BENEFITS AND COSTS OF DRINKING WATER, SANITATION AND HYGIENE INTERVENTIONS

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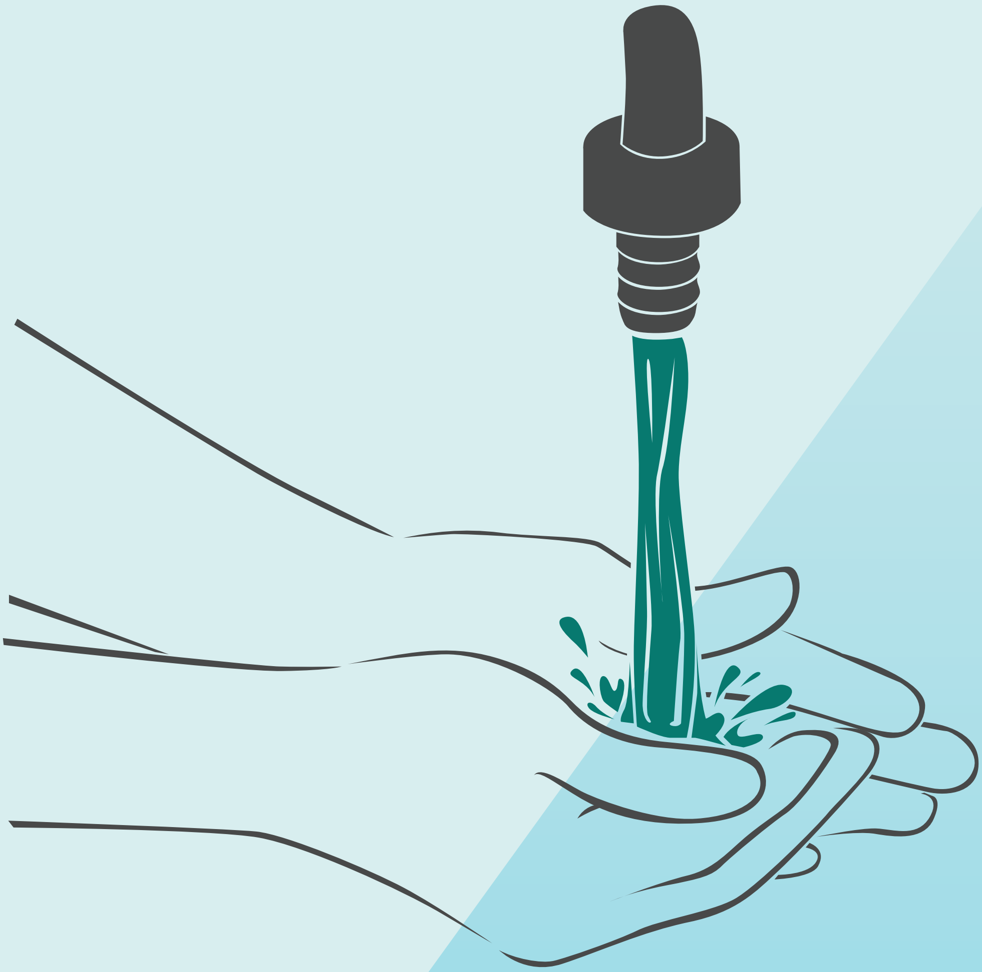

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Bangladesh Priorities

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Acronyms

AF	Attributable fraction
ALRI	Acute lower respiratory infection
BBS	Bangladesh Bureau of Statistics
BDT	Bangladeshi Taka
CCC	Copenhagen Consensus Center
CI	Confidence Interval
CLTS	Community Led Total Sanitation
DALY	Disability adjusted life year
DHS	Demographic and Health Survey
ft	feet
GBD	Global burden of disease
GDP	Gross domestic product
HH	Household
JMP	Joint Monitoring Programme
MICS	Multiple Indicator Cluster Survey
ml	milliliter
OR	Odds ratio
POU	Point-of-use
Ppb	parts per billion
PPP	Purchasing power parity
RR	Relative risk
SD	Standard deviation
µg	microgram
VSL	Value of statistical life
YLD	Year lost to disease
YLL	Year of life lost to premature death
WASH	Water, sanitation and hygiene
WHO	World Health Organization
WSP	Water and Sanitation Program

