Estimating the costs and health benefits of water and sanitation improvements at global level

Laurence Haller, Guy Hutton and Jamie Bartram

ABSTRACT

The aim of this study was to estimate the costs and the health benefits of the following interventions: increasing access to improved water supply and sanitation facilities, increasing access to in house piped water and sewerage connection, and providing household water treatment, in ten WHO sub-regions. The cost-effectiveness of each intervention was assessed in terms of US dollars per disability adjusted life year (DALY) averted. This analysis found that almost all interventions were cost-effective, especially in developing countries with high mortality rates. The estimated cost-effectiveness ratio (CER) varied between US$20 per DALY averted for disinfection at point of use to US$13,000 per DALY averted for improved water and sanitation facilities. While increasing access to piped water supply and sewage connections on plot was the intervention that had the largest health impact across all sub-regions, household water treatment was found to be the most cost-effective intervention. A policy shift to include better household water quality management to complement the continuing expansion of coverage and upgrading of services would appear to be a cost-effective health intervention in many developing countries.

Key words | cost-effectiveness analysis, sanitation, water and sanitation costs, water and sanitation improvements, water supply

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INTRODUCTION

Despite progress in recent decades, a significant proportion of the world's population still does not use some form of improved water supply and sanitation. 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). Poor access to safe water supply and sanitation services results in major threats to human health. Burden of disease analysis suggests that lack of access to a safe water supply, sanitation and hygiene is the third most significant risk factor for poor health in developing countries with high mortality rates (WHO 2002). Diarrhoea is the main disease associated with unsafe water and sanitation and is responsible for the deaths of 1.8 million people every year, 90% of which are children under five (WHO 2004). It is estimated that 1.6 million deaths per year are attributed to unsafe water supply and sanitation. This figure includes 88% of the deaths due to diarrhoeal diseases world-wide – which is considered to be the attributable fraction of diarrhoea due to unsafe water supply and sanitation (WHO 2002) – and 100% of the deaths from trachoma, schistosomiasis, ascariasis, trichuriasis and hookworm disease. Several other water and sanitation – related diseases are not accounted for in this figure, for example vector-borne diseases such as malaria and Japanese encephalitis which are linked to the development of water projects like dams or intensified irrigation schemes; and diseases related to chemical contamination such as unsafe concentrations of arsenic or fluoride in drinking water.

The United Nations Millennium Declaration confirmed the central role of water in sustainable development and in efforts to eradicate poverty (UN 2000). Compelling evidence has demonstrated that improving the use of safe water, sanitation facilities and better hygiene behaviour results in a

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significant positive health impact. In addition to the reduction of water, sanitation and hygiene-related diseases, increasing access to safe water and sanitation, also may confer many and diverse potential additional benefits, ranging from the easily identifiable and quantifiable -such as time saved due to closer access to water and sanitation services- to the intangible and difficult to measure -such as convenience and well-being (Hutton 2001). The benefits and the costs of increasing access to improved water and sanitation vary considerably depending on the type of technology selected. For rational decision-making it is crucial to carry out a sound economic evaluation of the various options available, because resources are scarce and choices have to be made about the use of resources. If benefits and costs are expressed in a common monetary unit (such as US dollars), it is possible to estimate if the total benefit of an intervention exceeds the total cost. This economic evaluation method is known as cost-benefit analysis (CBA). However, it is not always possible to quantify all impacts in dollar units. In that case, a cost-effectiveness analysis (CEA) can be undertaken. CEA shows the cost of achieving a given output. The output is measured in its natural unit such as healthy life years gained, disability-adjusted life-years (DALYs) averted, or time saved. CEA is the method of choice for resource allocation decision in the health sector (WHO 2003). The coherent analysis and presentation of data on both costs and health benefits, associated with differing levels of water and sanitation service would be of substantial value to decision-makers. Such tools would permit, for example, the determining of (i) the additional cost in converting a water supply from not improved public water points to household connections (ii) the burden of disease averted through such an upgrade, and thus (iii) the costs per disability-adjusted life-year (DALY) of such an upgrade. Given limited financial resources, this tool will help in selecting one or several options which would efficiently prevent and decrease water-related diseases or in achieving defined goals at the lowest possible costs. Evaluation of the costs and health benefits of water and sanitation interventions are important pieces of information for informed decision-making, alongside the assessment of other environmental, social, cultural and institutional factors which are often location-specific.

