitation is one of the least expensive and most effective means to improve public health and save lives. The concept of clean water and safe sanitation as essential to health is not a novel idea. In 350 B.C., Hippocrates recommended boiling water to inactivate "impurities". The U.S. and Central Europe, where water and sanitation services are nearly universal, significantly reduced water-, sanitation-, and hygiene-related diseases by the start of the 20th century by protecting water sources and installing sewage systems. However, in developing countries, water and sanitation services are still severely lacking. As a result, millions suffer from preventable illnesses and die every year (*1*). Many obstacles must be overcome to improve these statistics. The integration of public health into engineering problem solving is critical, but current efforts are insufficient. Through partnerships with local communities to implement water and sanitation solutions that consider environmental, cultural, and economic conditions, progress toward achieving and sustaining global coverage of water and sanitation services will be greatly enhanced.

In this article, we discuss three main themes about water, sanitation, and health in developing regions. First, water and sanitation services have markedly improved health and engendered many secondary benefits. These benefits could be enhanced and services expanded through greater collaboration between the fields of water and sanitation engineering and public health. Second, researchers should focus on the sustainability of water and sanitation services by developing strategies that holistically address the influence of the environment, culture, and economics on the implementation and long-term maintenance of treatment systems. Low-cost household technologies, as opposed to centralized systems, offer one means of addressing water and sanitation needs in a more integrated and sustainable manner. Third, the obstacles to improving water and sanitation services, such as lack of investment, lack of political will, and difficulty in maintaining services, must be overcome so that these services can be improved and global coverage ultimately achieved. This will require greater collaboration among the water, health, and education sectors in conducting community-based research and work, formulating evidence-based policies that allow for effective investments, and focusing on developing solutions that can be locally managed and maintained.

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Billions suffer without improved water and sanitation services

Global figures that describe the lack of water and sanitation services are alarming. More than 1.1 billion people do not have access to improved drink-

FIGURE 1

Comparison between lack of access to improved water and sanitation and deaths attributable to diarrheal diseases

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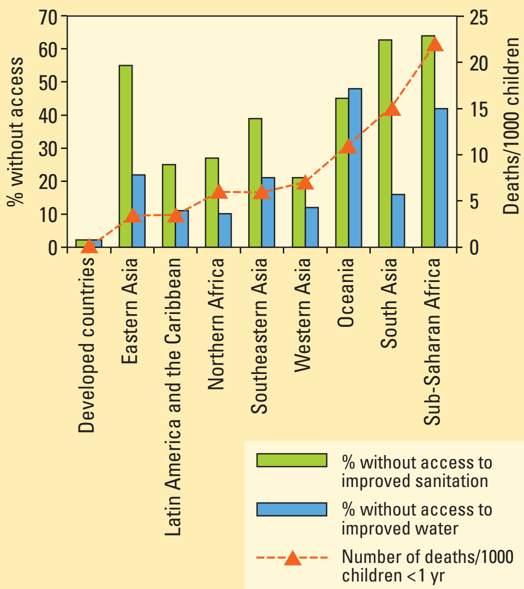

ing-water supplies (*1*). Lack of sanitation is an even larger problem; an estimated 2.6 billion individuals live without improved services (*1*). "Improved access" to water and sanitation may, but does not necessarily, represent access to water or sanitation services that meet international engineering and health standards, such as those set forth by World Health Organization (WHO) *Guidelines for Drinking Water Quality*. Rather, the term "improved access" usually represents households that obtain water from sources that are superior to traditional, unprotected ones. Sources that meet the definition of improved water include a household connection, borehole, protected dug well, protected spring, or rainwater collection (*1*). Connection to a public sewer or septic system or use of ventilated pit latrines and some simple pit latrines qualify as improved sanitation (*1*).

Figure 1 illustrates, by region, the percentage of the population without access to improved water and sanitation. To demonstrate how this impacts health, the figure also shows number of deaths per 1000 children younger than 1 year of age that are attributable to diarrheal diseases (*1*). Conditions are most severe in sub-Saharan Africa, where 42% of the population is without improved water, 64% is without improved sanitation, and deaths due to diarrheal diseases are greater than in any other region.

