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WATER, HEALTH, AND INCOME: A REVIEW

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ABSTRACT

This paper examines the impact of improved water access on health and incomes in the developing world, drawing on contributions from public health, economics, and anthropology. It argues that the "biological" pathways are reasonably well understood, with the effectiveness of interventions being ordered in the following way: improved household sanitation and hygiene practices; improvements in both quality and quantity of water supplies; increased quantity of water consumed and better water quality. However, the whole is greater than the sum of the parts; knowledge of hygienic practices *plus* improvements in sanitation *plus* use of greater quantities of water tend to lead to the largest improvements in health. By contrast, the "economic" pathways are less well understood. The full economic returns to investing in improved water access have not been determined, nor is the distributional impact of water access known, either across or within households. Although it is possible to order these interventions in terms of effectiveness, this ranking omits any consideration of cost.

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1. INTRODUCTION

About 1.3 billion people in the developing world lack access to clean and plentiful water. The consequences of this include 4.6 million deaths from diarrheal diseases and a further 20,000 deaths from ascariasis (roundworm).[1] There are over 200 million cases of schistosomiasis each year. Although dracunculiasis (guinea worm) is now restricted solely to parts of West Africa, there are still an estimated 4 million cases each year of this painful illness. The 500 million cases of trachoma each year lead to blindness in 8 million people.

This paper examines the existing literature on the impact of improved water access on health and incomes in the developing world. Its objectives are twofold. First, it seeks to summarize existing knowledge. Although a number of reviews exist, they tend to emphasize biological and scientific aspects and are often written for a specialist audience. By contrast, the scope of this review is deliberately wide, encompassing contributions from public health, economics, and anthropology. Second, it attempts to identify those areas where information is scarce and thus where further research will produce the greatest returns in terms of better policy and better health outcomes.

Specifically, it argues that the "biological" pathways through which improved water and sanitation affect health have been extensively studied. Interventions can be ordered from most-to-least-effective in the following way: improving household sanitation and hygiene practices, improving both quality and quantity of water supplies, increasing quantity of water consumed, and improving water quality. However, improvements in only one of these is unlikely to lead to dramatic drops in morbidity. The whole is greater than the sum of the parts; that is, knowledge of hygienic practices *plus* improvements in

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[1]All figures are taken from Esrey et al. (1991).

sanitation *plus* use of greater quantities of water tends to lead to the largest improvements.

Unfortunately, the "economic" pathways are less well-understood. The full health and economic returns to investing in improved water access have not been determined. The distributional impact of water access, across and within households, is not known. That is, who in a given community is most likely to benefit from improved water availability? Who benefits within the household by improving access to water? And finally, what is the cost of the various interventions?

The paper begins by outlining a conceptual framework that guides subsequent discussion. It then reviews the literature on the impact of improved water access on health and incomes. It concludes by suggesting directions for future study.

2. CONCEPTUAL FRAMEWORK

We begin with a simple conceptual model that extends the exposition set out in Behrman and Deolalikar (1988). Doing so captures the pathways by which improved water access affects health and productivity and provides a guide for our review of the evidence. Household preferences are represented by the following utility function:[2]

$$U = U(H^i,\ C^i_j,\ C^P,\ T^i_R) \qquad i = 1, \ldots, I, \tag{1}$$

[2]We assume, unrealistically, that the preference of all household members can be aggregated into a single household utility function; the assumption of a "unitary" household. Assuming that the household's preferences are the outcome of a cooperative bargaining process is not likely to change the theoretical paths through which improved access to water affects health and incomes, as this entails adding "extra-environmental parameters" to the reduced-form demand functions. Empirically, ignoring these variables may cause omitted variable bias. It is more difficult to make a priori predictions for a model based on a noncooperative framework; the exact result may depend on precisely how interactions between different household members are modeled. Alderman et al. (1995) provide a further discussion of these models.

where H^i is the health of the i^{th} individual; C^i_j is the consumption of j different commodities by i; C^P is consumption of a household public good ("cleanliness"), and T^i_R is consumption of leisure by i.

This is maximized subject to the following constraints. The first is a health production function:

$$H^i = H(C^i_j, C^P, T^i_R, E^i, E^M, E_H, T^i_H, T^{-i}_H, W^i, \eta^i, \Omega) \quad i = 1, ..., I, \tag{2}$$

where E^i and E^M are the education levels of i and the principal caregiver in the household (assumed to be that of an adult woman), E_H is knowledge of good health practices, T^i_H is time spent by i on producing health, T^{-i}_H is time spent by all other household members producing i's health, W^i is quality adjusted consumption of water by i, η^i is i's innate health endowment, and Ω is a vector of community characteristics that includes variables that affect an individual's health (such as the innate healthiness of an area).

The second is a water production function:

$$W^i = W(\varpi, T^i_W(D_W), T^{-i}_W(D_W), E_W, C^{WC}, E^M, A_W, H^i, \Omega) \quad i = 1, ..., I, \tag{3}$$

where ϖ is the quality of water available to the household; T^i_W and T^{-i}_W is the time spent by i and other household members collecting water and is assumed to be a function of distance to the source of water (D_W); E_W is knowledge of good health practices as they relate to water collection and storage; C^{WC} are complementary commodities, such as firewood, filters, and decontaminants used in the production of water; and A_W are capital goods, such as buckets and pots used in the transport and storage of water. Note that where households can choose among several sources of water, ϖ and D_W become choice variables. Individuals may use water from several sources. For example, individuals might use well water for personal consumption while bathing and washing clothes and utensils in rivers. Water quality at the point of consumption can differ from quality at the source as it is affected by factors such as location and duration of storage, whether different containers are used for fetching and storing water, the quality of storage containers, and knowledge of safe water practices.[3]

The third constraint is a wage production function:

$$P^i_L = P_L(H^i, C^i, E^i, \eta^i, \Theta) \quad i = 1, ..., \mathrm{I}, \tag{4}$$

where P^i_L is the wage of person i obtainable in the labor market and Θ is a vector of characteristics of the local labor market.