In an attempt to improve the quality and comparability of cost-effectiveness studies, the World Health Organization (WHO) developed guidelines for conducting generalized cost-effectiveness analysis (G CEA) (WHO 2003). These new guidelines are in principle suitable for all types of interventions which aim to sustain and improve health, and have been applied to more than ten risk factors (WHO 2002). They have been used in this study to evaluate the cost-effectiveness of a range of potential interventions designed to improve access to safe water and sanitation facilities. In this cost-effectiveness analysis, only the health benefits have been assessed but it is important to note that some of the additional benefits can be quantified and valued in a common monetary unit, in the context of a cost-benefit analysis. A cost-benefit analysis of several water and sanitation improvements at global level has been undertaken and results are reported in Hutton *et al.* (2007).

METHODS

The principal steps in the WHO G CEA guidelines are: (a) defining the study population; (b) defining the different intervention scenarios to be evaluated; (c) specifying the baseline scenario (d) assessing the healthy years gained due to each potential intervention relative to the baseline scenario; (e) calculating the cost of each potential intervention; (f) assessing the cost-effectiveness of the selected interventions in terms of US dollars per DALY averted.

As suggested in the WHO G CEA guidelines, the estimates include all costs regardless of which entity bears the costs and the health benefits are measured in DALYs averted. The guidelines also suggest that all interventions should be evaluated with the assumption that interventions are fully in use throughout a period of 10 years. At the end of this period the intervention stops being in use. The health impacts and the costs of all interventions were therefore evaluated on the basis of an implementation and use period of 10 years. In addition, no increase in population growth was used and no change in the disease of interest was taken into account. An age-weighting factor and a discounting rate of 3% were used. Complete details on the methodology have been published in the WHO guide for generalized cost-effectiveness analysis (WHO 2003).

Defining the study population

WHO separated the population of the globe into subgroups of countries on the basis of having similar rates of child and adult mortality. This resulted in 14 epidemiological sub-regions characterized by the WHO region acronyms as (AFR (African Region); AMR (Region of the Americas); EMR (Eastern Mediterranean Region); EUR (European Region), SEAR (South-East Asia Region) and WPR (Western Pacific Region)) and a letter for the mortality stratum (Table 1). Four sub-regions, EURA, EURC, AMRA and WPROA, were excluded from the analysis as in these regions more than 90% of the population already has access to in house piped water supply and sewerage connection.

Defining intervention scenarios

Estimating burden of diarrhoeal diseases due to water, sanitation and hygiene

The analysis has been restricted to diarrhoeal disease as it accounts for the main disease burden associated with poor water supply and sanitation. Prüss *et al.* (2002) estimated the global burden of diarrhoeal disease caused by unsafe water supply, sanitation and hygiene, using a 'scenario-based' approach. Six exposure scenarios were defined based on the type of existing water and sanitation infrastructure and the load of faecal-oral pathogens in the environment (Table 2). Scenarios VI to III are in a high faecal-oral pathogen environment, typical in developing countries. In scenario VI, populations do not have access to any type of improved water supply and sanitation facilities. Scenario IV corresponds to an improvement in both water and sanitation services. An improved water supply means a public standpost/pipe, a borehole, a protected spring or well, or collected rain water. Improvement does not necessarily mean that the water is safe, but rather that it meets minimum criteria for accessibility and measures are taken to protect the water source from contamination. An improved sanitation corresponds to a septic tank, a simple pit latrine, or a ventilated improved pit-latrine. Isolation of excreta means less probability of contamination of human environments. Scenario III corresponds, in this study, to a situation in which the population has access to improved water supply and sanitation facilities and better drinking water quality through household water treatment. Scenario II corresponds to the situation typically encountered in developed countries with high coverage of "high technology" services such as in house regulated piped water supply and sewer connection. Scenario I represents the minimum theoretical risk corresponding to the absence of transmission of pathogens causing diarrhoea through inadequate water, sanitation and hygiene. These two scenarios have a 'low' to 'medium' load of faecal-oral pathogens in the environment, and are associated with a regional incidence of diarrhoea of less than 0.3 per person per year.

The population of each WHO sub-region was assigned to the various exposure categories based on information on water and sanitation coverage levels in the year 2000, presented in the Global Water Supply and Sanitation Assessment 2000 report (WHO & UNICEF 2000) (Table 3).

List of interventions

For each sub-region, a set of potential interventions was assessed by moving different proportions of population to lower exposure categories. Six interventions were modelled:

- halving the proportion of people in 2000 who did not have access to both improved water sources and improved sanitation facilities;
- providing household water treatment using chlorine to all people without access to improved water supply in 2000;
- increasing access to improved water supply and improved sanitation services to reach a 98% coverage;
- increasing access to improved water supply and improved sanitation services plus household water treatment to reach a 98% coverage;
- increasing access to in house piped water with treatment to remove pathogens and quality monitoring as well as sewerage connection with partial treatment of waste waters, to reach a 98% coverage.

