Global cost-benefit analysis of water supply and sanitation interventions

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ABSTRACT

The aim of this study was to estimate the economic benefits and costs of a range of interventions to improve access to water supply and sanitation facilities in the developing world. Results are presented for eleven developing country WHO sub-regions as well as at the global level, in United States Dollars (US$) for the year 2000. Five different types of water supply and sanitation improvement were modelled: achieving the water millennium development goal of reducing by half in 2015 those without improved water supply in the year 1990; achieving the combined water supply and sanitation MDG; universal basic access to water supply and sanitation; universal basic access plus water purification at the point-of-use; and regulated piped water supply and sewer connection. Predicted reductions in the incidence of diarrhoeal disease were calculated based on the expected population receiving these interventions. The costs of the interventions included estimations of the full investment and annual running costs. The benefits of the interventions included time savings due to easier access, gain in productive time and reduced health care costs saved due to less illness, and prevented deaths. The results show that all water and sanitation improvements are cost-beneficial in all developing world sub-regions. In developing regions, the return on a US$1 investment was in the range US$5 to US$46, depending on the intervention. For the least developed regions, investing every US$1 to meet the combined water supply and sanitation MDG lead to a return of at least US$5 (AFR-D, AFR-E, SEAR-D) or US$12 (AMR-B; EMR-B; WPR-B). The main contributor to economic benefits was time savings associated with better access to water and sanitation services, contributing at least 80% to overall economic benefits. One-way sensitivity analysis showed that even under pessimistic data assumptions the potential economic benefits outweighed the costs in all developing world regions. Further country case-studies are recommended as a follow up to this global analysis.

Key words | cost-benefit analysis, costs, economic benefits, sanitation, water supply

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INTRODUCTION

In the developing world, diseases, associated with poor water and sanitation have considerable public health significance. In 2004, it was estimated that 4% of the global burden of disease and 1.6 million deaths per year were attributed to unsafe water supply and sanitation (WS&S), including inadequate personal and domestic hygiene (Prüss *et al.* 2002; World Health Organization 2003). This corresponds to 61 million disability-adjusted life-years lost (DALYs), taking into account burden of disease due to both morbidity and mortality. While there has been considerable investment in water and sanitation in developing countries since the 1980s, in 2004 an estimated 1.1 billion people were without access to safe water sources and 2.6 billion people lacked access to basic sanitation (WHO & UNICEF 2006). Nearly 80% of the people using water from unimproved sources are concentrated in three

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regions: sub-Saharan Africa, Eastern Asia and Southern Asia. In sub-Saharan Africa progress was made from 49% coverage in 1990 to 56% in 2004. For sanitation overall levels of use of improved facilities are far lower than for drinking-water - only 59% of the world population had access to any type of improved sanitation facility at home in 2004 (from 49% in 1990) (WHO & UNICEF 2006).

In order to increase the rate at which new populations have access to improved water supply and sanitation services, further advocacy is needed at international and national levels to increase the resource allocations to these services, and at population level to increase service uptake. In the current climate where poverty reduction strategies dominate the development agenda, the potential productivity and income effects of improved services is a significant argument to support further resource allocations to water supply and sanitation. While cost-effectiveness analysis is the method of choice for resource allocation decisions in the health sector (Tan-Torres Edejer *et al.* 2003), at present cost-benefit analysis remains the form of economic evaluation most useful for resource allocation between government-financed activities and within productive sectors (Hutton 2000; Curry & Weiss 1993; Layard & Glaister 1994). In this discussion it is important to distinguish between social cost-benefit analysis, which measures the overall welfare impact of interventions, and financial cost-benefit analysis, which measures only the direct financial implications of an intervention. The former – social cost-benefit analysis – is advocated for use in government decisions as it is more comprehensive, reflecting an intervention's overall impact on societal welfare.

In essence, an economic evaluation compares the value of all the quantifiable benefits gained due to a specific policy or intervention with the costs of implementing the same intervention. If benefits and costs are expressed in a common monetary unit (such as US dollars), as in cost-benefit analysis, it is possible to estimate if the total benefit of an intervention exceeds the total cost, and the annual rate of return on the investment. While there are many criteria for allocating resources between different ministries and government programmes, the relative economic costs and effects of different programmes and interventions remains an important one (Drummond *et al.* 1997). Furthermore, by identifying who benefits in welfare terms from development activities, cost-benefit analysis can assist in the development of equitable but sustainable financing mechanisms. Ideally, both costs and benefits should be disaggregated by different government ministries, donors, private households, commercial enterprises, and so on. Therefore, cost-benefit analysis should not only aim to provide information on economic efficiency, but also provide other policy-relevant information on who benefits and therefore who may be willing to contribute to the financing of interventions.

Despite the substantial amount of resources being allocated to water and sanitation activities worldwide, there are surprisingly few published economic evaluations of water and sanitation interventions (Hutton 2001). The grey literature is richer in different types of economic analysis, especially Development Banks (e.g. World Bank) through their process of project assessment before a project is financed. One global cost-benefit analysis was previously published by the World Health Organization, and those results have been revised for this present paper (Hutton & Haller 2004). A cost-effectiveness analysis of the same sets of interventions is published in this issue (Haller *et al.* 2007).

METHODS

Interventions

The range of options available for improving water supply and sanitation services is wide. The analysis presented in this paper was based on changes in water supply and sanitation service levels. In this analysis, 'improved' water supply and sanitation refer to low technology improvements:

- 'Improved' water supply generally involves better physical access and the protection of water sources, including stand post, borehole, protected spring or well or collected rain water. Improvement does not mean that the water is necessarily safe, but rather that it meets minimum criteria for accessibility and measures are taken to protect the water source from contamination.
- 'Improved' sanitation generally involves physically closer facilities, less waiting time, and safer disposal of excreta, including septic tank, simple pit latrine, or ventilated improved pit-latrine.

There are also further improvements which make the water or sanitation services safer, or more convenient:

- Water disinfection at the point of use. In this study, the use of chlorine is examined.
- Personal hygiene education.
- Regulated water supply through a household connection, giving water that is safe for drinking, and sewer connection, where sewage is taken away for off-site treatment and disposal.

Based on these different improvements, five "interventions" were modelled in this study, by assuming a shift between different exposure scenarios (Prüss *et al.* 2002) (also see Haller *et al.* 2007):

1. Water supply MDG: Halving the proportion of people who do not have access to improved water sources by 2015, with priority given to those already with improved sanitation.
2. Water supply and sanitation MDG: Halving the proportion of people who do not have access to improved water sources *and* improved sanitation facilities, by 2015 (millennium development goal 7, target 10).
3. Universal basic access: Increasing access to improved water and improved sanitation services to reach universal coverage by 2015.
4. Universal basic access plus point of use treatment: Providing household water treatment using chlorine and safe storage vessels, on top of improved water and sanitation services, to all by 2015. Although a recent review has shown the costs and health effects of point-of-use treatment to vary considerably between filtration, chlorination, solar disinfection and flocculation/disinfection (Clasen 2006), chlorination was chosen as one of the simplest and lowest cost options, at US$0.66 per capita per year.
5. Regulated piped water supply and sewer connection: Increasing access to regulated piped water supply and sewage connection in house, to reach universal coverage by 2015.

All the interventions were compared to the situation in 1990, which was defined as the baseline year for the MDG targets. Therefore, account is taken of the proportion of populations in each country who did not have access to 'improved' water and sanitation services in the baseline year (WHO/UNICEF/JMP 2000). The time horizon chosen in this analysis is 2015, reflecting the Millennium Development Goal target year and the end of the International Decade 'Water for Life'. Population projection until the year 2015 has been taken into account, using projected population growth rates by country from United Nations Statistics Division. Costs and benefits are presented in terms of equivalent annual value, based on the assumption that the targets are met by the year 2015.

Geographical focus

The population of the globe was separated into subgroups of countries on the basis of having similar rates of child and adult mortality. This resulted in 11 developing country epidemiological sub-regions characterized by the WHO sub-regions: AFR-D and AFR-E (African Region); AMR-B and AMR-D (Region of the Americas); EMR-B and EMR-D (Eastern Mediterranean Region); EUR-B and EUR-C (European Region), SEAR-B and SEAR-D (South East Asia Region) and WPR-B (Western Pacific Region). The letters B, C and D reflect the mortality stratum of each sub-region (Appendix A). This study was conducted at the country level, and the results aggregated (weighted by country population size) to give the eleven developing country WHO sub-region averages.

Cost measurement

The cost analysis is an incremental cost analysis, with estimation of the costs of extending coverage of water supply and sanitation services to those currently not covered. Incremental costs consist of all resources required to put in place and maintain the interventions, as well as other costs that result from an intervention. These are separated by investment and recurrent costs, reported in Haller *et al.* (2007). Investment costs include: planning and supervision, hardware, construction and house alteration, protection of water sources and education that accompanies an investment in hardware. Recurrent costs include: operating materials to provide a service, maintenance of hardware and replacement of parts, emptying of septic tanks and latrines, ongoing protection and monitoring of water sources, and continuous education activities. For the more advanced intervention 'regulated piped water supply and sewer connection', the costs of water treatment and distribution, sewer connection and sewage treatment, and regulation and control of water supply are also included.