The fourth is a farm production function:

$$Y^h = Y(H^i, C^i, E^i, T^i_F, A_F) \quad i = 1, ..., \mathrm{I}, \tag{5}$$

where Y^h is farm output aggregated over all crops and livestock; T^i_F is the amount of time spent by i in farm production; A_F is a vector of capital goods and inputs used in agricultural production.

Finally, there are time and full-income constraints:

$$T^i = T^i_R + T^i_H + T^i_W + T^i_L + T^i_F + T^i_{WC} \quad \forall \mathrm{I}, \tag{6}$$

where T^i_L is time spent by *I* in wage work. Note that T^i_{WC} will be a function of distances to such complementary goods, such as the distance to a source of firewood (D_{WC}).

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[3]Young and Briscoe's (1987) Malawian data provide a dramatic example of this.

Source	Sample Location	Fecal Coliform Colonies/100 ml
Piped water	Source	12
	House	16
Borehole	Source	46
	House	240
Unprotected wells and rivers	Source	540
	House	760

$$P_Y \cdot Y^h + 3 P_L^i \cdot T_L^i + R = P_A \cdot A + 3 P_W \cdot W^i + P_{WC} \cdot C^{WC} + P_P \cdot C^P + 3_{I=1} 3_{j=1} \; P_{Cj} \cdot C_j^i \qquad (7)$$

where the *P*s are the prices of the commodities and assets described above and *R* is exogenous income.[4]

Solving out this constrained maximization problem yields reduced-form demand functions for all choice variables in which all predetermined variables appear as arguments:

$W^i = w(E^i, E^M, E_H, E_W, A_F, A_W, R, P_Y, P_A, P_W, P_{WC}, P_P, P_{Cj,}\, \tilde{\omega}, D_W, D_{WC}, \eta^i, \Omega, \Theta);$
$H^i = h(E^i, E^M, E_H, E_W, A_F, A_W, R, P_Y, P_A, P_W, P_{WC}, P_P, P_{Cj,}\, \tilde{\omega}, D_W, D_{WC}, \eta^i, \Omega, \Theta);$
$P^i_L = p_L(E^i, E^M, E_H, E_W, A_F, A_W, R, P_Y, P_A, P_W, P_{WC}, P_P, P_{Cj,}\, \tilde{\omega}, D_W, D_{WC}, \eta^i, \Omega, \Theta);$
$Y^h = y(E^i, E^M, E_H, E_W, A_F, A_W, R, P_Y, P_A, P_W, P_{WC}, P_P, P_{cj}, \tilde{\omega}, D_W, D_{WC}, \eta^i, \Omega, \Theta).$

These identify a number of policy variables that affect the demand for water, health, wages, and agricultural production: improvements in innate quality ($\tilde{\omega}$); pricing policy for water, as exemplified by charging user fees (P_W); reducing distances to collect water (D_W); knowledge of good water practices (E_W); and the price and distances associated with the acquisition of complementary inputs (D_{WC} and P_{WC}). It also identifies the pathways through which changes in these improve well-being.

An improvement in water quality is hypothesized to have the following effects on health:

- a direct improvement in that person's health via the reduced exposure to waterborne pathogens;
- an indirect effect via improved ability to consume complementary commodities that also enhance health.

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[4]In a cooperative bargaining model of the household, this would be disaggregated by recipient.

In turn, better health increases income from wage and agricultural activities via the following:

- directly, via the wage and farm production functions; healthier individuals increase their "effective" hours spent in wage and farmwork;
- directly, by reducing the amount of time spent ill, thus releasing labor for productive activities;
- indirectly, by reducing the amount of time required to care for someone who is ill, thus releasing labor for productive activities;
- indirectly, by reducing the amount of time required for complementary activities, such as firewood collection, necessary when water is contaminated at the source;
- indirectly, via altering the portfolio of income-generating activities undertaken by the household. For example, individuals at risk from health interruptions might grow lower-value or lower-output crops whose yields are less susceptible to interruptions in labor supply. Improved access to water may permit households to make better use of complementary inputs.

These lead to further improvements in health via second-round effects: higher levels of income, which can be used to purchase goods that improve health; expenses associated with ill health fall, thus releasing funds for other purposes; improved health of caregivers increases the time they have available to improve the health of other household members; and greater consumption of leisure.

Reducing travel time to collect water will relax the time constraint. Time saved can be reallocated to leisure, health production, wage labor, and agricultural activities. Thus, health is improved both directly or indirectly via the impact of higher incomes. It is important to note the consequences of this change for time allocation among *all* household members. Consider a household where the man and woman farm separate plots of land, but contribute labor to each other's plot. The woman is solely responsible for water collection. If collection times are reduced, the woman may increase the amount of time she spends on farming, thus increasing income from agriculture and thus, it would appear, making the household better-off. However, the man might respond by reallocating his time to some other activity, such as leisure, and thus may be the real beneficiary of this change.[5]

The demand function for water indicates that reduced collection times may affect the quantity of water consumed (see Briscoe [1984a] and Mu, Whittington, and Briscoe [1990] for empirical examples). Less obviously, it may also improve water quality. Long distances discourage frequency of collection and thus extend storage periods, which, in turn, increases the exposure of the water to contaminants, as does carrying water over long distances (Burger and Esrey 1995).

There are four additional points to note. To keep the model relatively simple, the impact of improved water supplies on both child and adult mortality is ignored, though empirical findings are discussed in the next section. Also for reasons of simplicity, consideration of interactions between improved water quality and other investments in human capital, most notably children's schooling, is omitted. Pathways at work here include (1) the reallocation of time to school attendance and study, thus producing better schooling attainment; (2) better health that leads to direct improvement in schooling outcomes (Behrman 1996); (3) a linear specification of these demand functions overlooks the important fact, discussed in the next section, that health is affected by the interaction between water and sanitation access; and (4) poor water access, discussed below, which has a powerful adverse effect on both weight and height gain. An important question is whether such losses of growth are temporary or permanent. Martorell (1995) states:

[5]Women might still benefit if they gain control over a bigger share of household income and/or their new set of labor activities are less energy intensive.