The first intervention does not correspond precisely to the millennium development goal 7, target 10, as no increase in population growth and no projection in diarrhoeal disease incidence and case fatality rates were taken into account in the health benefits and the costs estimations.

Table 1 | 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.

Defining the baseline scenario

All the intervention scenarios were compared to the situation in 2000, which was defined as the baseline scenario. The baseline scenario represents the situation in which water and sanitation coverage levels in the year 2000, as estimated in the Global Water Supply and Sanitation Assessment 2000 report (WHO & UNICEF 2000), would be sustained.

Assessing the health impacts

Effectiveness of interventions

Each exposure scenario was assigned a relative risk (RR) of diarrhoea (Table 4). These were calculated by converting relative risks taken from the literature into risk reduction when moving between different exposure scenarios. The systematic review conducted by Fewtrell *et al.* (2005)

Table 2 | Selected exposure scenarios

Level	Description	Environmental faecal-oral pathogen load
VI	No improved water supply and no improved sanitation in a country which is not extensively covered by those services, and where water supply is not routinely controlled	Very high
Vb	Improved water supply and no improved sanitation in a country which is not extensively covered by those services, and where water supply is not routinely controlled	Very high
Va	Improved sanitation but no improved water supply in a country which is not extensively covered by those services, and where water supply is not routinely controlled	High
IV	Improved water supply and improved sanitation in a country which is not extensively covered by those services, and where water supply is not routinely controlled	High
III	Improved water supply and improved sanitation in a country which is not extensively covered by those services plus improved water quality	High
II	Regulated in-house piped water supply and full sanitation coverage, with partial treatment for sewage, corresponding to a situation typically occurring in developed countries	Medium to low
I	Ideal situation, corresponding to the absence of transmission of diarrhoeal disease through water, sanitation and hygiene	Low

Based on Prüss *et al.* (2002).

provided data to allow estimation of RRs between scenario IV, Va, Vb, and VI. According to that study, a reduction of 25% (95% CI 9%–38%) in diarrhoeal diseases can be observed when providing an improved water supply, and 32% (95% CI 13%–47%) when providing improved sanitation facilities. When providing both improved water supply and improved sanitation facilities, a reduction of 33% (95% CI 24%–41%) is achieved. A more recent review from Clasen *et al.* (2006) showed a reduction of 37% (95% CI 25%–8%) in diarrhoeal diseases by treating water in the household, using water chlorination. Data sources for relative risk transitions between scenario I, II and IV were taken from the Prüss-Üstün *et al.* study (2004). Their RR estimation was defined by published reviews and large surveys where available. These estimates are subsequently used in this cost-effectiveness analysis.

There is a great deal of uncertainty surrounding health risk changes associated with the shift between scenarios II and IV, which corresponds more generally to the transition between developed and developing regions with incomplete coverage of improved water supply and sanitation. It remains the most "data-scarce" risk transition as it is impossible to complete the coverage in piped water supply and sewer connection in a reasonable time frame, without simultaneous change in other determinants of health. This risk transition was then estimated on the basis of studies describing part of that transition, which includes improvement of drinking water quality and improvement of basic hygiene (Prüss-Üstün *et al.* 2004).

Effectiveness model

Estimating intervention effectiveness requires an assessment of the fatal and non-fatal health outcomes which occur when an intervention is introduced. In general, interventions might change the incidence, duration of time within different health states, or the case fatality rate. Because interventions to improve water supply and sanitation services are preventive interventions, the main outcome is first a reduction in the number of diarrhoea episodes and accordingly a proportionate reduction in the number of deaths. For each intervention in each sub-region, a new incidence rate was calculated based on the number of persons which were moved to lower exposure categories

Table 3 | Distribution of the population in exposure scenarios, 2000

Subregion	II [%]	IV [%]	Va [%]	Vb [%]	VI [%]
AFR-D	0	54	5	6	35
AFR-E	0	43	10	9	38
AMR-A	99.8	0	0	0	0.2
AMR-B	0	76	1	9	14
AMR-D	0	68	0	7	25
EMR-B	0	83	5	8	4
EMR-D	0	66	0	16	18
EUR-A	100	0	0	0	0
EUR-B	0	79	8	1	12
EUR-C	0	94	5	0	1
SEAR-B	0	70	3	7	20
SEAR-D	0	35	0	53	12
WPR-A	100	0	0	0	0
WPR-B	0	42	1	33	24

Based on WHO/UNICEF (2000).