For the initial investment cost of WS&S interventions, the main source of cost data inputs was the data collected for the Global Water Supply and Sanitation Assessment 2000 Report (World Health Organization & UNICEF 2000), which gave the investment cost per person covered in 3 major world regions (Africa, Latin America and the Caribbean, and Asia/Oceania), presented in Haller *et al.* (2007). The source of cost data for water purification using chlorination at the point of use was taken from a more recent study (Clasen 2006).

The estimation of running costs was, however, problematic due to lack of previous presentation of recurrent and investment costs in the peer-reviewed literature. Therefore, an internet search was conducted to identify expenditure statements (or budgets) of water and sanitation projects such as those of development banks, bilateral governmental aid agencies, and non-governmental organisations. The data extracted from this literature allowed estimations to be made of the annual per capita recurrent costs as a proportion of the original annual investment costs per capita, for different intervention and technology types. The recurrent cost data inputs are provided in Haller *et al.* (2007).

Health effects

Knowledge of the health effects of the five interventions is important not only for a cost-effectiveness analysis, but also for a cost-benefit analysis as some important economic benefits depend on estimates of health effect. Over recent decades, compelling evidence has been gathered that significant and beneficial health impacts are associated with improving water supply and sanitation services (Fewtrell *et al.* 2005). The analysis has been restricted to infectious diarrhoea as it accounts for the main disease burden associated with poor water, sanitation and hygiene (Prüss *et al.* 2002). Infectious diarrhoea includes cholera, salmonellosis, shigellosis, amoebiasis, and other bacterial, protozoal and viral intestinal diseases. These diseases are transmitted by water, person-to-person contact, animal-to-human contact, and food-borne and aerosol routes. As diarrhoea is the main disease burden from poor water and sanitation, for which there is data for all regions on incidence rates and deaths (Murray & Lopez 2000; Prüss *et al.* 2002), the impact on diarrhoeal disease is used in this study as the principal health outcome measure with an economic burden. Therefore, including only infectious diarrhoea will lead to a systematic underestimation of beneficial impact. The following two main outcomes are taken as being associated with diarrhoeal disease:

- Reduction in incidence rates (cases reduced per year).
- Reduction in the number of deaths (deaths averted per year)

These were calculated by applying relative risks taken from a literature review (Prüss *et al.* 2002) which were converted to risk reduction when moving between different exposure scenarios (based on the current water supply and sanitation coverage). For water treatment at the point of use, a more recent review of the literature was used to estimate the relative risk reduction using water chlorination, which yields a 37% reduction in diarrhoeal incidence (Clasen *et al.* 2006). Risk reductions are presented in Haller *et al.* (2007). The number of people in each exposure scenario were taken from coverage data collected for the Global Water Supply and Sanitation Assessment 2000 Report (WHO & UNICEF 2000).

Non-health benefits

There are many and diverse potential benefits associated with improved water and sanitation, ranging from the easily identifiable and quantifiable to the intangible and difficult to measure (Hutton 2001). A social cost-benefit analysis should include all the important socio-economic benefits of the different interventions included in the analysis, which includes both cost savings as well as additional economic benefits resulting from the interventions, compared with a do-nothing scenario (that is, maintaining current conditions) (Sugden & Williams 1978; Curry & Weiss 1993; Layard & Glaister 1994; Drummond *et al.* 1997).

Due to problems in measurement and valuation of some of the economic benefits arising from water supply and sanitation interventions, the aim of this present study is not to include all the potential economic benefits that may arise from the interventions, but to capture the most tangible and measurable benefits. Some less tangible or less important benefits were left out for three main reasons: the lack of relevant economic data available globally (Hutton 2001); the difficulty of measuring and valuing in economic terms some types of economic benefit (Hanley & Spash 1993; North & Griffin 1993; Field 1997); and the context-specific nature of some economic benefits which would reduce their relevance for a global cost-benefit analysis study.

For ease of comprehension and interpretation of findings, the benefits of the water supply and sanitation improvements were classified into three main types: (1) direct economic benefits of avoiding diarrhoeal disease; (2) indirect economic benefits related to health improvement; and (3) non-health benefits related to water supply and sanitation improvement. As a general rule, these benefits were valued in monetary terms – in United States Dollars (US$) in the year 2000 – using conventional methods for economic valuation (Curry & Weiss 1993; Hanley & Spash 1993; Field 1997). Details concerning the specific valuation approaches are described for each benefit below.

(1) Direct economic benefits of avoiding diarrhoeal disease

The direct economic benefits of health interventions consist partly of costs averted due to the prevention or early treatment of disease, and thus lower rates of morbidity and mortality. 'Direct' includes "the value of all goods, services and other resources that are consumed in the provision of an intervention or in dealing with the side effects or other current and future consequences linked to it" (Gold *et al.* 1996, page 179). In the case of preventive activities – including improvement of water supply and sanitation services – the main benefits (or costs avoided) relate to the health care and non-health care costs avoided due to fewer cases of diarrhoea. The savings associated with other water-based diseases are excluded as only diarrhoeal disease was included in this study.

Costs saved due to less cases of diarrhoea may accrue to the health service (if there is no cost recovery), the patient (if cost recovery) and/or the employer of the patient (if the employer covers costs related to sickness). On whom the costs fall will depend on the status of the patient as well as the country the patient is seeking care in, due to variation between countries in payment mechanisms. In economic evaluation, what is most important is not who pays, but what are the overall use of resources, and their value. Therefore, in the current analysis, the health service direct cost of outpatient visits and inpatient days are assumed to equal the economic value of these services.

For the treatment of diarrhoea, unit costs included the full health care cost (consultation and treatment), which varied by developing region according to region-specific unit costs (Mulligan *et al.* 2005). The total cost savings were calculated by multiplying the health service unit cost by the number of cases averted, using assumptions about health service use per case. Due to lack of studies presenting data on the number of outpatient visits per case, it was assumed that 30% of cases of diarrhoea would visit a health facility once. The analysis assumes that 8.2% of diarrhoea cases seeking outpatient care are hospitalised (unpublished data, World Health Organization), with an average length of stay of 5 days each. Other forms of treatment seeking are excluded due to lack of information on health seeking behaviour for informal care or self-treatment and the associated costs.

Non-health sector direct costs are mainly those that fall on the patient, costs usually related to the visit to the health facility, such as transport costs to health services, other visit expenses (e.g. food and drink) and the opportunity costs of time. The most tangible patient cost included was the transport cost, although there is a lack of data reported on average transport costs. In the base case it was assumed that 50% (range 0%−100%) of diarrhoeal cases seeking formal health care take some form of transport at US$0.50 per return journey, excluding other direct costs associated with the journey. Other costs associated with a visit to the health facility were also assumed such as food and drinks, and added to transport costs, giving US$0.50 per outpatient visit and US$2 per inpatient admission. Time costs avoided of treatment seeking are assumed to be included in the time gains related to health improvement.

(2) Indirect economic benefits related to health improvement

A second type of benefit is the productivity effect of improved health (Gold *et al.* 1996). These are traditionally split into two main types: gains related to lower morbidity and gains related to fewer deaths. In terms of the valuation of changes in time use for cost-benefit analysis, the convention is to value the time which would be spent ill at some rate that reflects the opportunity cost of time. It is argued that whatever is actually done with the time, whether spent in leisure, household production, or income-earning activities, the true opportunity cost of time is the monetary amount which the person would earn if they were working (Curry & Weiss 1993). However, given that many of the averted diarrhoeal cases will not be of working age, the population is divided into three separate groups and their time valued differently: infants and non-school age children (children < 5 years); school age children until 15; and adults (age 15 and over).

For those of working age, the number of work days gained per case of diarrhoea averted is assumed to be 2 days per case. The value of time is taken as the Gross National Income (GNI) per capita in the year 2000, as it reflects the average economic value of a member of society for each country, and the information collected internationally on GNI per capita is more reliable than minimum wage rates. Also, from an equity perspective, it is appropriate to assign to all adults the same economic value of time, so that high income earners are not favored over low or non-income earning workers or men over women.

For children of school age, the impact of illness is to prevent them from going to school, thus interrupting their education. It is assumed that each case of diarrhoea in children of school age results in 3 days off school per case. Given the recognised importance of proper schooling for future productivity as well as the overall welfare of society, it is important to value explicitly the social and economic implications of children missing school due to ill health (Organisation for Economic Cooperation & Development 2006). Hence, in the absence of established alternative methods for the valuation of children's time, the analysis gives children of school age the same value as for adults: the GNI per capita.