In an effort to bring global attention and resources to the problem, international organizations have created several water and sanitation initiatives. The UN, as part of its Millennium Development Goals (MDGs), has set a target of halving the proportion of people without access to safe drinking water and basic sanitation by 2015 (*2*). WHO has declared 2005–2015 the decade of water, with the goal of establishing the framework to eventually provide full access to water supply and sanitation for all people. In 2003, WHO also established the Household Water Treatment and Safe Storage Network, a consortium of nearly 100 organizations working throughout developing nations. The aims of the network include fostering collaboration, generating research, and exploring measures to scale up pilot projects. In another major initiative, WaterAid has helped foster citizen-action groups to improve services as part of a global grassroots movement in water and sanitation. In most countries, the proportion of people with access to improved water and sanitation increased from 1990 to 2002 (*1*). However, in the most impoverished regions, access remains dismal and, unless significant improvements occur, numerous countries, including many of those in sub-Saharan Africa, will not meet the UN MDGs for water and sanitation by 2015 (*3*).

The adverse health impacts attributable to lack of water and sanitation are significant. These effects are caused by exposure to pathogenic microbes through various routes, which are summarized in 6 categories in Table 1. The large number of categories is an indication of the extent to which water-,

TABLE 1

Categories of water-, sanitation-, and hygiene-related diseases

Category	Description/disease
Waterborne	Caused by the ingestion of water contaminated by human or animal excreta or urine containing pathogenic bacteria or viruses; includes cholera, typhoid, amoebic and bacillary dysentery, and other diarrheal diseases.
Water-based	Caused by parasites found in intermediate organisms living in water; includes dracunculiasis, schistosomiasis, and some other helminths.
Water-related	Caused by microorganisms with life cycles associated with insects that live or breed in water; includes dengue fever, lymphatic filariasis, malaria, onchocerciasis, and yellow fever.
Excreta-related	Caused by direct or indirect contact with pathogens associated with excreta and/or vectors breeding in excreta; includes trachoma and most waterborne diseases.
Water collection and storage	Caused by contamination that occurs during or after collection, often because of poorly designed, open containers and improper hygiene and handling.
Toxin-related	Caused by toxic bacteria, such as cyanobacteria, which are linked to eutrophication of surface-water bodies; causes gastrointestinal and hepatic illnesses.

Adapted with permission from Refs. 17, 44, and 45.

sanitation-, and hygiene-related diseases can affect populations. Many of the categories and diseases are closely associated. As we discuss later, this association complicates environmental risk analysis.

Nearly 60% of infant mortality is linked to infectious diseases, most of them water-, sanitation-, and hygiene-related (*4*). Globally, diarrhea is the third largest cause of morbidity and the sixth largest cause of mortality (*5*). Disability-adjusted life years (DALYs), a measure that combines the burden from death and disability in a single index, allows for the quantification of disease burden (*6*). The global disease burden from water-, sanitation-, and hygiene-related diseases is significant, accounting for ~82,196,000 DALYs (*7*). In addition to the burden from diarrhea, this estimate includes the impact from schistosomiasis, trachoma, and intestinal helminths. Table 2 illustrates the global extent of morbidity and mortality figures for diarrhea and other water-, sanitation-, and hygiene-related diseases. A study conducted by the Pacific Institute estimated that if no action is taken to address the lack of water, sanitation, and hygiene, as many as 135 million preventable deaths will occur by 2020 (*8*).

The adverse effects of a lack of water and sanitation services extend beyond the unequivocal consequence of diseases. The collection of water, primarily the responsibility of women and children, represents an additional burden. Up to 6 hours each day may be spent in search of water to meet household needs (*9*). Time spent in search of water forces children to miss school and women to forgo potential opportunities to engage in small business endeavors, such as growing and selling vegetables or weaving mats. A lack of water may prevent people from practicing proper hygiene habits, such as washing their hands before eating or after using a latrine. Water scarcity may also limit the ability to grow and water vegetables, thus depriving individuals of essential nutrients needed to fight diseases. In addition, the long-term consequences of diarrheal diseases have been linked to secondary health impacts, such as malnutrition and reduced cognitive function in children (*10*).