and the amount of exposure reduced in that population. The regional patterns of diarrhoeal diseases for the year 2000, including prevalence, incidence, mortality, duration of the disease and age specific disability weight were provided by the WHO Global Burden of Disease Unit (WHO 2002). The

Table 4 | Relative risks with lower and upper uncertainty estimates associated with scenarios

Scenario							
Approach	I	II	III	IV	Va	Vb	VI
Lower estimate	1	2.5	2.5	3.8	3.9	4.3	5.7
Best estimate	1	2.5	4.5	6.9	7	7.7	10.3
Upper estimate	1	2.5	4.5	10.0	10.1	11.2	14.9

Based on Prüss-Ustün *et al.* (2004) and Fewtrell *et al.* (2005).

number of healthy life years gained or DALYs averted by the whole population from reductions in incidence of diarrhoea was calculated using the WHO developed software POPMOD (WHO 2003). It consists of a simple population model as summarised in Figure 1.

In each sub-region, the population per sex and per age was distributed among the defined states, based on the year 2000 estimates of incidence, case fatality rates for the modelled disease and the general birth and mortality rates for the specific population. POPMOD was run first using these 2000 rates and the number of healthy life years lived by the studied population was estimated. The different rates used in the model were identical from one year to another due to the lack of data on overall diarrhoeal disease projections. No increase in population growth was taken into account. POPMOD was run a second time with the new incidence rate due to the specific chosen intervention. Interventions were assumed to be in place for a period of 10 years. The difference between the number of healthy life years lived by the population with and without the intervention gave the number of healthy years gained or DALYs averted due to that specific intervention. The efficacy of the different interventions varied from region to region as it was dependent on the current levels of exposure and the region-specific levels of incidence and case fatality rates.

Assessing the costs

Costs were calculated as the sum of all resources required to put in place and maintain the interventions. These costs included investment costs such as planning, hardware construction and house alteration and recurrent costs such as operation and maintenance of hardware, replacement of parts, emptying of septic tank, latrines, education, monitoring, regulation and control of water supply.

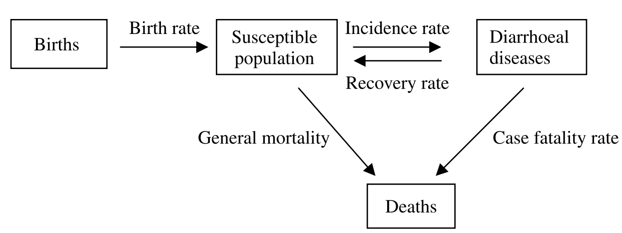

Figure 1 | Population model.

For the initial investment cost of water and sanitation interventions, the main source of cost data was the data collected for the Global Water Supply and Sanitation Assessment 2000 Report (WHO & UNICEF 2000), which gives the investment cost per person per technology covered in 3 major world regions (Africa, Latin America and the Caribbean, and Asia/Oceania), shown in Table 5.

No single source was available for the estimation of recurrent costs. Therefore, values from the literature were combined with assumptions for the various components of recurrent costs, giving the results which are presented in Table 6. Cost assumptions were based on the likely recurrent cost as a percentage of the annual investment cost. Assumptions were made about the length of life of the equipment involved in making the improvements (Table 6).

Total costs per technology were annualized using the formula of Drummond et al. (1997) and the WHO G-CEA guidelines:

$$E = P/A\,(y, r)$$

$$A\,(y, r) = 1 - (1 + r)^{-y}/r,$$

where E is the equivalent annual cost, P the purchase price, A the Annuity factor, r the discount (interest rate) and y the life span of the capital.

All cost estimations were calculated and presented in terms of US dollars, year 2000.

Table 5 | Initial investment cost per capita (US$ 2000)

	Initial investment cost per capita (US$ 2000)		
Improvement	**Africa**	**Asia**	**LA&C**
Water improvement			
House connection	102	92	144
Standpost	31	64	41
Borehole	23	17	55
Dug well	21	22	48
Rainwater	49	34	36
Disinfection at point of use	0.13	0.094	0.273
Sanitation improvement			
Sewer connection	120	154	160
Septic tank	115	104	160
VIP	57	50	52
Simple pit latrine	39	26	60

Based on WHO/UNICEF (2000).

Estimation of uncertainty

Fewtrell's and Clasen's systematic reviews (Fewtrell et al. 2005; Clasen et al. 2006) provide confidence intervals for the transition between scenarios III, IV, Va, Vb and VI. But some of the reviews and surveys used in the RR values between scenarios I, II and IV do not report confidence intervals. It was therefore difficult to combine the various sources of uncertainties. The main sources of uncertainty probably lie in the lack of reliable estimate for the risk transition between scenarios II and IV. Upper and lower boundaries were based on varying the estimates between scenario II and IV and were based on the Prüss-Üstün et al. study (2004).