For infants and children not of school age (under 5), it is likely that the carer of the child must spend more time caring for the child than is otherwise the case, or alternative child care arrangements must be made that impose an additional cost. The expected time ill per case of diarrhoea for a young child is assumed to be 5 days, which reflects the average of breast-fed infants (3.8 days) and formula-fed infants (6.2 days) in Mexico (Lopez-Alarcon *et al.* 1997). For the valuation of this illness time, it would not be wholly justifiable to give young child days a valuation of the full GNI per capita. However, in recognition of the opportunity cost of the child's carer, who would have been doing other productive activities with the time they cared for the sick child, a daily value is taken at 50% of the GNI per capita.

In terms of deaths avoided due to diarrhoea following improved water supply and sanitation services, the expected number is predicted from the health impact model as the number of diarrhoeal cases multiplied by the case fatality rate (unpublished data, World Health Organization). The convention in traditional cost-benefit analysis is to value these deaths avoided at the discounted income stream of the avoided death, from the age at which the person is expected to become productive (Suarez & Bradford 1993). Therefore, to predict the economic costs of premature mortality, the study estimates the number of productive years left to each of the three major age categories (under 5, 5–14, and over 15 years of age), then estimates the income that would be earned from averted fatalities, and discounts the income to the present time period at a discount rate of 3%. For those not yet in the workforce (those in the 0–4 and 5–15 age brackets), the current value for the future income stream is further discounted to take account of the lag before these individuals are assumed to be working. The value of time is taken as the GNI per capita for the year 2000.

(3) Non-health benefits related to water and sanitation improvement

One of the major and unarguable benefits of water supply and sanitation improvements, is the reduction in time expenditure (or time savings) associated with closer water and sanitation facilities. Time savings occur due to, for example, the relocation of a well or borehole nearer populations, piped water supply to households, and closer access to latrines and less waiting time for public latrines. These time savings give either increased production or more leisure time, which have a welfare implication and therefore carry with them an economic value.

Convenience time savings are estimated by assuming a daily time saving per individual for water supply and sanitation services separately and multiplying by the GNI per capita to give the economic benefit. Different time saving assumptions for water are made based on whether the water is supplied to the house (household connection) or within the community. As this was a global analysis, the estimate of time savings per household could not take into account the different methods of delivery of interventions and the mix of rural/urban locations in different countries and regions, due to the very limited data available from the literature on time uses. Two separate published reviews have revealed largely different studies, which are presented in Table 1 (Dutta 2005; Cairncross & Valdmanis 2006). The results of these studies show that even for single countries there are considerable variations in access to the nearest water supply for households that haul their water from outside the house or compound area. For example, studies in India have shown average daily collection times per household to vary from 0.5 hours (Saksena *et al.* 1995) to 2.2 hours (Mukherjee 1990). However, in no studies were water supply access times found to be reported of under 0.5 hours per household per day.

Therefore, given these wide variations in daily time spent accessing water from the international literature, as well as the expected enormous differences between settings in the developing world in water availability (current and future), based on the literature this study made general assumptions about time savings following water improvements for households that haul their water from outside the house or compound area. It was therefore assumed that, on average, a household gaining improved water supply saves 30 minutes per day (non-household source), and households receiving piped water save 90 minutes per household per day.

For improved sanitation, no data were found in the literature review for an estimate of time saved per day due to less distant sanitation facilities and less waiting time. No data on time to access sanitation facilities were presented or discussed in the references or in the two published reviews cited above for water supply (Dutta 2005; Cairncross & Valdmanis 2006). Therefore, the present study made assumptions based on the need of individuals using unimproved sanitation facilities (open defecation, shared or public facilities) to make several visits per day to a private place outside the home, giving an estimated 30 minutes saved per person per day with improved sanitation facilities.

Sensitivity analysis

Many of the data used in the model are uncertain. A few selected variables with the greatest impact on the results are presented in this paper using the technique of sensitivity analysis. These included the time gains per person due to better access; the value of time; diarrhoeal disease incidence; and intervention costs.

Given that the overall results were expected to be heavily determined by time savings, the time saving assumptions used in the sensitivity analysis for improved water access were the following: in the pessimistic scenario a time saving of one quarter of an hour was assumed per household for improved community access, with an average household size of 8 persons; in the optimistic scenario, one hour was saved per household per day for improved community access, in an average household of 4 persons. For sanitation access, the base case time saving per person was halved in the pessimistic scenario and increased by 50% in the optimistic scenario.

A realistic variation should also be reflected for the value of time, given its key importance in this study as an economic benefit. An alternative lower bound value to the use of GNI per capita as the base case is proposed by WHO, based on an IMF study (Senhadji 2000). This study suggests that people, on average, adults value their time at roughly 30% of the GNP per capita. In the optimistic scenario, the minimum wage was applied. World Bank data do not provide a minimum wage in all countries included in the present study. In general, in most countries where one exists, the minimum wage exceeds the GNI per capita. For countries without a minimum wage value, the WHO sub-regional average is applied.

For diarrhoeal disease incidence, low and high values were based on halving and increasing by 50% the base case incidence rates, respectively. For intervention costs, low and high cost values were substituted in the model based on

Table 1 | Time and distance to nearest water source available from the literature

Country	Context	Measured for	Time or distance	Reference *
Burkina Faso			0.63 hours to nearest source	(Nathan 1997)
Ghana	Rural	Women	3 hours/day	(Malmburg-Calvo 1994)
		Women	1.2 hours/day	(Toye 1991)
India		Household	0.93 hours/day	(Barnes & Sen 2003)
	National survey	Woman	2.2 hours/day	(Mukherjee 1990)
	Himalayan region	Household	0.5 hours/day	(Saksena *et al.* 1995)
		Women	1.23 hours to nearest source	(Nathan 1997)
Kenya	Small town	Household	10–30 minutes distance (median 15 minutes)	(Whittington *et al.* 1990)
Lesotho	10 villages		Closer water supply saved adult women 0.5 hours/day	(Feachem *et al.* 1978)
Mali	Sampara	Women	1 hour/day	(Dutta 2005)
Nepal		Women	1.15 hours/day	(Kumar & Hotchkiss 1988)
		Women	0.67 hours to nearest source	(Nathan 1997)
Nigeria			Up to 4–7 hours to nearest water source	(Whittington *et al.* 1991)
Sri Lanka		>10% of women	>1 km to nearest water source	(Mertens *et al.* 1990)
Tanzania	Makete (rural)	Women	1.8 hours/day	(Malmburg-Calvo 1994)
	Tanga (rural)	Women	2.7 hours/day	(Malmburg-Calvo 1994)
Vietnam		Household	0.6 hours/day	(World Bank 2001)
Zambia	Rural	Women	0.5 hours/day	(Malmburg-Calvo 1994)
Multi-country	23 African countries	Household	>0.5 hours/day for 44% of households	UNICEF Multi-Indicator Cluster Survey, reported in (Cairncross & Valdmanis 2006)
East Africa (Kenya, Tanzania and Uganda)	334 sites	Household	622 metres (rural) and 204 metres (urban) to nearest water source	(Thompson *et al.* 2003)
East Africa	Two rural masai communities	Women	0.9 hours/day	(Biran & Mace 2004)
		Girls	0.6 hours/day	(Biran & Mace 2004)

*References extracted from two reported literature reviews (Dutta 2005; Cairncross & Valdmanis 2006).

the different sets of assumptions (ranges) shown in Haller *et al.* (2007). Ranges are provided on four input variables to estimating annualized intervention cost: (1) length of life of hardware; (2) operation, maintenance, surveillance as % annual cost; (3) education as % annual cost; and (4) water source protection as % annual cost.

RESULTS

Numbers of people reached

Table 2 presents the number of people receiving improvements by WHO developing country sub-regions. Overall, 693 million people in developing regions would receive improvements in water supply if the MDG for water was reached. This corresponds to 9.6% of the world's predicted population of 7.2 billion in the year 2015. If both the water and sanitation targets were met, an additional 20.6% of the world's population would receive an improvement, which would be roughly 1.5 billion additional people compared to the water MDG alone. In bringing improved water and sanitation to all those currently without improved water or sanitation, 3.1 billion of the world's predicted population in 2015 would be reached, or 42.6%. Roughly two-thirds of the population receiving point-of-use improvements are in two sub-regions – SEAR-D and WPR-B. By improving the quality of drinking water by water purification at the point of use, a further 3.3 billion people could be reached by 2015, summing to a total of 88% of the world's population in 2015.

Predicted health impact

Table 2 also presents the total number of diarrhoeal cases (in millions) averted under each of the five interventions modelled. Out of an estimated annual number of cases of diarrhoea of 5.3 billion globally in developing countries, meeting the water MDG potentially prevents 155 million cases, increasing to 546 million cases prevented for the W&S MDG, and 903 million for universal access to water supply and sanitation. When adding water purification at the point of use, an estimated 2.5 billion cases are prevented annually in the developing world, which is 47% of the annual number of cases of diarrhoea. When regulated piped water supply and sewer connection are provided, a further 1.19 billion prevented cases, due mainly to better sewerage. Except for the water MDG intervention, in all other interventions more than 50% of the cases averted are in SEAR-B and WPR-B.