Executive summary

This paper presents an assessment of the benefits and costs of i) interventions to mitigate exposure to arsenic in drinking water; ii) provision of improved on-site household sanitation; and iii) promotion of regular handwashing with soap.

As many as 98% of the population in Bangladesh have access to an improved drinking water source. This is a tremendous achievement at Bangladesh's income level. It was, however, discovered that many of the tubewells were contaminated by arsenic, a problem affecting 25% of households with concentrations above the WHO guideline.

Bangladesh has also made huge strides in sanitation. Open defecation has almost been eradicated, down from 34% of the population in 1990. And there has been a substantial increase in improved, non-shared facilities, but also a substantial increase in households sharing facilities. Thus in 2015, 61% of the population had access to improved non-shared sanitation while 28% shared facilities with other households.

The single most effective hygiene practice is regular handwashing with soap. Albeit somewhat higher than regional averages in low- and middle-income countries, 7 studies indicate that only about 18% of the population in Bangladesh practice handwashing with soap (Freeman et al, 2014).

The paper finds that as many as 45-63 thousand people die prematurely each year due to arsenic in drinking water in Bangladesh, of which almost all can be avoided by the interventions assessed in this paper. The paper also finds that around 11 thousand deaths can be avoided from improved sanitation and handwashing with soap.

The three arsenic mitigation interventions – deep tubewells, pond sand filter, and rainwater harvesting – are found to provide health benefits that are 6 – 35 times higher than the cost of the interventions, depending on arsenic concentrations and method of valuation of health benefits.

The BCRs are highest for deep tubewells followed by rainwater harvesting and pond sand filter. Thus from an economic and health perspective, deep tubewell is the preferred option. It is also the option that generally requires least maintenance, has the lowest risk of bacteriological contamination, and is likely to be the most reliable options in both the dry and rainy season. However, there may be locations where deep tubewells cannot satisfactorily replace shallow tubewells with arsenic, and communities may choose to opt for pond sand filter or rainwater harvesting.

The two sanitation interventions – improved sanitation for households currently with unimproved facilities and non-shared improved sanitation for households currently sharing a facility with other households – provide benefits that are 1.4 – 2.3 times higher than the costs. These benefits do not include intangible benefits such as status and comfort, which are more difficult to estimate.

And the regular handwashing with soap provides benefits that are 1.05 – 1.35 higher than costs for mothers and young children, but only 1/4th of costs for older children and other adults.

The relatively low benefit-cost ratios of improved sanitation and handwashing with soap mainly reflect two basic realities. Firstly, Bangladesh has achieved substantial reductions in child mortality and diarrheal case fatality rates. This lowers the health benefits of the interventions. Secondly, the valuation of the health benefits is proportional to the country's income level in order to be realistic about affordability. The monetized benefits are therefore relatively low, as GDP per capita in Bangladesh was about US$ 1,330 in 2014.

The main conclusion of the assessment in this paper is the very high benefits relative to costs of combatting exposure to arsenic in drinking water. This is not only the case for households exposed to concentration levels above the Bangladeshi standard of 50 ppb, but also for households exposed to concentrations as low as the WHO guideline of 10 ppb. The BCRs are highest for deep tubewells which from an economic and health perspective is the preferred option wherever they suitably can be implemented.