For the cost estimations, low and high cost values were based on the sets of assumptions for recurrent costs presented in Table 6.

RESULTS

Costs of interventions

The annual costs of improving access to safe water supply and adequate sanitation services varied depending mainly on the increase in the number of persons having access to better water and sanitation service levels, and the type of technology selected. The costs of increasing access to safe water and adequate sanitation vary from high when sophisticated technology is used, to substantially lower when simple technology, that demands low maintenance, is used. When dividing the total annual costs by the entire population of the sub-region, the annual cost per capita

Table 6 | Assumptions used in the recurrent cost calculation

Improvement	Length of life In years (+ range)	Operation, Maintenance, Surveillance as % annual cost (+ range)	Education as % annual cost (+ range)	Water source protection as % annual cost (+ range)
Water improvement				
House connection	40 (30–50)	30 (20–40)		10 (5–15)
Standpost	20 (10–30)	5 (0–10)		10 (5–15)
Borehole	20 (10–30)	5 (0–10)		5 (0–10)
Dug well	20 (10–30)	5 (0–10)		5 (0–10)
Rainwater	20 (10–30)	10 (5–15)		0
Sanitation improvement				
Sewer connection	40 (30–50)	25 (20–30)	10 (0–10)	–
Septic tank	30 (20–40)	10 (5–15)	5 (0–10)	–
VIP	20 (10–30)	5 (0–10)	5 (0–10)	–
Simple pit latrine	20 (10–30)	5 (0–10)	5 (0–10)	–

becomes quite insignificant. Table 7 shows the estimated costs of the five interventions, by world sub-region.

- The expected annual cost of chlorination at point of use ranged from US$3 million in EMRB (US$0.02 per capita) to US$89 million in WPRB (US$0.09 per capita).
- The estimated cost of increasing access to improved water supply and sanitation ranged from US$137 million in EMRB (US$0.99 per capita) to US$5.6 billion in WPRB (US$3.64 per capita).
- The estimated annual cost of increasing access to in house piped water supply and sewer connection ranged from US$918 million in AMRD (US$12.89 per capita) to US$19.2 billion in SEARD (US$15.47 per capita).

Cost-effectiveness of interventions

Figure 2 presents the costs of water and sanitation interventions versus the healthy life years gained in AFRO D and AFRO E, for a 10 year period of implementation and use of interventions.

- It shows that piped water supply and sewer connection would achieve maximum health gains (71 million DALYs averted) but investment and recurrent costs would also be quite important (ranging from US$ 48 to 60 billion).
- Disinfection at point of use total costs would remain the lowest compared to the other interventions (ranging from US$ 338 to 461 million), but still would provide high health improvements (between 17 and 19 million DALYs averted).

Similar patterns were observed in the other sub-regions, in terms of costs and health benefits. Table 8 shows the health gains in average annual healthy years gained, per intervention, by world sub-region.

The average cost-effectiveness ratios (CER measured in US$ per DALY averted which corresponds to the total costs divided by health effects) were much higher in AMRB, EMRB, EUROB and SEARB than in the other sub-regions. The percentage of access to improved water and sanitation in these regions is high compared to other sub-regions (respectively 76%, 83%, 79%, and 70%) and the diarrhoea incidence and prevalence rates are lower than in the D and E regions, therefore the health benefits are lower compared

Table 7 | Average annual cost of interventions (US$ 2000)

	Africa		The Americas		Eastern Mediterranean		Europe	South and South–East Asia		Western Pacific
	AFRO D	**AFRO E**	**AMRO B**	**AMRO D**	**EMROB**	**EMRO D**	**EURO B**	**SEARO B**	**SEARO D**	**WPRO B**
Total population (million)	294.1	345.5	430.9	71.2	139.1	342.6	218.5	293.8	1241.8	1532.9
Total cost per year (million)										
Halve pop w/o access to improved WS&S	500	649	461	108	70	253	179	292	2,442	2,849
Disinfection at point of use	34	46	34	9	3	15	17	16	35	89
Improved WS&S (98% coverage)	981	1,273	904	211	137	495	350	573	4,787	5,585
Improved WS&S + Disinfection (98% coverage)	1,015	1,319	938	220	140	510	367	588	4,822	5,674
Piped water supply and sewer connection (98% coverage)	4,879	6,044	4,225	918	1,341	3,277	2,091	5,110	19,213	17,457
Cost per capita per year										
Halve pop w/o access to improved WS&S	1.70	1.88	1.07	1.51	0.50	0.74	0.82	0.99	1.97	1.86
Disinfection at point of use	0.12	0.13	0.08	0.13	0.02	0.04	0.08	0.05	0.03	0.06
Improved WS&S (98% coverage)	3.33	3.68	2.10	2.97	0.99	1.45	1.60	1.95	3.85	3.64
Improved WS&S + Disinfection (98% coverage)	3.45	3.82	2.18	3.09	1.01	1.49	1.68	2.00	3.88	3.70
Piped water supply and sewer connection (98% coverage)	16.59	17.49	9.80	12.89	9.64	9.57	9.57	17.39	15.47	11.39