> Considerable information has accumulated to show that almost all of the growth retardation observed in developing countries has its origins in the first two or three years of life. Data from Egypt, Kenya, and Mexico . . . indicate that most of the deceleration in growth occurs before age 2.. . . A study of poor Indian boys found that stunting at 5 years of age was the key factor determining small adult stature . . . . Long-term prospective studies from rural Guatemala also indicate that growth retardation is largely confined to the first few years of life. No catch-up growth occurred in either boys or girls over 5 years of age. (Martorell 1995, 19-20).

If the Martorell view is correct, the impact of poor water access during childhood has life-long consequences.[6] The loss of stature in infancy leads to loss of stature in adulthood, which, in turn, is associated with premature mortality due to increased risk of cardiovascular and obstructive lung disease (World Bank 1993). "Small pelvic size among stunted women increases the risk of maternal and infant mortality" (World Bank 1993, 76) and is also associated with lower birth weights. Small stature is also associated with loss of income for these individuals as adults.

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[6]Dissenting views include Behrman, Deolalikar, and Lavy (1995), Bouis et al. (1994), and Tanner (1976).

3. THE IMPACT OF IMPROVED WATER SUPPLY ON HEALTH

We begin by reviewing the literature on the impact of improved water supplies on mortality, before turning to its affect on morbidity. Given the voluminous nature of the literature on the latter topic, this is divided between a detailed examination of studies relating to the incidence of and morbidity from diarrhea and a more concise review of their impact on dracunculiasis, hookworm infection, schistosomiasis, and trachoma. Attention is then turned to the influence of improved water supplies on anthropometric measures.

IMPACT ON IMPROVED WATER SUPPLIES ON MORTALITY

Brockerhoff (1995) examines the impact of piped water on early child mortality using recent Demographic and Health Survey data from five East African countries. In addition to his measure of water quality, his regressors include child and maternal characteristics, measures of preventative health, a "standard of living index," but no measure of household sanitation. As Figure 1 shows, he finds that exposing children reduces mortality in all five countries, with a much bigger proportionate effect found in Kenya relative to Malawi, Tanzania, and Zambia, all of which have much higher mortality rates. Unfortunately, his regressions are quasi-reduced forms, as they mix exogenous regressors with choice variables.

Esrey and Habicht (1988), using data from the 1976-77 Malaysian Family Life Survey, examine the impact on infant mortality of maternal literacy, piped water, and access to toilets.[7] They found a synergistic relationship between maternal literacy and piped water; reductions in mortality rates from either factor were enhanced if the other factor was also present. Using the same data set, Butz, Habicht, and DaVanzo (1984) examined the impact of improved water and sanitation together with breast-feeding on

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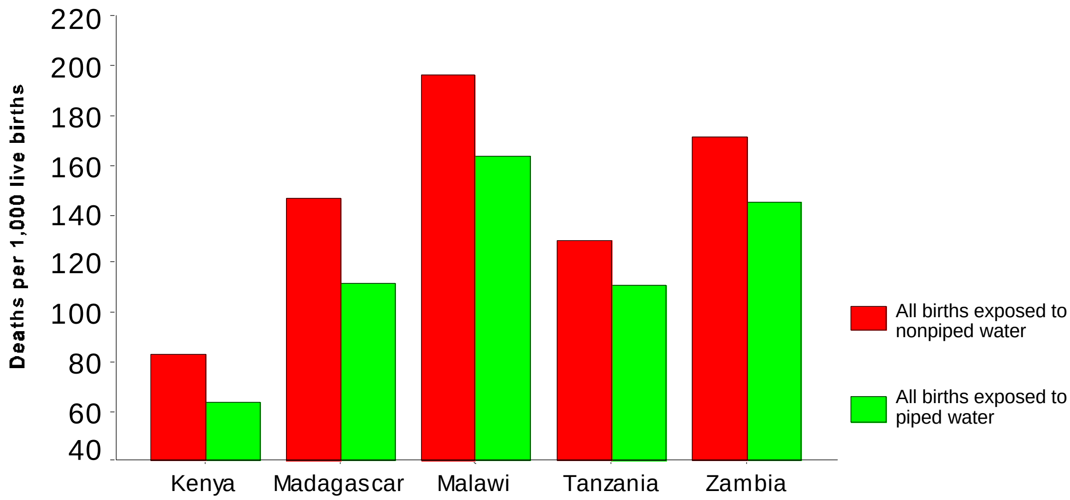
[7]A related study with similar findings is DaVanzo (1988).

Figure 1 Impact of drinking water source on early child mortality



Source: Brockerhoff (1995).

infant mortality. A key finding was that the presence of *both* improved water and sanitation had the biggest impact in terms of reduced mortality. Merrick (1985) finds that in Brazil, piped water in the home led to larger reductions in preschooler mortality among low-income households.

Studies on the impact on mortality among older children and adults are rare. Using more aggregated data, Knight and Song (1993) find that access to safe water in rural China reduces mortality rates of children under 15, though it has no significant effect on infants under one.

IMPACT OF IMPROVED WATER SUPPLIES ON DIARRHEA

This area has been extensively studied, especially within the public health literature with respect to the effect of water supply on the incidence of diarrhea. Esrey et al.'s (1991) review finds that in the majority of studies, improvements in water quality reduced the incidence of diarrhea. Further, “. . . of the 15 studies that examined the effect of increased amounts of water specifically and independently of water quality, all but one reported a positive impact" (p. 613). Studies using the framework set out in Section 2 are comparatively rare. The best example is that of the Cebu Study Team (1992), who examined the incidence of diarrhea in rural and urban areas of Cebu, the Philippines. They estimate a health production function, carefully taking into account the endogeneity of many right-hand-side regressors. They find that contamination of the households' source of water is associated with greater incidence of diarrhea in children under 1 year in urban areas, but not in rural areas.[8] In a three-country study, Haddad et al. (1995) found that if the source of water was artesian, the probability of experiencing diarrhea was higher among preschoolers in the Philippines. However, access to piped water or water from protected wells had no effect on the incidence of diarrhea among preschoolers in Ethiopia or Pakistan. VanDerslice and Briscoe (1995) take this analysis one step further and consider the joint impact of water and sanitation interventions in Cebu. The positive impact of improved water is greatest for families living under good sanitary conditions; reducing the concentration of fecal coliforms by two orders of magnitude leads to a 40-percent reduction in diarrheal incidence. Improved drinking water has no effect in neighborhoods with poor sanitation.