In terms of cases avoided per capita, if the whole population disinfected their water at the point of use on top of improved water supply and sanitation, the gains would be as high as 0.65 cases averted per person in Africa, and between 0.28 and 0.46 in all other developing country regions except EUR-B and EUR-C. Of these cases, globally around 50% are gained by the 0–4 age group.

The number of deaths avoided due to less cases of diarrhoea was estimated using case fatality rates for diarrhoea for each WHO world sub-region. The estimated number of lives saved in developing regions from meeting the water MDG is 125,000, increasing to 440,000 for water and sanitation MDG combined. If the entire world's population has access to improved water supply and sanitation, about 730,000 lives could be saved per year. Roughly 53% of these avoided deaths are in SEAR-D and WPR-B, and a further 33% in AFR-D and AFR-E.

Treatment costs saved due to less diarrhoea cases

The potential annual health sector costs saved in developing regions amount to an estimated US$500 million per year if the water MDG is met, rising to US$1.7 billion per year for the combined WS&S MDG and US$2.9 billion for universal basic access. In some of the least developed sub-regions (e.g. AFR, AMR, EMRO-D, DEAR-D) the per capita savings are at least US$0.12 for the water MDG, rising to at least US$0.40 for WS&S MDG, and more than US$0.60 for universal basic access. These results are closely linked to the avoided cases per capita predicted by the model, but also the cost saving assumptions used such as the ambulatory care and hospitalisation unit costs, and the proportion of cases admitted to hospital.

The patient treatment and travel costs saved are much lower than the health sector costs saved. The global patient cost savings are estimated at US$46 million per annum for the water MDG, rising to US$160 million for the WS&S MDG. The patient cost savings per capita is negligible for

Table 2 | Population targeted and diarrhoeal disease burden averted, by intervention and world sub-region

	Africa		**The Americas**		**Eastern Mediterranean**		**Europe**		**South and South-East Asia**		**Western Pacific**
Variable	**AFR-D**	**AFR-E**	**AMR-B**	**AMR-D**	**EMR-B**	**EMR-D**	**EUR-B**	**EUR-C**	**SEAR-B**	**SEAR-D**	**WPR-B**
Total population, 2015 (million)	487	481	531	93	184	189	238	223	473	1,689	1,488
Annual diarrhoea cases (million)	620	619	459	93	133	153	87	43	304	1,491	1,317
Total number of people receiving interventions until 2015 (million population)											
Water MDG	96	116	40	11	10	13	18	2	47	109	219
WS&S MDG	200	232	100	26	22	33	37	10	102	645	708
WS&S Universal basic	227	279	127	29	32	40	50	17	123	1,073	998
Universal basic + Disinfected	487	481	531	93	184	189	238	223	473	1,689	1,673
Regulated piped WS + sewer connection	487	481	531	93	184	189	238	223	473	1,689	1,673
Number of diarrhoea cases averted per year (thousand cases)											
Water MDG	28,082	27,695	9,091	3,153	1,001	3,213	1,056	108	7,477	26,092	42,584
WS&S MDG	83,656	85,792	27,522	9,121	4,037	9,370	3,635	541	22,072	139,891	139,500
WS&S Universal basic	117,381	126,288	44,458	13,120	6,968	14,347	6,112	1,021	32,597	262,732	255,753
Universal basic + Disinfected	303,531	308,518	197,666	42,726	53,761	65,617	35,929	16,669	132,961	717,064	648,574
Regulated piped WS + sewer connection	437,876	439,980	308,336	64,106	87,581	102,659	57,475	27,983	205,467	1,043,922	931,477

most countries for basic improvements in water and sanitation, at under US$0.10 per capita, except for SEAR-D where universal basic access to water and sanitation yields estimated benefits of US$0.52 in that sub-region. However, although relatively insignificant, these benefits could be important for households where the health benefits of the interventions are enjoyed, especially households with children. This is especially true where patients have to travel long distances to the health facility, and where public health facilities charge for their services or private health care is used.

Days gained from less illness

The number of days gained due to lower incidence of diarrhoea in adults, children and infants varies considerably. The distribution of days of illness avoided, by sub-region and by age group is illustrated in Figure 1 for the combined water supply and sanitation MDG. Under the assumption that 2 work days are lost per case of adult diarrhoea, the global gain is 89 million working days for the total working population aged 15–59 for the water MDG. For the WS&S MDG, the global gain rises to 310 million working days gained. 71% of these benefits accrue to two world sub-regions WPR-B and SEAR-D. For universal access to WS&S, 550 million working days gained, which increases to 1.5 billion when water is purified at the point of use. For children aged 5 to 14 years old, assuming an average of 3 days off school per case of diarrhoea, the global gain is almost 76 million days per year for the water MDG, rising to over 264 million days per year for the WS&S MDG. 79% of these benefits accrue to the four sub-regions

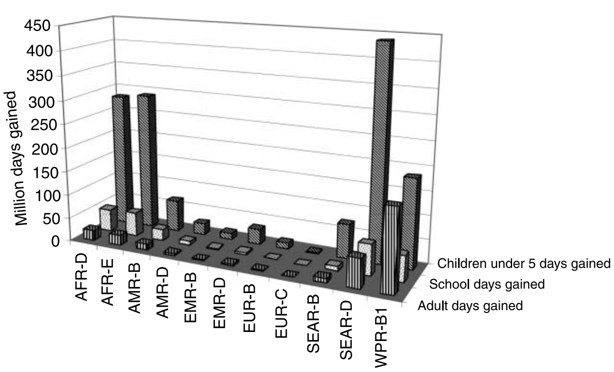

Figure 1 | Days of illness avoided due to meeting water and sanitation MDGs.

AFR-D, AFR-E, SEAR-D and WPR-B. For universal access to WS&S, 435 million school days are gained, which increases to 1.3 billion when water is purified at the point of use. The number of days gained for children under 5 due to averted cases of diarrhoea – at a gain per case of diarrhoea averted of 5 days – is 400 million days gained for the water MDG, 1.4 billion for the WS&S MDG, and 2.3 billion for universal basic access, 6.8 billion for universal basic access and water purification at the point of use.

Convenience time savings

Table 3 shows the annual time gain by WHO sub-region associated with the improved accessibility of water supply and sanitation facilities following from the five interventions. The annual number of hours gained from meeting the water MDG is estimated at just under 30 billion hours (or about 4 billion working days), increasing to 297 billion hours for the WS&S MDG (or about 40 billion working days). This shows that the greatest proportion of time gain from the combined WS&S MDG is from sanitation interventions – i.e. the closer proximity of toilets or less waiting time for public facilities. For the developing regions that benefit the most, around 10 hours are gained per capita per year from meeting the water MDG when spread over the entire population, and 50 hours per capita from the WS&S MDG. Universal basic access to WS&S save around 100 hours per capita per year, spread over the entire population. There is another big gain for all developing regions when moving from universal basic access to universal piped water supply, giving about 200 hours saved per capita per year. Figure 2 illustrates where the gains are distributed in developing world sub-regions, for the WS&S MDG, and shows that 70% of the global gains are in two sub-regions SEAR-D and WPR-B.

Economic value of all benefits together

The economic benefits presented above are aggregated and presented in Table 3 by WHO sub-region. The global value ranges from US$23 billion for the water MDG, to US$219 billion for WS&S MDG, and upwards of US$400 billion for universal basic access. Figure 3 shows that WPR-B takes the largest share of total economic benefits (36%), followed by

Table 3 | Convenience time savings and total economic benefit, by intervention and world sub-region

	Africa		The Americas		Eastern Mediterranean		Europe		South and South-East Asia		Western Pacific
Variable	**AFR-D**	**AFR-E**	**AMR-B**	**AMR-D**	**EMR-B**	**EMR-D**	**EUR-B**	**EUR-C**	**SEAR-B**	**SEAR-D**	**WPR-B**
Total population, 2015 (million)	487	481	531	93	184	189	238	223	473	1,689	1,488
Convenience gains due to closer WS&S facilities (million hours per year)											
Water MDG	4,085	4,925	1,688	483	405	565	787	104	1,997	4,640	9,317
WS&S MDG	23,121	26,101	12,735	3,131	2,624	4,211	4,220	1,520	12,089	102,508	98,678
WS&S Universal basic	46,242	52,202	25,470	6,261	5,248	8,423	8,439	3,040	24,177	205,016	197,355
Universal basic + Disinfected	46,242	52,202	25,470	6,261	5,248	8,423	8,439	3,040	24,177	205,016	197,355
Regulated piped WS + sewer connection	107,853	106,603	57,345	14,042	25,061	30,593	24,544	12,916	105,983	292,445	201,231
Total economic benefit (US$ million per year)											
Water MDG	983	1,314	4,211	405	489	395	771	80	1,047	1,359	4,276
WS&S MDG	5,231	6,446	28,735	2,271	2,633	2,393	3,697	1,469	5,324	24,234	46,837
WS&S Universal basic	9,935	12,302	56,835	4,405	5,203	4,652	7,357	2,937	10,512	48,243	93,405
Universal basic + Disinfected	12,560	15,531	65,658	5,287	7,495	6,359	8,299	3,357	12,329	54,104	98,461
Regulated piped WS + sewer connection	25,893	39,019	139,154	11,440	37,152	22,396	23,802	13,765	58,196	76,822	97,103

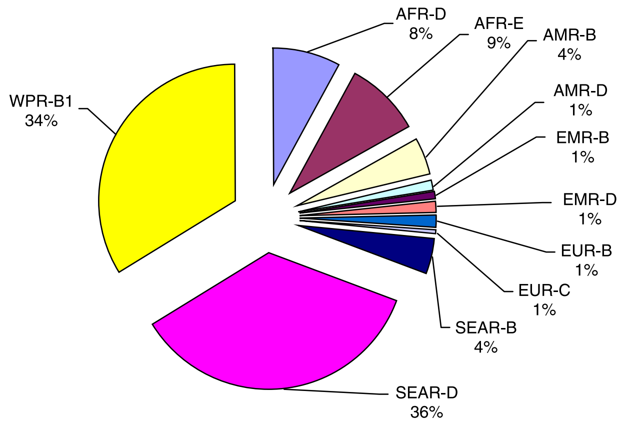

Figure 2 | Distribution (%) of convenience time savings from meeting the WS&S MDG target, by developing world sub-region.