Status of drinking water, sanitation and hygiene

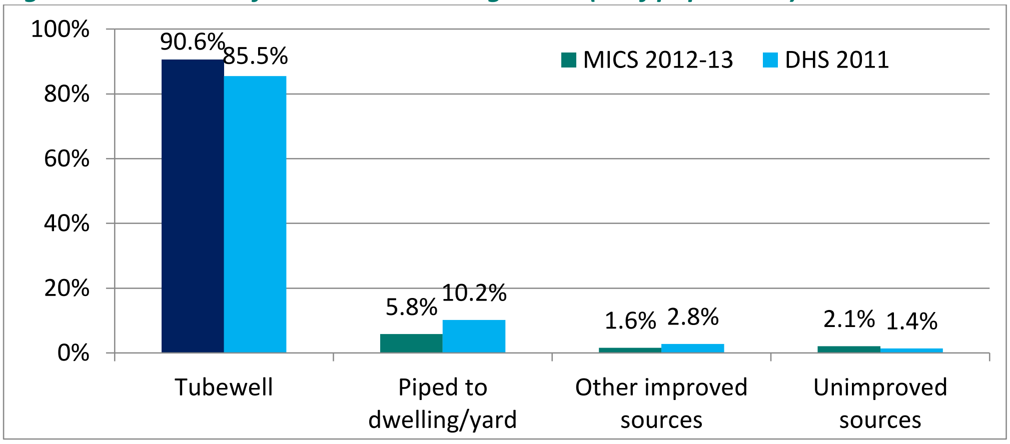
Six domains of household drinking water, sanitation and hygiene are reviewed to inform a selection of interventions for which benefits and costs are assessed. The domains are:

i) Sources of drinking water
ii) Quality of drinking water (arsenic, microbiological)
iii) Point-of-use (POU) treatment of water prior to drinking
iv) Water quantity and access
v) Access to sanitation
vi) Handwashing with soap

Sources of drinking water

The Joint Monitoring Programme (JMP) of WHO/UNICEF classifies household drinking water sources into improved and unimproved sources. As many as 98% of households in Bangladesh have access to an improved drinking water source according to the Multiple Indicator Cluster Survey (MICS) 2012-13 and the Demographic and Health Survey (DHS) 2011 (figure 1.1). The predominant source in rural areas is tubewells (96%). The predominant sources in urban areas are tubewells (55-70% depending on data source) and piped water to dwelling/yard (24-37%). Thus the issue of simply improved versus unimproved sources of household drinking water is no longer the main issue in Bangladesh.

Figure 1.1. Sources of household drinking water (% of population)

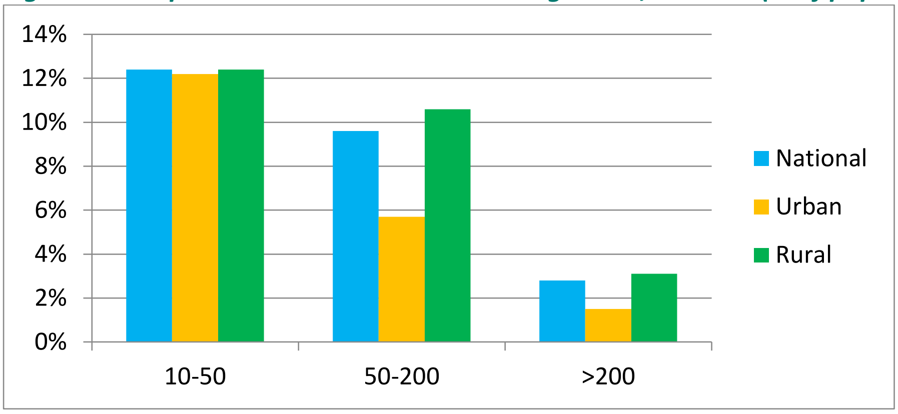


Source: Produced from NIPORT et al (2013) and BBS/UNICEF (2014).