Five papers—by Briscoe (1984b); Esrey, Feachem, and Hughes (1985); Esrey and Habicht (1986); Esrey et al. (1991), and Burger and Esrey (1995)—summarize the many studies examining the impact of improvements in water quality, quantity, and sanitation on diarrheal morbidity. Figure 2, based on Esrey et al. (1991), gives a flavor of the results found in these reviews. For example, among those studies that satisfy certain

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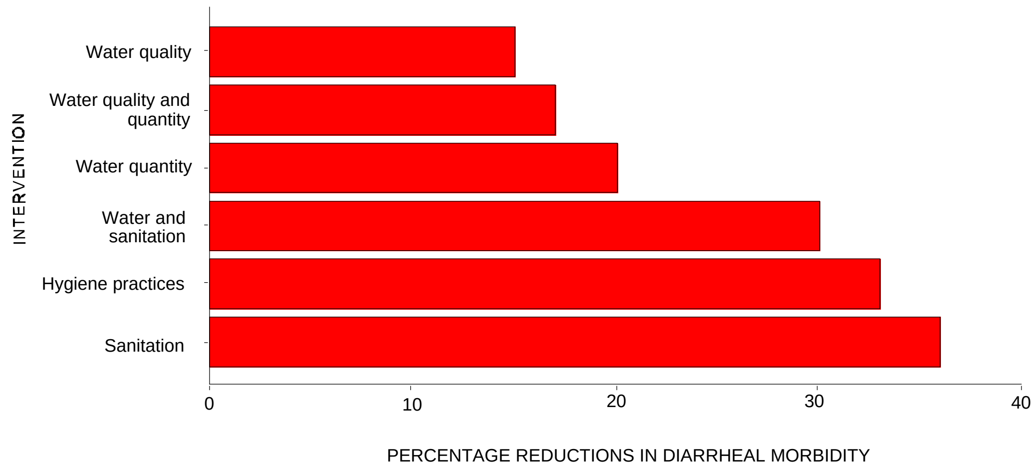
[8]VanDerslice and Briscoe (1993) take this analysis one step further. They investigate, using the same data set, the causes of diarrhea in infant, including as separate regressors water contamination at source and in the house. They find that contamination at source has a much bigger impact on the likelihood of diarrhea whereas water contamination at the household level has no significant impact on the incidence of diarrhea. Their explanation is that contaminants within the household are the result of intrahousehold transmission of diarrheal pathogens and that, over time, household members will build up immunity to these via prior exposure. They also interact water quality at source with boiling water (which they endogenize) and find that this offsets the impact of contaminated water.

methodological criteria, they find that interventions that focus both in water and sanitation lead to a median reduction in morbidity from diarrheal diseases of 26 percent.

Figure 2 suggests that the impact of various interventions can be ordered from most- to least-effective in the following fashion: improving household sanitation and hygiene practices; improving both quality and quantity of water supplies; increasing quantity and improving quality. This ordering results from the manner in which diarrhea can be contracted. First, diarrhea can occur following the ingestion of water contaminated with the infectious agents of diarrhea. In addition, water containing pathogenic bacteria, at doses below those necessary to infect humans, may be used for the preparation of food, at which time the bacteria may incubate and multiply in the food. Viral and protozoal agents of diarrhea, which do not multiply outside of their hosts, may also be transmitted in this manner (Esrey and Habicht 1986).

Thus, knowledge of these routes of transmission is important in preventing diarrhea. Clemens and Stanton (1987) examine the impact of three educational interventions designed to alter water-sanitation behaviors in Bangladesh: proper hand washing before food preparation; defecation away from the house in a proper site; and suitable disposal of waste and feces thus preventing access to waste products by young children. Although households in the study appeared to only act upon the first of these recommendations, there was a striking fall in the incidence of diarrhea in the intervention areas. However, such knowledge is only useful when there is provision and use of sufficient quantities of water for personal and domestic hygiene, so as to permit the washing of hands, food, and utensils in order to reduce the major infectious

Figure 2 Impact of water and sanitation interventions on diarrheal morbidity



Source: Esrey et al. (1991).

agents of diarrhea.[9] Gilman et al. (1993) find that mothers in a Peruvian shantytown were well aware of the importance of good hygiene practices, but problems with water availability meant that these were not always followed. Increasing the quantity of water available may permit greater frequency of food preparation, thus reducing the consumption of contaminated food products (Briscoe 1984b; Esrey and Habicht 1986).

Additionally, improvements in the disposal of feces are important in reducing the prevalence of diarrheal agents within the household.[10] Burger and Esrey comment,

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[9]Increasing the quantity of water available may permit greater frequency of food preparation, thus reducing the consumption of contaminated food products (Briscoe 1984b; Esrey and Habicht 1986).

[10]Note that the type of sanitation facility may also be important. Pickering et al. (1987) find that in urban Gambia, children in households with a latrine present have a slightly higher number of episodes than those children in households with no sanitation facilities, whereas those with a flush toilet had a lower incidence.

> . . . proper disposal of contaminated feces may reduce the number of pathogens being transmitted through several routes of exposure such as food, hands, and drinking water. Once in the environment, pathogens may not only survive and disperse but thrive in food or media that is ingested by young children (pp. 157-158).

However, access to proper sanitation does not guarantee that they will be used. The Imo State Evaluation Team (1989) found that even with the construction of improved latrines, children aged 2-5 continued to use bushes or fields and children 12-23 months defecated in or around the home.