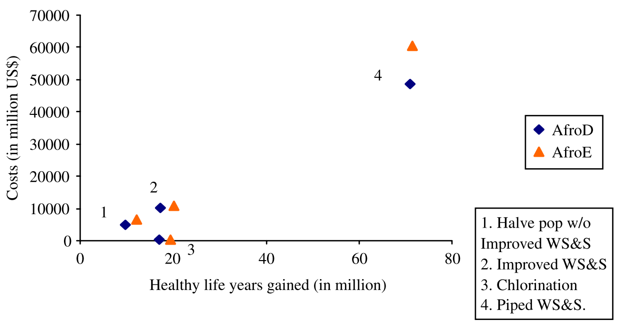

Figure 2 | Costs of interventions vs. healthy life years gained in AFROD and AFROE.

to the other regions. However, the costs of improving access to safe water and sanitation are still important, leading to high cost-effectiveness ratios. The estimated CER for disinfection at point of use varied between US$20 per DALY averted in AFRD to US$684 per DALY averted in AMRB. The CER of interventions achieving a 98% coverage in improved water supply and sanitation services (low technologies) ranged from US$528 in EMRD to US$12,949 per DALY averted in EURB and was between US$684 in EMRD and US$9,049 per DALY averted in EURB for in house piped water supply and sewer connection (high technologies) (Table 9). The most cost-effective intervention across all sub-regions was disinfection at point of use. Although in house piped water and sewer connection was the most expensive intervention, the difference in cost-effectiveness between increasing access to low technologies and high technologies was low in many sub-regions.

Uncertainty analysis

Best- and worst-case scenarios were derived for the cost-effectiveness ratios by using the low and high cost values of the sets of assumptions for the recurrent costs, in addition to the lower and upper values reported above for the risk transition between scenarios.

Figure 3 shows the cost-effectiveness ratios under low and high assumptions for the sub-region AFROD. The principal finding from this sensitivity analysis was that chlorination at point of use remains the most cost-effective intervention but in-house piped water and sewer connections has a lower cost-effectiveness ratio than improved water and sanitation services under high assumptions, which is already the case in certain sub-regions. In general the ranking of interventions in terms of CER did not change.

DISCUSSION

Main findings

The report of the Commission on Macroeconomics and Health suggested that interventions with an annualized cost of less than three times the GDP (Gross Domestic Product) per capita for each DALY averted, are cost-effective interventions, and those with an annual cost of less than the GDP per capita for each DALY averted are very cost-effective. Interventions falling into that category represent good value for money (WHO 2001). Using this as a yardstick, most water and sanitation interventions were cost-effective in most sub-regions, the exceptions being the European region, SEARB and WPRB (Table 9). The cost-effectiveness of interventions varies from region to region as it is dependent on the region-specific levels of incidence and case fatality rates, the number of persons being reached by each intervention and the cost structures. Water and sanitation interventions are much more effective in the regions where the diarrhoea case fatality rate is high, such as in the D and E regions, compared to the B regions.

Previous studies have estimated the cost-effectiveness of water supply, sanitation and hygiene interventions to prevent diarrhoea. An influential article by Walsh and Warren concluded that the annual cost per death averted by providing a community standpipe and any sort of sanitation in sub-Saharan Africa is very high compared to curative measures (Walsh & Warren 1980). They estimated a cost of US$ 3600 per child death averted in 1979, approximately US$ 10,000 in 1996 prices. Varley argued that “software-related” interventions, such as hygiene education or regulation of drinking water are highly cost-effective compared to “hardware” interventions. He estimated the cost-effectiveness of “hardware” interventions, being defined as the presence of adequate water supply and sanitation facilities, to be US$ 1152 per DALY averted in 1996, in children under 5 living in slums or peri-urban areas. He estimated the CER of “software” interventions to be US$ 44 per DALY averted in children under 5 (Varley 1998).