AMR-B (22%) and SEAR-D (19%). The African sub-regions together account for only 9% of the global economic benefit due to the relative GNI per capita values, which were used to value convenience time savings, productivity impact of improved health status and averted deaths. The relatively high share in AMR-B is due to the higher GNI per capita in that region (upward of US$4,000 per capita for the larger countries in the region such as Mexico and Brazil), and large population size in AMR-B of 0.53 billion.

The share of overall benefits contributed by different categories of benefit is presented in Figure 4 for the WHO sub-region AFR-D, for the WS&S MDG. The results show that the value of time savings due to more convenient

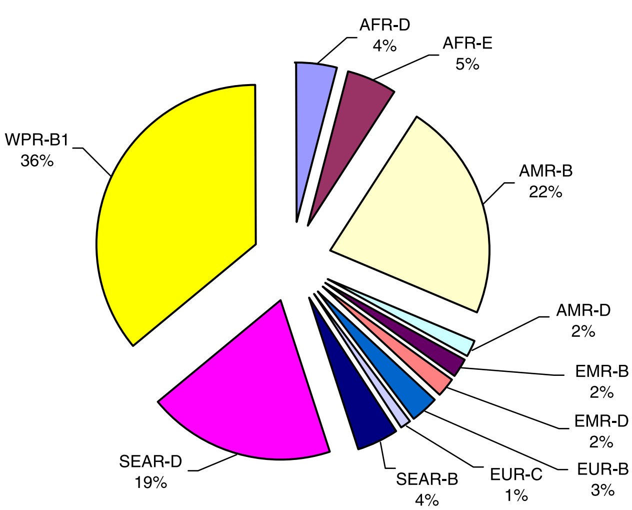

Figure 3 | Distribution (%) of global economic benefits from meeting the WS&S MDG target, by developing world sub-region.

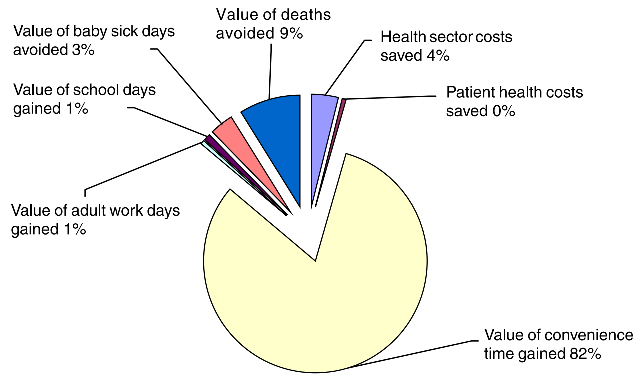

Figure 4 | Distribution of economic benefits for WS&S MDG target, by type of benefit in AFR-D.

services dominates the other benefits, contributing 82% of the overall economic benefits, followed by value of averted deaths (9%), health sector costs (4%) and value of morbidity giving more adult work days and children school days, and less children < 5 sick days (5%).

Intervention costs

Table 4 shows the estimated costs of achieving the targets defined by the five interventions, by world sub-regions. Meeting the water MDG in developing regions has an annual cost of US$1.78 billion, while adding the sanitation MDG leads to a significant cost increase at US$9.5 billion annually, giving a combined W&S MDG annual cost of US$11.3 billion annually (figures reflect the year 2000). Universal access to W&S costs twice the W&S MDG, at US$22.6 billion annually. Two reasons explain the significantly higher cost of sanitation compared to water: first, the higher annual per capita cost of improved sanitation, and the lower current coverage compared to MDG targets. Two sub-regions – SEAR-D and WPR-B - dominate the global costs of reaching the combined water and sanitation MDGs, with 64% of the costs between them.

By adding point of use water treatment, an additional US$4.2 billion is added annually, giving a total developing country cost of US$26.8 billion. This represents a relatively small addition to the annual costs given the associated health and economic benefits. However, piped regulated water supply and sewer connection, which involve a massive investment in hardware as well as running costs, costs US$136 billion annually in developing countries,

Table 4 | Annual intervention costs and overall benefit-cost ratios, by intervention and world sub-region

	Africa		The Americas		Eastern Mediterranean		Europe		South and South-East Asia		Western Pacific
Variable	**AFR-D**	**AFR-E**	**AMR-B**	**AMR-D**	**EMR-B**	**EMR-D**	**EUR-B**	**EUR-C**	**SEAR-B**	**SEAR-D**	**WPR-B1**
Total population, 2015 (million)	487	481	531	93	184	189	238	223	473	1,689	1,488
Annual cost to meet targets until 2015 (million US$)											
Water MDG	222	268	133	38	24	33	52	8	121	282	566
WS&S MDG	947	1,074	631	157	100	163	186	71	466	3,628	3,621
WS&S Universal basic	1,894	2,149	1,262	315	201	325	373	143	933	7,257	7,243
Universal basic + Disinfected	2,216	2,466	1,613	376	322	450	530	290	1,245	8,371	8,347
Regulated piped WS + sewer connection	12,528	12,201	11,765	2,320	3,275	4,054	4,602	4,206	12,164	35,074	32,767
Benefit-Cost Ratio (US$ economic return on US$1 expenditure)											
Water MDG	4.4	4.9	31.6	10.6	20.1	12.1	14.7	10.4	8.6	4.8	7.6
WS&S MDG	5.5	6.0	45.5	14.4	26.3	14.7	19.8	20.6	11.4	6.7	12.9
WS&S Universal basic	5.2	5.7	45.0	14.0	25.9	14.3	19.7	20.6	11.3	6.6	12.9
Universal basic + Disinfected	5.7	6.3	40.7	14.1	23.3	14.1	15.7	11.6	9.9	6.5	11.8
Regulated piped WS + sewer connection	2.1	3.2	11.8	4.9	11.3	5.5	5.2	3.3	4.8	2.2	3.0

which represents an almost 5-fold cost increase from the lower technology interventions.

Spread over the entire population of the developing world, the annual per capita cost is relatively insignificant, even in resource constrained settings. In meeting the water MDG, an annual cost US$0.3 per capita would need to be invested, rising to US$1.86 for the W&S MDG, US$3.7 for universal basic access, and US$4.40 for universal basic access and point-of-use treatment. The per capita cost varies between regions, with the highest per capita costs in the African sub-regions (> US$0.56) for the water MDG, and for the combined W&S MDG the annual cost rises to over US$2 per capita in Africa, SEAR-D and WPR-B.

Cost-benefit ratios

Table 4 shows the benefit-cost ratios for developing country WHO sub-regions, taking into account all the costs and benefits quantified in the analysis. The most important finding is that in all regions and for all five interventions, the benefit-cost ratio (BCR) is significantly greater than 1, recording values in developing regions of between 4 and 32 for the water MDG, between 5 and 46 for the WS&S MDG and universal basic access, and between 5 and 41 for universal basic access with water disinfection at the point of use. The benefit-cost ratio for regulated piped water supply and sewer connection is considerably lower than the basic improvements, ranging between 2 and 12. This is explained by the fact that the intervention costs are considerably higher, while the increase in economic benefits such as health benefits and time savings are more marginal.

In AFR-D and AFR-E the benefit-cost ratio for the basic interventions ranges between 4.4 and 6.3; in WPR-B1 and SEAR-D the cost-benefit ratios are slightly higher at between 4.8 and 12.9; and in AMR-D the benefit-cost ratios range between 10.6 and 14.4. The cost-benefit ratio tends to be higher in the more developed regions, mainly for the reason that the cost estimates may be underestimated for these regions and the value of time is considerably higher than in less developed regions. Hence, in the more developed regions such as EUR-B and AMR-B, the true benefit-cost ratios are likely to be lower than those reported.