A key implication of these studies is that reducing one pathway of transmission, but permitting others to remain in place, is unlikely to lead to dramatic drops in morbidity. Rather, knowledge of hygienic practices *plus* improvements in sanitation *plus* use of greater quantities of water is likely to lead to the largest improvements. Young and Briscoe's (1987) study of the effect of environmental sanitation on diarrhea morbidity in Malawi exemplifies this. They find that combining improvements in water supply *and* the presence of a latrine in the household reduces the likelihood that a child gets diarrhea, controlling for child age, feeding practices, per capita water consumption, and maternal characteristics. (Note that the study is flawed, because as Section 2 indicates, water consumption is a choice variable.)

Conversely, improving water quality has the smallest impact, because it fails to address these other pathways. This is exemplified by a series of studies of the impact of the provision of borehole supplies of water in several rural communities in Imo State, Nigeria, reported in Huttly et al. (1987, 1990); Blum et al. (1990); and the Imo State Evaluation Team (1989). Although water quality at the borehole was relatively good, it deteriorated in the carrying containers and after storage. It was further contaminated by individuals whose hands would come into contact with water when taking water from a storage container for a drink.

An important aspect to note is the age pattern in diarrheal illness. A number of studies find incidence and severity most pronounced among 6-to-12-month-old children (Martorell et al. 1975; Kirkwood 1991). Children younger than six months are less at risk, provided they are exclusively breast-fed. VanDerslice, Popkin, and Briscoe (1994) find that among urban Filipino infants in the first six months of life (Cebu City), administration of just a small quantity of contaminated water supplements nearly doubles the risk of diarrhea.[11] Children in the 6-to-12-month age group are typically being introduced to weaning foods that, being prepared with water, exposes them for the first time to diarrheal pathogens. They also become more mobile; this may lead to contact and ingestion of pathogens.

Finally, Esrey, Feachem, and Hughes (1985) examine whether the impact of water and sanitation interventions vary by characteristics of the household. They compare reductions in diarrhea morbidity by magnitude of service improvement and adult literacy rate in the country in which the study was situated.

They find that large service improvements have a much greater effect on reducing diarrheal morbidity. More interesting is the inverse relationship they find between adult literacy and mean improvements. The biggest fall occurs when large service improvements are correlated with low levels of literacy. One interpretation is that better educated parents are better able to protect their children's health, even when the environment is poor; so that improvements in services have a bigger impact on the offspring of those less well-educated. This is not the only interpretation. Adult literacy could be proxying, for example, income levels.

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[11]They find that poorer household water quality and no private excreta disposal increased the likelihood of infection. Poor community sanitation had no effect, but when community sanitation is interacted with exclusive breast-feeding, it increased infection but the interaction term reduces it. Note that they treat breast-feeding as exogenous. Also, they divide the sample by community sanitation. Communities with good sanitation, poor water quality, no private excreta disposal, and excreta in the yard all raise incidence. In households residing in areas with poor community sanitation, neither water quality nor excreta in the yard are significant.

IMPACT OF IMPROVED WATER SUPPLIES ON DRACUNCULIASIS, HOOKWORM INFECTION, SCHISTOSOMIASIS, AND TRACHOMA

Esrey et al. (1991) summarize the literature of the impact of improved water and sanitation on a number of other diseases: ascariasis (roundworm), dracunculiasis (guinea worm), hookworm infection, schistosomiasis, and trachoma (Table 1).

Table 2 gives a more detailed examination of these studies and indicates that better sanitation has a more potent effect on reducing morbidity from ascariasis, hookworm, and schistosomiasis than does improved drinking water. Additionally, improving the quality of water used in domestic and/or personal hygiene has a more marked effect on ascariasis, trachoma, and schistosomiasis. For example, a Kenyan study (Kholy et al. 1989) found that the installation of boreholes, but not laundry or shower facilities, failed to reduce the households reliance on high-risk marshes and ponds for bathing and thus had minimal impact on schistosomiasis. Indeed, only dracunculiasis would appear to respond dramatically to improving the quality of drinking water. Esrey et al. (1991) summarize the relationship between water and sanitation interventions and morbidity from these diseases. They note that interventions with a positive impact will have a more powerful effect when part of a package (Table 2).

There are few studies that follow the framework outlined in Section 2; these focus on the impact of water quality. Cohen (1988), estimating a reduced-form demand function, finds no impact on "recent child illness" for urban Sudanese children. Pitt and Rosenzweig (1985) also estimate a reduced-form demand function on severity of illness. They do not find any significant effects of water supply on adult male and female illness, but do find that the presence of public lavatories worsens adult female

Table 1 Expected percentage reductions in morbidity from improved water and sanitation for selected diseases ("better studies only")

Disease	Number of Studies (N)	Median Reduction	Range of Reduction
		(percent)	(percent)
Ascariasis	4	29	15-83
Dracunculiasis	2	78	75-81
Hookworm	1	4	-
Schistosomiasis	3	77	59-87
Trachoma	7	27	0-79

Source: Esrey et al. (1991).

Table 2 Relations between water and sanitation interventions and morbidity from selected diseases

	Improved Drinking Water	Water for Domestic Hygiene	Water for Personal Hygiene	Human Excreta Disposal
Ascariasis	+	++	-	++
Dracunculiasis	++	-	-	-
Hookworm	-	-	-	++
Schistosomiasis	-	++	++	++
Trachoma	-	+	++	-

Note: "Interventions marked with one or two pluses have an impact on a particular disease: an intervention marked '++' will have a stronger impact than one marked '+'; '-' the intervention has little or no impact" (Esrey et al. 1991, 610).

health. Appleton (1992) examines the impact of water quality on the incidence and duration of illness among adults and children in Côte d'Ivoire, Kenya, and Tanzania. In terms of incidence,

> Nowhere did piped water have significantly favorable effects when compared with the default of getting water from a river or stream. Moreover, it often had significant unfavorable effects. . . it increases the incidence of illness among adults in urban Côte d'Ivoire and children in rural Côte d'Ivoire. It has the same effect on females in three other rural subsamples: adults in rural Côte d'Ivoire, children in Kenya, and adults in Kenya" (p. 241).