Table 8 | Average annual healthy years gained per intervention (discounted 3%, age weighted)

	Africa		The Americas		Eastern Mediterranean		Europe	South and South–East Asia		Western Pacific
	AFRO D	**AFRO E**	**AMRO B**	**AMRO D**	**EMROB**	**EMRO D**	**EURO B**	**SEARO B**	**SEARO D**	**WPRO B**
Total population (million)	294.1	345.5	430.9	71.2	139.1	342.6	218.5	293.8	1241.8	1532.9
HY gained per year										
Halve pop w/o access to improved WS&S	981,976	1,214,961	49,016	41,231	18,188	509,734	18,787	77,503	1,910,487	513,446
Disinfection at point of use	1,705,583	1,942,916	48,980	65,301	9,889	528,417	31,035	102,970	550,462	426,443
Improved WS&S (98% coverage)	1,717,969	2,010,174	87,583	76,020	27,556	938,966	27,028	133,839	3,514,069	934,453
Improved WS&S + Disinfection (98% coverage)	4,881,993	5,239,890	380,808	269,859	174,652	3,219,853	146,725	494,625	8,028,486	2,274,016
Piped water supply and sewer connection (98% coverage)	7,098,689	7,150,547	594,712	408,207	270,822	4,793,667	231,056	756,660	10,647,617	3,121,971
HY gained per 100,000 per year										
Halve pop w/o access to improved WS&S	334	352	11	58	13	149	9	26	154	33
Disinfection at point of use	580	562	11	92	7	154	14	35	44	28
Improved WS&S (98% coverage)	584	582	20	107	20	274	12	46	283	61
Improved WS&S + Disinfection (98% coverage)	1,660	1,517	88	379	126	940	67	168	647	148
Piped water supply and sewer connection (98% coverage)	2,414	2,070	138	573	195	1,399	106	258	857	204

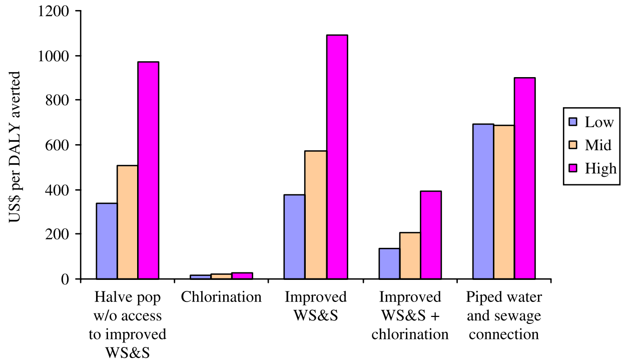

Figure 3 | Cost-effectiveness ratios under low and high assumptions in AFROD.

Although Varley's results are within the ranges of estimations found in this analysis, it is difficult to compare results from this study with the ones from previous studies, because of the difference between the methodologies used. The cost-effectiveness of potential water and sanitation interventions could vary widely depending on many parameters such as the region, the baseline level of diarrhoea morbidity and mortality, the chosen type of technology, the impact surveys which were selected to estimate the risk transition between two exposure scenarios, the baseline scenario, etc.

Results from this cost-effectiveness analysis indicate that the provision of in house piped water supply and sewer connection is the intervention that maximizes health gains (Table 8) but it is also the most expensive intervention. For many developing countries, difficulties in financing this type of technology would arise because of economic constraints. Improving water supply and sanitation services through low-cost technologies such as protected wells and pit latrines might be more appropriate options for countries with limited budgets, although the health and additional benefits would not be as large. The available funds should be used efficiently and be focussed on the poor and on the areas of greatest need. Many of the world's people in developing countries continue to obtain their water from a source outside their premises and carry it back to their homes (WHO & UNICEF 2004). Improving the microbial quality of collected water stored in households as a strategy to further reduce waterborne disease risks would be a complementary option which can be implemented effectively, quickly and affordably. On a short-term basis, while

Table 9 | Average cost-effectiveness ratios (US$ per DALY averted)

	Africa		The Americas		Eastern Mediterranean		Europe	South and South-East Asia		Western Pacific
	AFRO D	AFRO E	AMRO B	AMRO D	EMROB	EMRO D	EURO B	SEARO B	SEARO D	WPRO B
Halve pop w/o access to improved WS&S	***510***	**534**	**9,414**	**2,614**	**3,844**	***496***	9,505	3,769	**1,278**	5,550
Disinfection at point of use	***20***	***24***	***684***	***138***	***330***	***28***	***551***	***155***	***63***	***210***
Improved WS&S (98% coverage)	**571**	**633**	**10,326**	**2,778**	**4,973**	**528**	12,949	4,278	1,362	5,977
Improved WS&S + Disinfection (98% coverage)	***208***	***252***	***2,463***	***816***	***803***	***159***	**2,502**	**1,189**	**601**	**2,495**
Piped water supply and sewer connection (98% coverage)	**687**	**845**	**7,104**	**2,249**	**4,950**	**684**	9,049	6,753	1,804	5,592
Regional GDP per Capita (US$ 2000)	534	681	4,320	1,643	5,355	1,127	2,447	971	452	1,106