Sensitivity analysis

Although the base case results suggest all the interventions modelled to be cost-beneficial, even highly cost-beneficial, it is important to understand how these results might change under different assumptions or input data values. Figures 5 to 8 show the benefit-cost ratios under low and high assumptions for four key model variables separately, which were thought to play a determining role in the results:

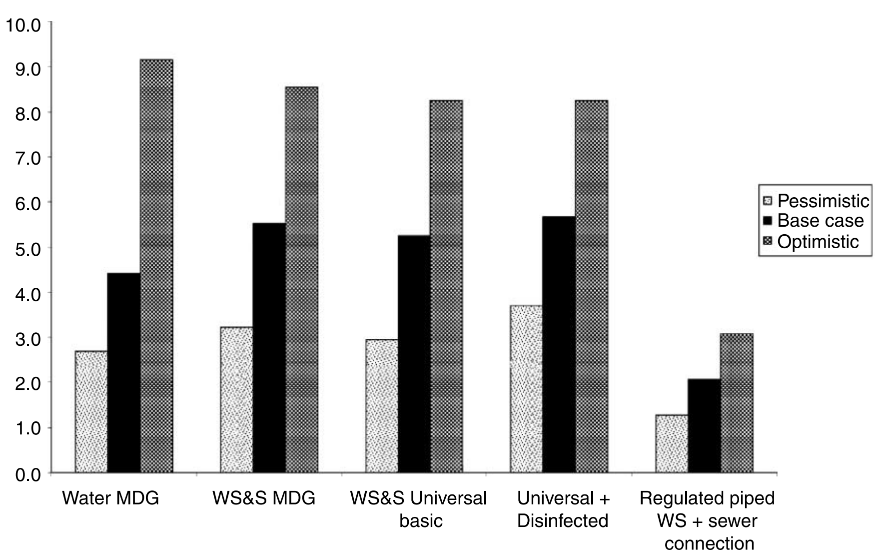

Figure 5 | Benefit-cost ratios under low and high convenience time gain assumptions, AFR-D.

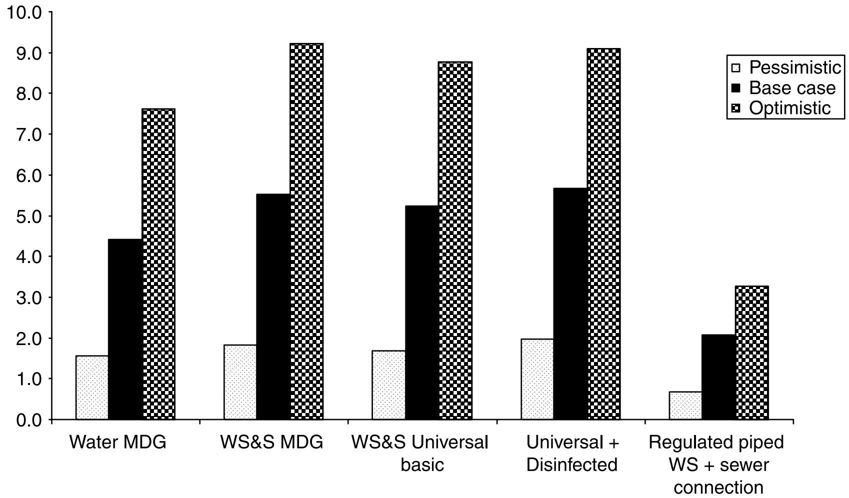

Figure 6 | Benefit-cost ratios under low and high time value assumptions, AFR-D.

convenience time gain assumptions; value of time assumptions; diarrhoeal disease incidence assumptions; and intervention cost assumptions. The Figs. show the benefit-cost ratios to be highly sensitive to the input values in three of the four sensitivity analyses. The greatest impact is when a high intervention cost assumption is used, and also the alternative time gain and time value assumptions have considerable impact on the benefit-cost ratio. However, in none of the four one-way sensitivity analyses did the benefit-cost ratio become less than 1.0, which would have lead to a change in overall study conclusion. On the other hand, when two-way or multi-way sensitivity analyses are performed using pessimistic assumptions, thus combining different types of uncertainty, the benefit-cost ratio becomes less than 1.0. However, such an extreme analysis was not considered appropriate, as it would lead to a negative study conclusion that is not perhaps warranted by the actual level of uncertainty in the model variables. Furthermore, the sensitivity analysis was incomplete, in the sense that some types of uncertainty relating to variable inclusion could not be tested due to lack of data or complexity of analysis. For example if some of the potential economic benefits relating to home production or agricultural activities had been included for contexts where such benefits are

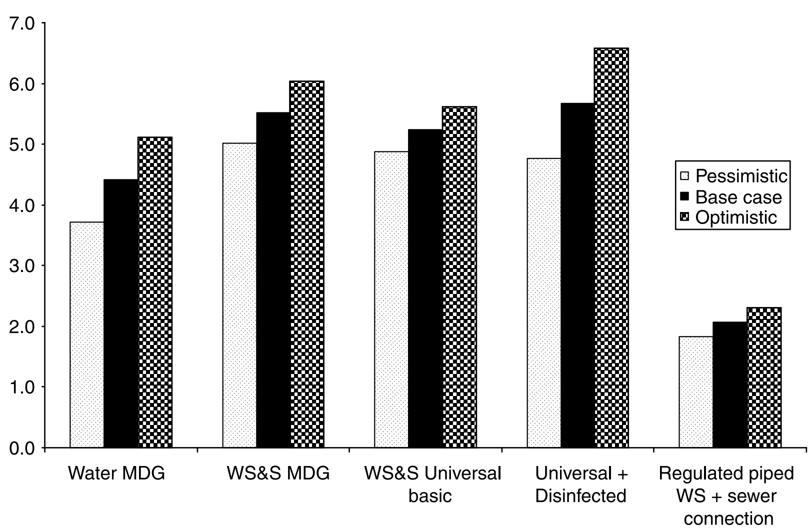

Figure 7 | Benefit-cost ratios under low and high diarrhoeal baseline incidence assumptions, AFR-D.

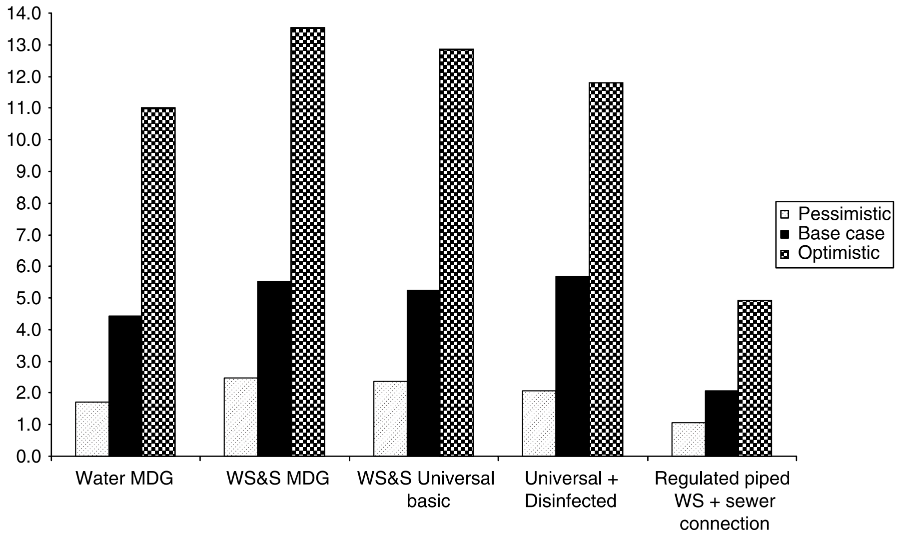

Figure 8 | Benefit-cost ratios under low and high intervention cost assumptions, AFR-D.

relevant, the benefit-cost ratios could have been considerably higher.

DISCUSSION

Interpretation of main findings

In interpreting the impressive cost-benefit ratios presented in this study, an important caveat needs to be noted. The caveat relates to the fact that the study presented is a social and not a financial cost-benefit analysis. The measure of economic benefit is social welfare in the broadest sense, and focuses on a hypothetical although real set of benefits, as opposed to tangible and financially measurable benefits. A distinction is useful between the costs and benefits part of the equation: the majority of costs reflect financial costs, although some non-financial costs are included such as community time input. On the other hand, the benefits reflect a range of expected financial as well as economic savings to the intervention beneficiaries, covering reduced costs to the health service and patient in seeking health care, the value of the beneficiaries being able to continue their daily activities unimpeded, the economic value of less mortality, and the expected developmental benefits related to less time being devoted to water haulage and time spent accessing toilets.

Furthermore, valuation of welfare effects in monetary terms brings with it problems and can lead to inappropriate interpretation of the results, due to lack of agreement on appropriate valuation methodologies and due to lack of evidence to support the underlying values some variables are assigned in the model. The potential impact on the results of some of these uncertainties has been examined in one-way sensitivity analysis; however, the fuller examination of all the uncertainties present in the model is a much greater task. For example, the value of time has many aspects which cannot be captured in a single alternative value (such as 30% of GNI per capita instead of 100%). There are such large differences, as shown in the literature, in how different individuals and sections of the population value their time (e.g. the presence of unemployment, underemployment or seasonal labour, which all affect an individual's perspective on the value of their time), that a single global value clearly does not capture reality.