TABLE 2

Morbidity and mortality rates for selected water-, sanitation-, and hygiene-related diseases

Disease	Estimated morbidity (episodes per year)	Estimated mortality (deaths per year)	Cause/link: Unsanitary disposal of excreta	Cause/link: Unsafe drinking water	Cause/link: Poor hygiene	Cause/link: Water resources development[a]
Diarrheal diseases	1 billion	2.2 million	✓	✓	✓	
Intestinal helminths	1.5 billion	100,000	✓	✓	✓	
Schistosomiasis	200 million	200,000	✓			✓
Trachoma	150 million[b]	—	✓		✓	

[a] Water resources development refers to dams and farm irrigation schemes that have increased snail habitat, a vector for the schistosomiasis-causing parasites, and the likelihood of exposure with additional individuals working in irrigated fields where the snail breeds.
[b] This reflects the number of active cases. Approximately 6 million cases of preventable blindness are due to trachoma.
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Foundation for improved health

Substantial evidence indicates that water, sanitation, and hygiene interventions improve health. A multifaceted review of the health effects from improved water supply and sanitation found significant reductions in both the severity and prevalence of diarrhea and infectious diseases (*11*). Specifically, dracunculiasis, schistosomiasis, and trachoma were reduced by 77%, 78%, and 27%, respectively. Improved water and sanitation serve as important barriers to the various routes of pathogen exposure summarized in Table 1. Furthermore, compared with medical treatment, water and sanitation services provide a more cost-effective and locally sustainable solution for alleviating the impacts of water-, sanitation-, and hygiene-related diseases (*12*).

In the past decade, further evidence has emerged that supports the beneficial outcomes of water, sanitation, and hygiene interventions in developing countries. A meta-analysis of the impact of such interventions concluded that increasing water quantity reduced the occurrence of diarrheal diseases by 25%, whereas point-of-use (POU) household water treatment and improved sanitation led to reductions in diarrheal diseases of 35% and 32%, respectively (*13*). Sanitation and POU interventions may have resulted in greater reductions because they directly block pathways of exposure. In contrast, increasing water quantity has the potential to indirectly improve hygiene practices, such as hand washing, by providing households with a greater total amount of water that can be used for additional tasks. Interestingly, no improved benefit in disease reduction was seen in households where multiple interventions were introduced (*13*). This may indicate that health gains are not additive and/or that confounding factors become increasingly significant when the effects of multiple interventions are measured. A recent review of 30 randomized and quasi-randomized controlled studies supports earlier conclusions that POU household treatment is more effective in preventing diarrhea compared with treating water at the source (*14*). The above studies and several others provide convincing evidence for the health benefits that result from improved water and sanitation.

Environmental risk and pathogen pathways

Taking action to improve health requires understanding the factors that influence exposure and health outcomes. The Multiple Exposure–Multiple Effect (MEME) model provides a way to systematically understand the interrelated nature of these factors (*15*). Exposure may be the result of proximal causes, such as drinking water that becomes contaminated with excreta-related pathogens in the home, or distal causes, such as climate. Although the pathways of exposure have been described, the