Similar adverse effects are generally found in terms of the impact on duration of illness.

IMPACT OF SAFE WATER ON ANTHROPOMETRIC MEASURES

Esrey, Feachem, and Hughes (1985) summarize early studies within the public health literature from five countries. In Bangladesh, improvements in both quality and availability have no impact on height or weight and these have only a minor impact on weight-for-age in the Philippines. By contrast, increased availability improves height-for-age and weight-for-height in Colombia and weight-for-age in Saint Lucia. Results from Nigeria are more puzzling, with improvements in availability improving weight measures but adversely affecting height. Huttly et al. (1990) find that the Imo State (Nigeria) drinking water supply and sanitation project lead to an improvement in weight-for-height but not for height-for-age for children under the age of three years. This would appear to reflect improved water quality, as they recorded no increase in quantity consumed. Esrey, Habicht, and Casella (1992) find that ownership of latrine and increased water usage together generate better child health in terms of both weight and length gain in rural Lesotho. Using the same sample, Esrey et al. (1988) report that children whose families relied exclusively on the new water supply for their drinking and cooking needs grew 0.438 centimeters and 235 grams more in six months than children whose families supplemented the new water supply with the use of contaminated traditional water for drinking and cooking. However, their results are based on regressions that include a number of choice variables such as breast-feeding and frequency of bathing.

There are a number of economic studies, broadly utilizing the framework set out in Section 2, that examine the impact of improved water access on height and weight, though these, too, focus solely on water quality. Across the nine studies summarized in Table 3, five find that better water quality improves child height, three find no effect, and one finds a deterioration. Both studies that examine weight-for-height report a positive impact.

A number of the studies within the economics literature explore the interaction between safe water and other household characteristics. Barrera (1990) finds that safe water effects are highly age dependent. For example, there is a small positive effect for older children (11-15 years) but a big negative effect for children 0-2 years. However, when this variable is interacted with maternal education, he finds that height-for-age improves with improved water supplies for less well-educated mothers. Thomas and Strauss (1992) interact their measure of access to safe water (number of buildings with water connections per 1,000 people) with per capita expenditures. In both urban and rural areas, the interaction term is *positive*, though only significant in rural areas. They speculate that unobserved water quality is better in areas where high-income households live.

Esrey's (1996) multivariate analysis using Demographic and Health Survey data from eight countries is the only study that interacts household sanitation with water supply. As in the literature on diarrheal morbidity, improved water quality only improves child height and weight when sanitation is also improved.

Table 3 Studies within the development economics literature that examine the impact of safe water supplies on child health

Study	Country	Findings
Hoddinott and Kinsey (1996)	Zimbabwe	Improves height-for-age improves weight-for-height
Thomas and Strauss (1992)	Urban Brazil	Improves height-for-age
Thomas and Strauss (1992)	Rural Brazil	Worsens height-for-age
Thomas, Strauss, Henriques (1991)	Brazil	No effect on height-for-age
Strauss (1990)	Cote d'Ivoire	Improves height-for-age
Barrera (1990)	Philippines	No effect on height-for-age
Hossain (1989)	Bangladesh	No effect on height-for-age
Horton (1988)	Philippines	Improves height-for-age Improves weight-for-height
Horton (1986)	Philippines	Improves height-for-age

4. THE IMPACT OF IMPROVED WATER SUPPLY ON TIME ALLOCATION AND INCOME

TIME ALLOCATION

In a widely cited study, Cairncross and Cliff (1987) compared women's time allocations in two Mozambican villages. One, Namaua, had a standpipe in the main village square. In the other village, Itanda, women had to make a two-hour round-trip to collect one 30-litre bucket of water *plus* queue for an additional three hours. Women's time allocation in the two villages is given in Figures 3a and 3b.

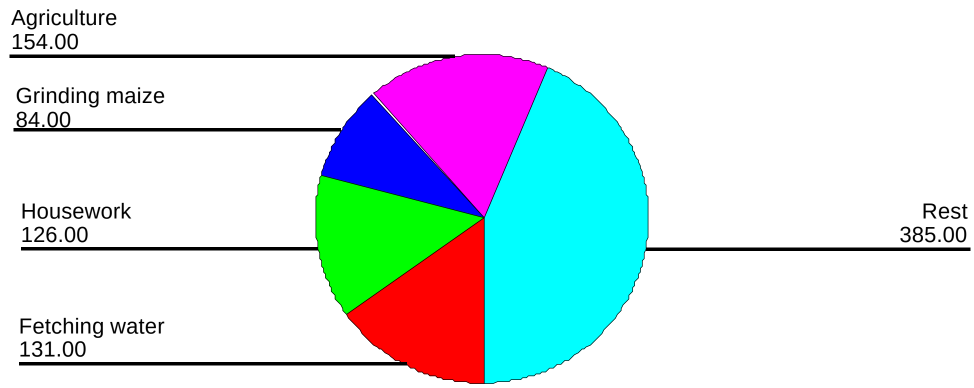
Women in Namaua spend much more time "at rest" (eating, personal hygiene, meetings, and relaxing) than do women in Itanda. Increased amounts of time are also devoted to "housework" (food preparation, breast-feeding, bathing children, cleaning, collecting firewood).[12] Cairncross and Cliff also find that in Namaua, much more water is used for bathing, washing dishes and food, and washing clothes, although this is not quantified. Blum et al. (1987) found that the provision of piped water in Imo State, Nigeria, reduced median daily collection times from 6 hours to 45 minutes in the dry season. However, they found that improved water availability had no effect on increasing usage rates. By contrast, although total collection times did not fall in a Kenyan study, closer proximity to water supplies resulted in more frequent trips and greater use of water.

Burger and Esrey (1995) report the findings of a number of unpublished studies on women's use of time released as a result of closer water supplies. These include operating home gardens (Thailand, Peru, Panama, Malawi, and the Philippines); agricultural work (Ghana); livestock and small stock tending (Thailand, Peru, Malawi, and the Philippines); and nonagricultural enterprises (Thailand, Malawi, and the Philippines).