A further aspect to consider in using the results of this study for policy decisions is the omission of variables in the analysis. At such a high level of aggregation – the WHO sub-regional level – the choice over the variables to be included needed to remain simple. A more comprehensive cost-benefit analysis would have included: the health impacts of improved WS&S other than diarrhoeal disease such as trachoma and vectors; the saved costs of switching away from other more expensive water sources such as tanker trucks or vendor-supplied water; economic benefits related to options for labour-saving devices and increased water access leading to home production possibilities and labour-saving devices; impact of water and sanitation projects on agricultural productivity (irrigation, fertiliser); leisure activities; aesthetics; and non-use values associated with water supply and sanitation improvements. Non-use benefits are divided into option value (the possibility that the person may want to use it in the future), existence value (the person values the fact that the environmental good exists, irrespective of use), and bequest value (the person wants future generations to enjoy it) (Hanley & Spash 1993; Georgiou *et al.* 1996; Field 1997). These various benefits were excluded for reasons of lack of data on impact and difficulties in making assumptions, difficulties in valuation, or because their benefit was expected to be small compared with other benefits included.

Financing considerations

While cost-benefit analysis can be carried out to identify clearly all the beneficiaries and the (potential) financers of development projects, the analysis does not provide answers to the question of who should pay or where the funding will come from. This represents a particular challenge to economic evaluation when health care interventions have non-health sector costs and benefits, as the objective of the health ministry – "to maximise health with a given budget" – may come into conflict with other societal objectives, including the maximisation of non-health related welfare. If all costs and benefits are included in a cost-benefit analysis, then a full analysis can be made of financing options.

One of the problems associated with identifying beneficiaries in order to identify those willing to pay for the costs is that the main beneficiaries (patients, and the population more generally) do not always understand the full benefits until after the investment has taken place. For example, if a household does not understand fully the links between water quality and health or between water source and household time expenditure, then improvement in water access and quality are unlikely to be undertaken for health or economic reasons. This is where the technique of information sharing (Information, Education and Communication (IEC) or Behaviour Change Communication (BCC)) is crucial to influence the potential beneficiaries to be an agent for change, one aspect of which is to be willing to make a financial or an in-kind contribution (eg labour, materials). However, a constraint faced by households is that a large share of annual intervention costs are incurred in the first year of the intervention (investment cost), while economic benefits accrue over a longer time period. This raises the question about who is prepared to finance such an investment with benefits that are hard to know in advance and that are long-term in nature. Furthermore, the availability of credit, especially in rural settings, is not easily available to make up the temporary gap in finances. These factors together lead to a type of 'market failure', where potential consumers of improved water and sanitation facilities are not fully informed about the benefits of such a product, and where financing sources for such an investment are in short supply. The end result of this market failure is that private consumers have extremely limited options for financing the initial investment requirements of water supply and sanitation improvements up-front.

There is one group of potential beneficiaries where the financing constraint is easier to overcome. Many households incur costs for their existing supply of water, for example those who purchase their water (e.g. bottled water or from a local water vendor or delivered by tanker truck) or those who treat their water by boiling or filtering it. In their case, when an alternative low-cost WS&S intervention is delivered, the cost saving from switching away from more expensive water options may lead to a net financial gain. In such cases, households need to be made aware of the opportunities for alternative low-cost WS&S interventions which will lead to a net welfare gain, including a potential financial saving.

In terms of whether the health sector would be interested in financing the interventions, in most regions and for most interventions the health sector is unlikely to be interested or capable to pay a significant contribution to the overall costs. This is because hardware interventions for WS&S are outside the core activity of a health ministry, but also because the real savings to the health sector are negligible in comparison to the annual intervention costs, as shown in this analysis. Benefits of improving access to safe water and sanitation accrue mainly to households and individuals. Compared to the potential cost savings reported in this study, it is unlikely that the health sector will ever be able to recover these costs, as only a small proportion are marginal costs directly related to the treatment cost of the health episode. In fact, as most health care costs such as personnel and infrastructure are fixed costs which do not change with patient throughput in the short-term, the real cost saving is probably insignificant. On the other hand, when considered from the social welfare angle, the reduced burden to the health system due to less patients presenting with diarrhoea will free up capacity in the health system to treat other patients. Furthermore, the health system can play a role in leveraging resources and funds from other sectors or from financing agents, to fill financing gaps.

The implication of these arguments is that there should exist a variety of financing sources for meeting the costs of water supply and sanitation improvements, depending on the income and asset base of the target populations, the availability of credit, the economic benefits perceived by the various stakeholders, the budget freedom of government ministries, and the availability of non-governmental organisations to promote and finance water and sanitation improvements. However, it is clear that the meagre budget of the health sector is insufficient to finance water supply and sanitation improvements. On the other hand, it can play a key role in providing the 'software' (education for behaviour change) alongside 'hardware' interventions, involving the close technical cooperation of the health sector.

CONCLUSIONS

This study has shown that there is a strong economic case for investing in improved water supply and sanitation services, when the expected cost per capita of different combinations of water supply and sanitation improvement are compared with the expected economic benefits per capita. Under base case assumptions the cost-benefit ratio is at least US$5 in economic benefit per US$1 invested, and even under pessimistic data assumptions in the one-way sensitivity analysis, the benefits per dollar invested remained above the threshold of US$1 in most sub-regions. When potential benefits that were omitted from the analysis are included, the economic case for investment in water supply and sanitation interventions becomes stronger, depending on the context. The annual cost of increasing access to basic improved water supply and sanitation to all is under US$10 per person reached in all developing regions.

While these findings make a strong case for investment in water supply and sanitation improvement, it should be recognised that many of the benefits included in this analysis may not give actual financial benefits. For the time gains calculated or the number of saved lives, these do not necessarily lead to more income-generation activities. Also, for the averted costs of health care for diarrhoea cases, these savings to the health sector and the patient may not be realised as the greatest proportion of health care costs are usually fixed costs. On the other hand, it is clear that populations do appreciate time savings, such as the benefits of more time spent at school for children, less effort in water collection (especially women and children), less journey time for finding places to defecate, or more leisure time. In the recognition that these non-health and non-financial benefits are important to take into account in a study on social welfare, this analysis has shown that these benefits are potentially considerable and provide a strong argument for investment in improved water supply and sanitation. Further country case-studies are recommended as a follow up to this global analysis.

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DISCLAIMER

J. Bartram is a staff member of the World Health Organization. He and the other authors alone are responsible of the views expressed in this publication and such views do not necessarily represent the decisions, policy or views of the World Health Organization.

REFERENCES

Barnes, D. & Sen, M. 2003 *The impact of energy on women's lives in rural India*. IBRD/World Bank, Washington D.C., Available online at: http://www.esmap.org/filez/pubs/FinalIndiaforWeb.pdf.

Biran, A. J. & Mace, R. 2004 Families and firewood: a comparative analysis of the costs and benefits of children in firewood collection and use in two rural communities in Sub-Saharan Africa. *Human Ecology* **32**(1), 1–25, Available online at: http://www.springerlink.com/content/nj34p7x47n726r17/.

Cairncross, S. & Valdmanis, V. 2006 Water supply, sanitation and hygiene promotion. In *Disease Control Priorities in Developing Countries*, 2nd edition. (ed. D. Jamison, J. Breman, A. R. Measham, G. Alleyne, M. Claeson, D. B. Evans, P. Jha, A. Mills & P. Musgrove). Oxford University Press, New York, USA.

Clasen, T. 2006 *Household Water Treatment for the Prevention of Diarrhoeal Disease*. PhD Thesis. University of London, London School of Hygiene & Tropical Medicine.

Clasen, T., Roberts, I., Rabie, T., Schmidt, W. & Cairncross, S. 2006 Interventions to improve water quality for preventing diarrhoea. In *The Cochrane Library*. Update Software, Oxford, Issue 3.

Curry, S. & Weiss, J. 1993 *Project analysis in developing countries*. MacMillan Press.

Drummond, M. F., O'Brien, B., Stoddart, G. L. & Torrance, G. W. 1997 *Methods for the Economic Evaluation of Health Care Programmes*. Oxford University Press, UK.

Dutta, S. 2005 Energy as a key variable in eradicating extreme poverty and hunger: A gender and energy perspective on empirical evidence on MDG #1, DFID/ENERGIA project on Gender as a Key Variable in Energy Interventions. Draft version, September 2005.

Feachem, R., Burns, E., Cairncross, S., Cronin, A., Cross, P. & Curtis, D. 1978 *Water, health and development: an interdisciplinary evaluation*. Tri-Med Books, London, UK.

Fewtrell, L., Kaufmann, R., Kay, D., Enanoria, W., Haller, L. & Colford, J. M. Jr 2005 Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis. *Lancet Infectious Diseases* **5**(1), 42–52.

Field, B. C. 1997 *Environmental Economics*. McGraw-Hill, New York.