FIGURE 2

Exposures and health outcomes are complicated by interrelated factors

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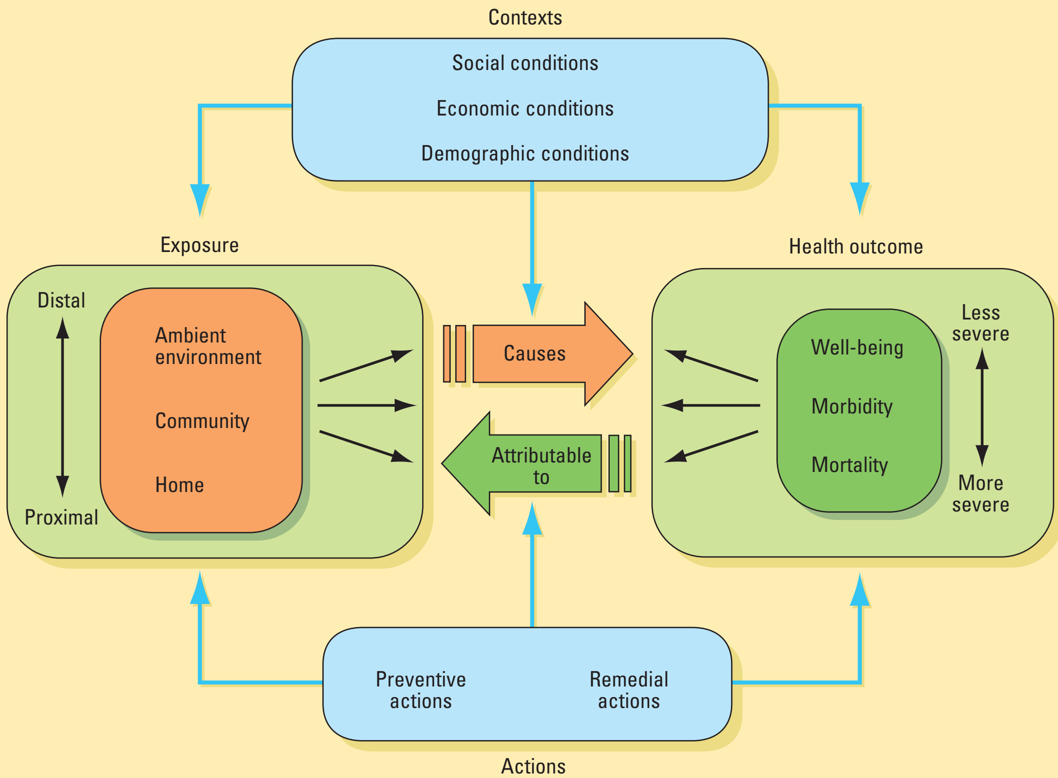

relative influence of various factors, especially those resulting from social, economic, and demographic conditions, on both exposure and health are less well understood. The linkages between these factors within the framework of the MEME model are illustrated in Figure 2.

The MEME model serves as a basis for examining the ability of water, sanitation, and hygiene interventions to reduce exposure and improve health outcomes. For interventions to be effective in reducing risk and blocking pathogen pathways, they must consider the environmental, cultural, and economic conditions of a particular community. An example of such an intervention is community-led sanitation, which began in Bangladesh and has spread throughout South and Southeast Asia. It focuses on sustainability by supporting communities in prioritizing needs and developing sanitation interventions that incorporate local materials and marketing strategies to encourage latrine construction. The result has been an explosion of new, innovative, community-developed and -managed technologies, significant health gains, and overall improvements in well-being (*3*).

Risk assessment increases in complexity when pathogens have several routes of transmission and/or vertebrate hosts. An example of a pathogen with multiple routes is *Chlamydia trachomatis*, the bacterium that causes the potentially blinding disease trachoma. The disease is transmitted when droplets containing *C. trachomatis* are spread through touching infected eyes, contact with contaminated pillows and clothes, and eye-seeking flies—*Musca sorbens*—that serve as mechanical vectors (*16*). When animal and human hosts coexist, both can serve as reservoirs for pathogen survival and reproduction, compounding the challenge of describing risk of exposure. Examples include nontyphi *Salmonella*, *E. coli*, and the bovine species of *Cryptosporidium* (*17*). As we describe in the following section, reducing the potential sources of pathogens through POU household treatment and improved sanitation can significantly reduce the risk of exposure (*18*).