It has not been possible to find a published study as to what extent labor is reallocated within the household, though Burger and Esrey (1995) report an unpublished study that found that assistance from other family members in water collection declined when improved water sources were introduced in Kenya, Guatemala, and Mexico.

[12]Esrey (personal communication) notes an unpublished Guatemalan study that finds that women save around 350-500 kilocalories per day if water is brought closer to home. Time is reallocated to weaving, child care, and leisure.

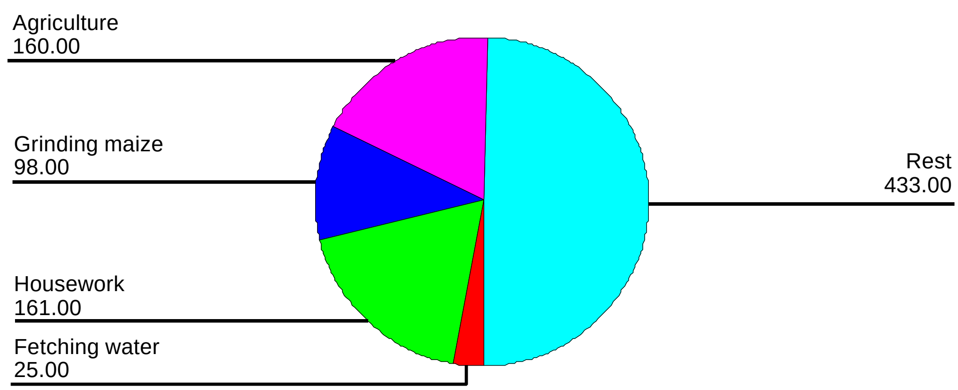
Figure 3a Women's time allocation in Itanda, Mozambique



Source: Cairncross and Cliff (1987).

Time expressed in minutes per day.

Figure 3b Women's time allocation in Namaua, Mozambique



Source: Cairncross and Cliff (1987).

Time expressed in minutes per day.

There are few studies that examine whether better water, by reducing the incidence of various illnesses, reduces time spent looking after ill children. Bentley et al. (1995, 68) report that "mothers alter their usual activity patterns only slightly in response to acute diarrhea episodes" in rural Peru. This suggests that gains in time for adults may be minimal. However, Pitt and Rosenzweig (1990, 985) find that in Indonesia, "teenaged daughters were significantly more likely to increase their participation in household care activities, to decrease their participation in market activities and to drop out of school compared to teenaged sons in response to increases in infant morbidity."

INCOME

There are few studies that examine the impact of improved water access on household incomes. Chippaux, Banzou, and Agbede (1992) estimate that the annual cost of dracunculiasis is 16,000 CFA francs per patient or 15 percent of workers' income in Benin. Brieger and Guyer (1990) find that the average duration of guinea worm infection is long, about 15 weeks. However, they note,

> It becomes obvious in the context of peasant agriculture that days down to illness do not always translate into direct financial loss. The timing of the illness may not coincide with the planting of a particular crop. The duration of the illness may be short enough for the farmer to compensate for the days lost. Some crops have flexible planting dates. The disability level may be small enough to allow the farmer to get around (p. 109).[13]

Verma and Srivastava (1990) attempt to measure the cost of workdays lost as a result of malaria, acute diarrheal diseases, trachoma and conjunctivitis, and scabies in terms of foregone income and expenses. Drawing on data from three villages in rural India, they

[13]Farmers' in their sample claimed that average income loss from guinea worm was around $300, but this was not verified.

multiply days lost as a result of illness by average per capita daily income to arrive at a figure for lost income. For example, they estimate that diarrheal disease costs each person (in 1981 U.S. dollars) around $3.40 per day. However, they do not appear to differentiate among the loss of labor by different household members, which would seem to be a rather questionable procedure. Nor do they take into account the possibility that adult illness may lead to a reallocation of tasks among other household members.

There are virtually no studies that quantify the impact of water access on adult productivity in either agriculture or in the labor market.[14] Nor has any study attempted to link the indirect effects of better water supply on adult productivity to increases in the use of goods that could enhance child health.

A rough indication of the consequences of ill-health caused by poor water supply during childhood on adult earnings is provided by Pinstrup-Andersen et al. (1993). They combine Martorell's (1995) argument that growth lost in early childhood is lost permanently with Haddad and Bouis's (1991) examination of the impact of height on wages. They find that height reduction in childhood leads to estimated losses in labor productivity of 8.63 percent for severely stunted individuals and 6.04 percent for the moderately stunted. Assuming a daily wage of $2.50 and a working year of 300 days, they estimate that the global annual economic loss in income due to stunting is $8.68 billion.

An alternative approach to this issue is taken by Whittington, Mu, and Roche (1990). They estimate the value of time spent collecting water by comparing choices made by Kenyan households who purchase water from a kiosk against the opportunity of collecting water from a free, public source, which is not as close. They value the time spent collecting this free water, in terms of the money that they would have otherwise had to pay the vendor, at US$0.31 per hour, a figure 25 percent higher than the market wage for unskilled work.

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[14]The exception is a study by Barbosa and Pereira da Costa (1981), who find significant productivity losses due to severe cases of schistosomiasis among sugarcane cutters in Brazil. Also, see Wiemer (1987).

5. SUMMARY AND DIRECTIONS FOR FUTURE STUDY

One consistent finding emerges from studies that examine the impact of improved water access on health, whether these be studies of mortality, diarrheal or other disease morbidity, or anthropometric measures. A hierarchy of interventions can be ordered from most-to-least effective in the following fashion: improvements in household sanitation and hygiene practices; improving both quality and quantity of water supplies; increasing quantity of water consumed and improving water quality. However, improvements in only one of these is unlikely to lead to dramatic drops in morbidity. The whole is greater than the sum of the parts; knowledge of hygienic practices *plus* improvements in sanitation *plus* use of greater quantities of water tends to lead to the largest improvements.