Georgiou, S., Langford, I., Bateman, I. & Turner, R. K. 1996 Determinants of individuals' willingness to pay for reduction in environmental health risks: A case study of bathing water quality. *CSERGE Working Paper* GEC 96–14.

Gold, M. R., Siegel, J. E., Russell, L. B. & Weinstein, M. C. 1996 *Cost-effectiveness in Health and Medicine*. Oxford University Press, UK.

Haller, L., Hutton, G. & Bartram, J. 2007 Estimating the costs and health benefits of water and sanitation improvements at global level. *Journal of Water and Health* **5**(4),467–480.

Hanley, N. & Spash, C. L. 1993 *Cost-benefit Analysis and the Environment*. Edward Elgar, Cheltenham, UK.

Hutton, G. 2000 Considerations in evaluating the cost-effectiveness of environmental health interventions, Sustainable Development and Healthy Environments Cluster, World Health Organization. WHO/SDE/WSH/0010.

Hutton, G. 2001 Economic evaluation and priority setting in water and sanitation interventions. In *Water Quality: Guidelines, Standards and Health. Risk assessment and management for water-related infectious disease* (ed. L. Fewtrell & J. Bartram) IWA Publishing, London.

Hutton, G. & Haller, L. 2004, Evaluation of the non-health costs and benefits of water and sanitation improvements at global level, Report undertaken for the Evidence and Information for Policy Department, in collaboration with the Department for Protection of the Human Environment, World Health Organisation. WHO/SDE/WSH/0404.

Kumar, S. & Hotchkiss, D. 1988 *Consequences of deforestation for women's time allocation, agricultural production, and nutrition in hill areas of Nepal*. International Food Policy Research Institute, Washington, D.C.

Layard, R. & Glaister, S. 1994 *Recent developments in cost-benefit analysis*. Cambridge University Press, UK.

Lopez-Alarcon, M., Villalpando, S. & Fajardo, A. 1997 Breast-feeding lowers the frequency and duration of acute respiratory infection and diarrhoea in infants under six months of age. *Journal of Nutrition* **127**, 436–443.

Malmburg-Calvo, C. 1994 Case study on the role of women in rural transport; access of women to domestic facilities, *World Bank: Sub-Saharan Africa Transport Policy Program, Working Paper No. 11*.

Mertens, T., Fernando, M., Marshall, T. F., Kirkwood, B. R., Cairncross, S. & Radalowicz, A. 1990 Determinants of water quality, availability and use in Kurunegala, Sri Lanka. *Tropical Medicine and Parasitology* **41**(1), 89–97.

Mukherjee, N. 1990 People, water and sanitation: what do they know, believe and do in rural India. National Drinking Water Mission, Government of India, New Delhi

Mulligan, J., Fox-Rushby, J., Adam, T., Johns, B. & Mills, A. 2005 *Unit costs of health care inputs in low and middle income regions*, DCCP Working Paper No. 9. September 2003, revised June 2005.

Murray, C. & Lopez, A. 2000 *The Global Burden of Disease*. World Health Organization, Harvard University.

Nathan, D. 1997 Woodfuel interventions with a gender base. *Wood Energy News* **12**(1), 19.

North, J. & Griffin, C. 1993 Water source as a housing characteristic: Hedonic property valuation and willingness to pay for water. *Water Resources Research* **29**(7), 1923–1929.

Organisation for Economic Cooperation and Development 2006 *Economic valuation of environmental health risks to children*. OECD, Paris.

Prüss, A., Kay, D., Fewtrell, L. & Bartram, J. 2002 Estimating the global burden of disease from water, sanitation, and hygiene at the global level. *Environmental Health Perspectives* **110**(5), 537–542.

Saksena, S., Prasad, R. & Joshi, V. 1995 Time allocation and fuel usage in three villages of the Gharwal Himalaya, India. *Mountain Research and Development* **15**(1), 57–67.

Senhadji, A. 2000 Sources of economic growth:an extensive accounting exercise, IMF institute. *IMF staff papers* **47**, 129–158.

Suarez, R. & Bradford, B. 1993 The economic impact of the cholera epidemic in Peru: an application of the cost-if-illness methodology. Water and Sanitation for Health Project; WASH Field Report No. 415.

Sugden, R. & Williams, A. 1978 *Principles of Practical Cost-Benefit Analysis*. Oxford University Press, UK.

Tan-Torres Edejer, T., Baltussen, R., Adam, T., Hutubessy, R., Acharya, A., Evans, D. B., Murray, C. J. L., Thompson, J., Porras, I., Tumwine, J. K., Mujwahuzi, M. R., Katui-Katua, M. & Johnstone, N. 2003 *Making Choices in Health: WHO Guide to Cost-Effectiveness Analysis*. World Health Organization, Geneva.

Thompson, J., Porras, I., Tumwine, J., Mujwahuzi, M., Katui-Katua, M., Johstone, N. & Wood, L. 2003 *Drawers of water II: 30 years of change in domestic water use and environmental health in East Africa*. International Institute for Environment and Development, London.

Toye, J. 1991 Ghana case study. In *Aid and Power: The World Bank and Policy-Based Lending, Vol. 2, Case Studies* (ed. P. Mosley, J. Harrigan & J. Toye). Routledge, London.

Whittington, D., Lauria, D. T. & Mu, X. 1991 A study of water vending and willingness to pay for water in Onitsha, Nigeria. *World Development* **19**(2/3), 179–198.

Whittington, D., Mu, X. & Roche, R. 1990 Calculating the value of time spent collecting water: Some estimates for Ukunda, Kenya. *World Development* **1990**(18), 2.

WHO & UNICEF 2000 *Global Water Supply and Sanitation Assessment 2000 Report*. WHO, Geneva.

WHO & UNICEF 2006 *Meeting the MDG Water and Sanitation Target: The Urban and Rural Challenge of the Decade*, WHO, Geneva and UNICEF, New York.

WHO/UNICEF/JMP 2000 *Global Water Supply and Sanitation Assessment 2000 Report*, World Health Organization, United Nations Children's Fund, Water Supply and Sanitation Collaborative Council.

World Bank 2001 Project appraisal document on a proposed loan to the Socialist Republic of Vietnam for the Ho Chi Minh City environmental sanitation project. Urban Development Sector Unit, Vietnam Country Department of the World Bank.

World Health Organization 2003 *World Health Report*. WHO, Geneva.

APPENDIX A: WHO WORLD SUB-REGIONS

Table A | Countries included in World Health Organization epidemiological sub-regions

Region*	Mortality stratum**	Countries
AFR	D	Algeria, Angola, Benin, Burkina Faso, Cameroon, Cape Verde, Chad, Comoros, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Madagascar, Mali, Mauritania, Mauritius, Niger, Nigeria, Sao Tome And Principe, Senegal, Seychelles, Sierra Leone, Togo
AFR	E	Botswana, Burundi, Central African Republic, Congo, Côte d'Ivoire, Democratic Republic Of The Congo, Eritrea, Ethiopia, Kenya, Lesotho, Malawi, Mozambique, Namibia, Rwanda, South Africa, Swaziland, Uganda, United Republic of Tanzania, Zambia, Zimbabwe
AMR	B	Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Brazil, Chile, Colombia, Costa Rica, Dominica, Dominican Republic, El Salvador, Grenada, Guyana, Honduras, Jamaica, Mexico, Panama, Paraguay, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Uruguay, Venezuela
AMR	D	Bolivia, Ecuador, Guatemala, Haiti, Nicaragua, Peru
EMR	B	Bahrain, Cyprus, Iran (Islamic Republic Of), Jordan, Kuwait, Lebanon, Libyan Arab Jamahiriya, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Tunisia, United Arab Emirates
EMR	D	Afghanistan, Djibouti, Egypt, Iraq, Morocco, Pakistan, Somalia, Sudan, Yemen
EUR	B	Albania, Armenia, Azerbaijan, Bosnia And Herzegovina, Bulgaria, Georgia, Kyrgyzstan, Poland, Romania, Slovakia, Tajikistan, The Former Yugoslav Republic Of Macedonia, Turkey, Turkmenistan, Uzbekistan, Yugoslavia
EUR	C	Belarus, Estonia, Hungary, Kazakhstan, Latvia, Lithuania, Republic of Moldova, Russian Federation, Ukraine
SEAR	B	Indonesia, Sri Lanka, Thailand
SEAR	D	Bangladesh, Bhutan, Democratic People's Republic Of Korea, India, Maldives, Myanmar, Nepal
WPR	B	Cambodia, China, Lao People's Democratic Republic, Malaysia, Mongolia, Philippines, Republic Of Korea, Viet Nam
		Cook Islands, Fiji, Kiribati, Marshall Islands, Micronesia (Federated States Of), Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu

*AFR = Africa Region; AMR = Region of the Americas; EMR = Eastern Mediterranean Region; EUR = European Region; SEAR = South East Asian Region; WPR = Western Pacific Region.
**B = low adult, low child mortality; C = high adult, low child mortality; D = high adult, high child mortality; E = very high adult, high child mortality.

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