A shift to household technologies

Lending institutions and national governments have traditionally focused on implementation of large, centralized treatment systems. Such systems do not serve rural areas, where populations are dispersed and the proportion served is less than half that in urban areas (*1*). Rapidly growing, unplanned, periurban areas are also not effectively served by centralized systems (*19*). Centralized approaches are often plagued by high capital costs, lack of proper operation, and an overreliance on treatment technologies that cannot be afforded or maintained. Given the shortfalls of centralized systems, it is apparent that a variety of options are needed, especially in developing countries, where conditions are challenging. A decentralized approach that relies on household water treatment and sanitation technologies may present a viable alternative (*19–22*).

POU treatment. POU treatment offers a locally modified and managed solution in areas where centralized systems are ineffective. The critical advantage of POU treatment is that it provides a barrier to pathogen exposure immediately before consumption. Even when source water is deemed "safe", poor hygiene during collection, storage, and handling of water results in contamination (*23*). For example, reduction in diarrheal diseases is doubled when water is treated immediately before use (*13*). Therefore, for maintaining the quality of treated water within the home, safe storage is an important complement to POU. An extensive review of POU technologies concluded that "simple, acceptable, low-cost interventions at the household and community level are capable of dramatically improving the microbial quality of household stored water and reducing the attendant risks of diarrheal disease and death" (*24*).

In laboratory studies, POU technologies have demonstrated removal and/or inactivation of pathogens at varying rates. PUR, a flocculant/disinfectant that is sold in individual packets, is the most effective, providing >7 log removal of bacteria and >4 log removal of viruses (*21*). Chlorine bleach typically achieves only 2 log removal for both bacteria and viruses (*25*). Chlorine is particularly poor for treating turbid water (>1 nephelometric turbidity unit) or chlorine-resistant pathogens, including many types of protozoan cysts. However, the chlorine residual protects against recontamination; this is especially important in homes where hygiene is substandard.

Health gains from POU techniques will only be realized if treatment is effective in the communities where such technologies are used. This is a greater challenge than achieving high removal rates of pathogens in the controlled laboratory environment. Recent studies in Kenya, Guatemala, and India have demonstrated that use of POU treatments leads to a reduction in diarrhea by 40% for PUR and solar disinfection and by up to 85% for chlorine (*20*, *26*, *27*). These results suggest that although chlorine is less effective in removing bacteria and viruses, it may lead to a greater reduction in diarrhea because of economic and cultural advantages relating to low cost, ease of use, and its ability to be manufactured locally. Other studies, however, have not found such a large advantage for chlorine. A study in Guatemala that evaluated sodium hypochlorite (bleach) and PUR demonstrated no significant difference between the two technologies, both of which reduced diarrhea by ~25% (*28*). Precise rankings of POU-based disease reduction are difficult to ascertain, as we describe in the following paragraph, but more qualitative conclusions are possible. The review on household technologies concluded that solar disinfection with clear plastic bottles and chlorination plus storage in an improved vessel led to significant reductions in diarrhea and other infectious diseases (*24*).

Conclusive results about which POU technologies are the most effective in improving health are still lacking. Because of heterogeneities between communities and in the methodology of epidemiological studies, comparing outcomes is difficult. The performance of POU treatments is highly dependent on source water quality and the degree to which households adhere to the operation and maintenance requirements. A review of the promotion of chlorine disinfection in Malawi found that incorrect dosage (8–100% of the appropriate concentration was used) resulted in a chlorine residual that was far less than suggested (*29*). An additional challenge is determining whether health outcomes are primarily due to POU treatment or confounding factors, such as hand washing, education, economic wellbeing, and culture. For example, a drinking-water and hand-washing study in squatter settlements in Karachi, Pakistan, found no significant difference in reduction of daily longitudinal prevalence of diarrhea among households that used POU technologies alone (64%), hand washing alone (51%), and a combination of POU treatments and hand washing with soap (55%) (*30*). Therefore, additional comparative and longitudinal health studies are required to determine which technologies are most effective.