Quality of drinking water

The wide provision of tubewells, as a protection against microbacteriological contamination, is a major accomplishment in Bangladesh. Very unfortunately, however, it turned out that many aquifers contain arsenic. Consequently, 25% of households have arsenic concentrations in drinking water above the WHO (provisional) guideline of 10 parts per billion (ppb) or microgram per liter (µg/L)[1] and 12% above the Bangladeshi standard of 50 ppb (µg/L) according to MICS 2012-13 (figure 1.2).

Figure 1.2. Population with arsenic in drinking water, 2012-13 (% of population)

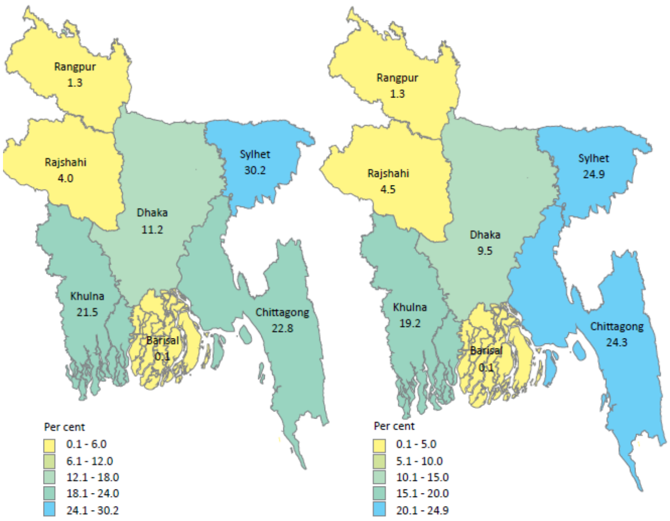


Source: Produced from BBS/UNICEF (2014).

The prevalence of arsenic in Bangladesh is much higher in tubewells than in piped water supply or other sources of drinking water. And several studies have found that arsenic contamination is far more widespread in relatively shallow tubewells than in deep tubewells. According to the MICS 2009, 71% of households have “shallow” tubewells of depth < 5oo ft while 16% have “deep” tubewells of depth > 550 ft (BBS/UNICEF, 2010).

The prevalence of arsenic also varies geographically. Less than 5% of the population has arsenic > 50 ppb in their source water and drinking water in the northwest while almost 25% have this level of arsenic in their drinking water in eastern Bangladesh (figure 1.3).

Figure 1.3. Percent of population with source water (left) and drinking water (right) with arsenic > 50 ppb



Source: BBS/UNICEF (2014)

[1] This is also the legal standard in the US and the EU.

The MICS 2012-13 also measured E.coli contamination of household source water and drinking water (BBS/UNICEF, 2014). 19% of households had source water with high or very high contamination levels of greater than 10 E.coli colony forming units per 100 milliliter of water (> 10 CFU/100 ml). 38% of households had drinking water with these levels of contamination, suggesting that contamination takes place between the point of collection and use (during the process of fetching, storing, and dispensing water). One intervention to address this problem is household point of use treatment of drinking water, such as boiling or filtering.

Point-of-use drinking water treatment

Improved drinking water sources are generally less contaminated by microbiological pollution than unimproved sources. However, improved sources are also at risk of contamination. Household point-of-use (POU) treatment has therefore been advocated to mitigate risk of contamination, both for households with and without improved drinking water sources.

As few as 10% of households in Bangladesh practice POU drinking water treatment. Boiling or filtering is the most common practices. Treatment is far more prevalent among urban households (26-31%) than among rural households (3%), and among households with unimproved drinking water sources (25%) versus much less than 10% among those with improved sources (BBS/UNICEF, 2014; NIPORT et al, 2013).

Water quantity and access

Availability and convenient access to plentiful water is essential for good health. One indicator included in the Bangladesh DHS 2011 and MICS 2012-13 surveys is time to obtain (drinking) water. According to the surveys, 71-75% of households have water on premises and 21-25% have water within 30 minutes round trip. And only 3-4% have a more than 30 minutes round trip for fetching (drinking) water (BBS/UNICEF, 2014; NIPORT et al, 2013).