Bold cost-effective; ***bold and italic*** very cost-effective.

time elapses during the extension of coverage and upgrading of piped water and sewage services, this option appears to rapidly and efficiently reduce diarrhoea incidence.

Limitations

It is likely that the health impacts of interventions described in this analysis are significantly under-estimated because:

- the effects on disease outcomes other than diarrhoea have not been taken into account. A wide range of health outcomes such as infectious hepatitis, trachoma, schistosomiasis and other geohelminthiases would also be affected by the same interventions to greater overall benefit;
- impacts on the case fatality rate have not been taken into account. Decreasing the incidence will likely have beneficial impact on nutrition and the risk of dying from diarrhoea would therefore be decreased;
- this analysis has been restricted to the acute health effects of diarrhoea. The long-term effects of multiple diarrhoeal episodes, including delayed weight recovery and possible malnutrition have not been considered.

On the other hand, some potential negative impacts of changes to water and sanitation technologies were not taken into account. For example, sanitation improvement such as household sewer connection with partial treatment of waste waters may mean discharge of sewage into the natural environment or into an open sewer, allowing the possibility of re-infection or the habitat for vectors to breed. These negative health impacts arising from environmental damage and the costs of water resources conservation have not been included in this analysis.

On the cost side, total funding of water and sanitation interventions is difficult to estimate and may vary widely depending on the methodology used and assumptions made. Any calculation to this end will suffer from many uncertainties and substantial data gaps.

Moreover, one should be careful when comparing the cost-effectiveness ratios of water and sanitation interventions with for example curative interventions. While it is possible to capture all the costs in a cost-effectiveness ratio, only health benefits have been included in these calculations and the results need to be interpreted in that light. Although not analysed in this study, in addition to the reduction of water and sanitation-related diseases, providing better access to an improved water supply and sanitation may confer many and diverse potential additional benefits, ranging from the easily identifiable and quantifiable -such as expenditures averted due to less illness and reduction in time expenditure (or time savings) associated with closer water and sanitation facilities – to the intangible and difficult to measure -such as convenience, well-being- (Hutton 2001). Subtracting the averted treatment costs due to fewer cases of illness would lower the estimated cost-effectiveness ratios of interventions. Providing water supply and sanitation facilities closer to homes may result also in significant reduction in time expenditure especially for mothers and girls. Such time gains may lead to increased production, better school attendance or more leisure time, and thus could result in significant economic and social benefits which are not included in the CEA ratio. When comparing treatment interventions with water and sanitation interventions, it would be incorrect to compare them on the basis of only deaths or DALYs averted (Briscoe 1984). When making comparisons between interventions with multiple impacts (such as water and sanitation improvements) to interventions whose sole purpose is to avert deaths (such as an oral rehydration therapy program), a consistent and fair approach must be used, and should take into account both the health gains and the non-health gains, in the decision process. Further work in that area has been undertaken (Hutton & Haller 2004).

Cost-effectiveness analysis is a useful tool for rational decision-making but it has its limitations and it will not provide information for all the factors which need to be taken into account. In order to select the most appropriate intervention for a particular setting, attention should be paid to the health and non-health benefits, the costs, and other parameters such as the environmental and social feasibility, and the sustainability of such an option, which are very much location-specific.

CONCLUSIONS

This analysis found that water and sanitation interventions were cost-effective in most sub-regions. Using improved water and sanitation facilities such as, a protected dug well and a ventilated improved pit latrine, within reasonable walking distance, provides substantial health benefits. Access to a higher level of services such as on plot piped water would bring a further major improvement in health. These benefits are likely to be accompanied by substantial time savings that may contribute significantly to household economy. Because the burden of disease associated with unsafe water supply, sanitation and hygiene is mainly concentrated in children in developing countries, emphasis should be placed on interventions likely to yield an accelerated and affordable health gain in this group. Disinfection of drinking water at the point of use with chlorine and safe storage vessels is one option of this type. A policy shift to include better household water quality management as a short-term solution, to complement the continuing expansion of coverage and upgrading of services would appear to be a cost-effective health intervention in many developing countries.

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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.

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