Understanding the primary motivators that drive households to use POU technologies is important for sustaining use and achieving long-term health gains. Some of the main factors are affordability, aesthetic and taste preferences, and the ability to manufacture POU technologies locally. The cost of POU treatments is a serious hurdle to adoption, especially in developing countries such as Tanzania, where for decades a "free water for all" policy existed (*31*). Placing a price on POU units is important to recover production costs and increase sense of ownership. However, water is viewed as a fundamental human right, and denying access because of inability to pay creates a serious ethical dilemma (*19*, *32*). POU technologies that can be generated locally—such as chlorine which has been manufactured, packaged, and distributed by local microenterprises under brands such as WaterGuard in Tanzania and Safe Water (Sûr'Eau) in Madagascar—are more likely to be sustained after initial funding ceases. In contrast, PUR currently cannot be manufactured locally, thus preventing its widespread adoption and distribution. Long-term, sustained use of POU technologies may be reinforced as individuals experience the benefits of improved water and sanitation. Furthermore, reductions in water-, sanitation-, and hygiene-related diseases allow individuals to engage in more productive work and attend school, both of which may lead to economic development, improved standards of living, and more hygienic conditions.

Household sanitation. A simple pit latrine, one of the most basic forms of household sanitation, offers an inexpensive alternative to expensive and environmentally intensive sewage systems. Although sanitation is important for the safe disposal of excreta—the source of pathogens that cause the majority of water-, sanitation-, and hygiene-related diseases—it has not received the same attention as water treatment (*33*). One of the major challenges with sanitation is developing and implementing innovative, user-friendly, low-cost systems (*34*).

Current efforts focus on overcoming some of the limitations of the simple pit latrine and expanding sanitation coverage. Some evidence has linked the standard latrine to contamination of groundwater by bacteria and nutrients (*35*). In addition, traditional latrines may harbor offensive odors and flies. The ventilated improved pit latrine improves on the standard design by allowing odors to escape, preventing flies from entering, and in many cases sealing the pit to prevent groundwater contamination (*33*). Ecological sanitation, although practiced in China for centuries, has only recently been gaining acceptance throughout the world as an effective means to recycle the nutrients in excreta for use in agriculture. This improves crop production and, ultimately, the nutritional health of the population (*36*).

A typical latrine design consists of a superstructure that sits above a raised, sealed vault. The toilet, either of the sitting or standing variety, usually diverts urine and excreta into two separate chambers within the vault. Urine, which is nearly pathogen-free and contains high amounts of nitrogen and phosphorus, can be diluted with water and used immediately for crop fertilization. Excreta must remain in the vault for a period of several months to allow for pathogen removal through die-off, desiccation, and predation by microorganisms (*36*). Once pathogen removal is nearly complete and excreta can be safely handled, it can be applied to crops. Advantages of ecological sanitation include the ability to empty and reuse storage vaults, production of an organic and free source of fertilizer, and prevention of groundwater pollution that can occur when pits are unsealed and located near the aquifer.

The promotion and large-scale implementation of latrines are at least as important as, if not more important than, improvements in sanitation design. Latrine marketing does not focus on extolling the virtues of improved health but rather on other benefits such as reduced smell, cleaner surroundings, privacy, and less embarrassment when visitors need to use facilities (*37*). Combining low-cost technology with marketing efforts to secure community participation and management has been a successful way of expanding sanitation coverage. One notable example is in India, where 1 million pit latrines, which can be modified to suit different incomes and preferences, have been built since 1970 under the auspices of the nongovernmental organization Sulabh International Social Service Organization (*3*). Further efforts are required in the marketing and implementation of household latrines before similar success can be realized throughout the globe.

Obstacles to achieving water and sanitation for all

In many developing countries, a lack of financial resources and a low prioritization of water and sanitation constrain both the maintenance and expansion of services. In addition, lack of accountability, corruption, and inefficient management all plague efforts to improve water and sanitation. The lack of water quality standards and the difficulty in enforcing standards also limit the ability to improve health outcomes. Even countries where such standards exist frequently lack the personnel, monitoring equipment, and political will to ensure that quality and health guidelines are enforced (*38*).