Unfortunately, this finding is not sufficient to form a basis for policy. First, there is substantial scope for methodological improvement. Studies within the public health literature often rely on "intervention" and "control" comparisons. Although this is an excellent idea in principal, comparability across sites is often limited to a few key variables. Unobserved community characteristics—Ω in Section 2's health demand functions—are not taken into account. Within the economics literature, interventions are typically expressed in terms of improvements or changes at the community level, such as access to piped water and sometimes travel times. This neglects the important finding in the public health literature that it is water quantity, not quality, that is of greater importance. Economic studies have failed to pick up the distinction between quality at the source and quality at the point of consumption, even though these may differ dramatically. Indeed, by typically examining only water quality at the community level, economists appear to focus their efforts on the least powerful intervention! Not all studies include measures of sanitation or their interaction with access to water. As VanDerslice and Briscoe (1995) emphasize, this makes interpretation of their results difficult. Those studies that do control for sanitation typically fail to recognize that this is, in fact, a choice variable on the part of the household. Basic econometric theory demonstrates that the inclusion of an endogenous variable can generate biased parameter estimates, yet this does not appear to have been incorporated into this literature.[15] Finally, a common methodological flaw is to ignore considerations of endogenous program placement and selective migration. If the intervention is not exogenous, this contaminates both the demand and structural functions described above and renders it impossible to evaluate changes in distribution as described here (Deaton 1995; Strauss and Thomas 1995).

Second, the full economic returns to improved water access are unknown. As Section 2 shows, it is relatively straightforward to hypothesize potential effects. Unfortunately, the few extant studies are, at best, only partial analyses and are often marred by strong and unrealistic assumptions. For example, the approach taken by Verma and Srivastava (1990) implicitly assumes that a day of illness translates into a day of lost labor. This neglects, inter alia, the following possibilities: that this represents a loss of leisure as opposed to work; that other household members could reduce labor time spent in other activities; or that labor could be hired in. Valuing this time lost at average per capita daily income is also incorrect as it neglects the issue of timing of illness. A day's illness might be more costly to a household during the planting season if that season is short and labor markets function poorly than it would if the planting period was longer or if the illness occurred outside the agricultural season. Nor does such an analysis take account of the loss of productivity while working. There is no study that links water access to adult health to returns to adult labor while working. Vulnerability to illness might have more subtle effects on income, in terms of choice of crops grown or activities entered into. No study exists that examines the second-round effects on health generated by these interventions. Finally, the full economic returns to improved water access also includes future income that accrues to today's children, who achieve greater gains in

[15] In fact, as noted in several places in Section 2, the inclusion of other endogenous variables in these analyses is all too common.

height during infancy and early childhood. Estimation of these gains depends critically on the assumptions made about catch-up growth.

The lack of detailed analysis of the distributional consequences of improved water access within communities and within households is striking.[16] There are a myriad of possibilities. If the rich are better able to smooth consumption in the face of shocks to income such as illness, reducing the incidence and severity of illness caused by poor water access will have positive effects on distribution because their benefits will accrue primarily to those less well-off. The mean impact could be quite small, but concentrated among those most in need of assistance. Alternatively, the mean impact might be large, but concentrated entirely in the top half of the distribution—those who are healthy become healthier, while those who are less healthy see little change in their plight. Suppose the time taken to collect water is reduced. If poor households' ability to generate more income is not constrained by time, but instead by lack of access to other inputs, they might not be able to increase income, whereas a richer household might be in a better position to do so. Note, too, that the metric for measuring distribution will matter here. If the poor family uses the time freed up to increase the amount of time spent on child care, it is possible that a distribution of child health will improve, whereas the distribution of income will worsen. Nor has anyone properly assessed the distributional consequences within households. Who *really* benefits, in terms of time allocation and gains in health and incomes, when access to water is improved: women, men, children?[17]

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[16]The existing literature provides no strong conclusions. Compare two Brazilian studies reviewed here. Merrick (1985) finds that improved water supply has a larger effect on child mortality among poorer households; Thomas and Strauss (1992) argue that better water access has a greater impact on the health of children in better-off households.

[17]Conceptually, a number of approaches suggest themselves. The model developed by Pitt, Rosenzweig, and Hassan (1990), in which an intervention that benefits a particular household member is re-distributed according to household concerns regarding equity and efficiency, is one possibility. Another area of investigation is whether changes in water access have distributional consequences in the context of a collective household model. For example, in Chiappori's (1997) model, does such an intervention change the household sharing rule?

From a policy perspective, it would be desirable to measure the cost-effectiveness of interventions that improve access to water. What is the marginal impact of an additional dollar spent on reducing travel times or improving water quality or better knowledge of water practices or improved sanitation? Are interventions more cost-effective when introduced as a package or when introduced individually? Should interventions aim to eliminate a pathway of infection, or make more marginal improvements in all pathways? Given the many omissions in the literature, it is not possible to undertake such a calculation. Such an exercise would also have to contend with the problem of aggregating and comparing heterogenous outcomes over a heterogenous population. Additional methodological issues are noted by Burger and Esrey (1995). Is the intervention targeted to eliminate the main route to pathogen exposure? How sensitive is its impact, given actions already being undertaken by the population being studied? Finally, the measurement of costs is far from straightforward, as Hammer (1993), Martines, Phillips, and Feachem (1993), and Okun (1988) make clear.[18]

Accordingly, analysis of the economic returns to improved water access, and studies that explore the distributional consequences of such interventions, represent areas in which research could provide valuable insights. Such studies, together with further analysis of the impact on health that take into account the methodological criticisms noted above, will permit a fuller understanding of the cost-effectiveness of improved water access. In addition, future work will benefit from a multidisciplinary approach. Individuals working within one discipline make remarkably little reference to work undertaken in other disciplines—the absence of any reference in economic studies to the importance of quantity of water consumed in improving health, a major theme of the public health literature for at *least* 10 years—being a striking, but by no means the only, example. There is substantial merit in combining several approaches in any new study.

[18]Given these difficulties, some authors argue that such an exercise is counter-productive and that priority should instead be attached to services that people are willing to pay for (VanDerslice and Briscoe 1995).

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