Decentralization has not solved perhaps the largest problem facing water and sanitation projects—sustaining long-term use and operation. For example, at the conclusion of the 5-year, $135 million Indonesian Rural Water Supply and Sanitation Sector Project, fewer than half of the ~3 million intended beneficiaries had received any services (*39*). In addition, only 30–40% of the water and sanitation facilities constructed were still functioning or in use 4 years after the project was completed (*39*). This demonstrates both an initial lack of capacity and/or political will to implement services and a lack of local incentive to operate and maintain facilities. Efforts in rural Africa had similar outcomes. Throughout the continent, of the ~250,000 hand pumps currently installed, <50% are estimated to be operational (*40*). Six months after implementation of a chlorine-disinfection and safe-storage project in rural Kenya, on average only 33% of households had chlorine residual (evidence of use of POU treatments) and <20% had purchased storage pots (*41*). Project participation in individual villages was variable, ranging from 0 to 76%. This suggests that further understanding of the factors that lead to adoption, even within regional areas, is critical for sustaining interventions and achieving health gains.

Increasing funding alone is not the solution. Irrespective of the type of system, an emphasis should be placed on implementing demand-based rather than supply-based systems, where communities commit to partnering in the development of locally based systems. Once local partnerships and management structures have been established, governmental agencies and nongovernmental organizations should assist in establishing an effective monitoring program in conjunction with a financial system that uses both local and government funds to pay for ongoing maintenance and improvements.

Overcoming the challenges

Overcoming the obstacles to providing water and sanitation for all will require policies and investments that address the interrelated nature of water, sanitation, and health. Policies and funding initiatives that focus on either water and sanitation or disease treatment ought to be replaced by integrated endeavors with a focus on disease prevention. Such a strategy will serve to enhance the already proven cost-effectiveness of improvements in water and sanitation and make use of overlapping areas of knowledge and responsibility. Such integrated approaches are especially important in developing countries, where funding and resources are scarce and competing needs are immense.

Three main areas require further investigation to provide the information and necessary tools to tackle current challenges. First, current knowledge about water, sanitation, and health should be translated into action through community projects and research. Community-based research includes gaining a better understanding of the key factors driving long-term use of interventions, establishing hygiene behavior-change initiatives within existing community structures, and creating consumer demand for interventions through marketing efforts. Evidence from community research should be used to modify and improve existing policies and investments. Second, improved methodology and indicators should be developed for quantifying the health impacts of interventions for water, sanitation, and hygiene. These indicators should be easy for local communities to monitor and will enable projects to base claims of "improving health" on quantifiable evidence, rather than on selected personal narratives. Last, additional, randomized, controlled studies could assist researchers in understanding health outcomes from different interventions, especially among key subgroups, such as children or immunocompromised individuals (*42*). Longitudinal, multiyear studies that examine the environmental, social, and economic circumstances in which interventions are likely to fail or succeed are also important. Such studies are critical so that cost-effective investments can be made in water, sanitation, and health projects (*43*).

Collaboration and sustainability: the path forward

Integration of engineering and public health through collaboration on research and project work, combined with meaningful partnerships with local communities, will enhance the sustainability of water and sanitation efforts. Health risks and outcomes can only truly be understood and addressed by understanding the relative influence of the environment, in conjunction with social, economic, and demographic factors. Interventions must reflect the needs and the capacity of local communities to carry out operation and maintenance. Low-cost household water and sanitation technologies provide a viable alternative to centralized systems that in many cases have failed to meet the sustainability criterion. Advantages of household technologies include user ownership, incorporation of local materials and innovation, and proven health benefits. However, even household systems face obstacles, and further research is required.

Including health in the equation is a challenge that we can no longer ignore. Clean water and sanitation are essential elements in achieving a basic standard of health for the globe. The ultimate impact on health, however, depends largely on the extent to which interventions are implemented, used, and maintained. If we are serious about implementing innovative solutions that effectively provide basic water and sanitation services to developing countries, we must be willing to openly and humbly engage with the very communities where services are lacking. This will necessitate understanding community needs, learning from local innovators, and developing projects that can be locally managed and sustained. The results of such efforts will undoubtedly increase the rate at which we approach the UN MDGs and serve the billions who currently live without basic water or sanitation.

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