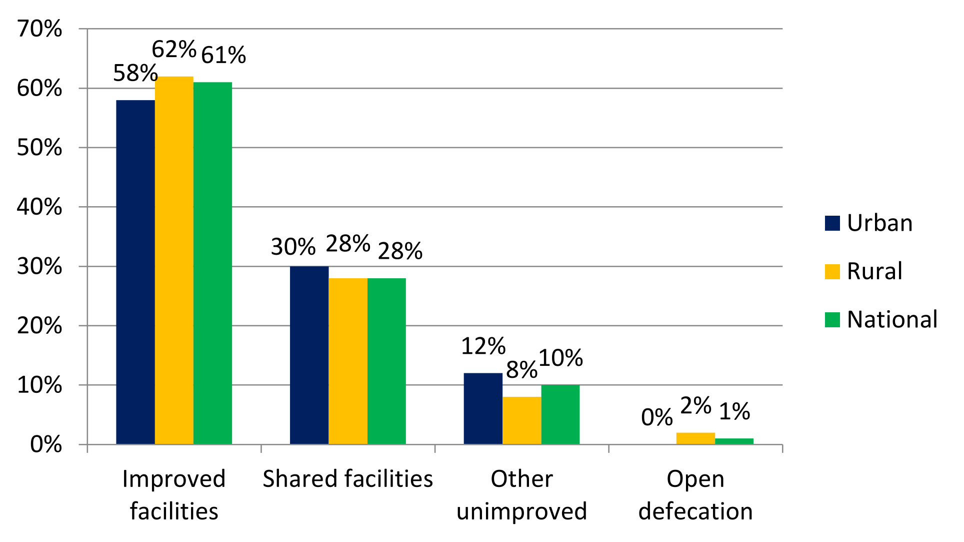
Access to sanitation

An estimated 61% of the population in Bangladesh had access to an improved, non-shared sanitation facility in 2015 according to the Joint Monitoring Programme of WHO/UNICEF (WHO/UNICEF, 2015).[2] 28% shared facilities, 10% had other unimproved facilities, and only 1% practiced open defecation (had no access to facility). Rural coverage rates of improved, non-shared facilities were somewhat higher than the urban rate.

[2] The Joint Monitoring Programme (JMP) of WHO/Unicef does not recognize a sanitation facility that is shared by two or more households as an improved facility.

The trend since 1990 has been a substantial increase in improved, non-shared facilities, a substantial increase in households sharing facilities, a substantial decline in open defecation, and a moderate decline in use of unimproved facilities.

Figure 1.4. Household sanitation facilities, 2015 (% of population)



Source: WHO/UNICEF (2015).

The most common improved sanitation facility in urban areas is flush/pour flush toilet (54%) followed by pit latrine with slab (29%). The most common improved sanitation facility in rural areas is pit latrine with slab (47%) followed by flush/pour flush toilet (23%) (BBS/UNICEF, 2014).[3]

Handwashing with soap

The single most effective hygiene practice is handwashing with soap at critical junctures, according to a large body of research literature. Critical junctures include before preparing food, before feeding a child, after defecation, and before and after cleaning a child.

According to the Bangladesh DHS 2011 and MICS 2012-13 household surveys, 82%-86% of households had an observed place for handwashing. However, only 25% to 59% of these households had water *and* soap at this place (BBS/UNICEF, 2014; NIPORT et al, 2013). Freeman et al (2014) reports from 7 studies in Bangladesh that 18% of the population practice handwashing with soap. This is slightly higher than the average rates in low- and middle-income regions of the world (13-17%), albeit much lower than in the high-income regions (43-49%).

[3] Here including both non-shared and shared facilities.

Interventions

Two main principles guided the selection of WASH domains for the assessment of benefits and costs of interventions:

i) The percentage of the population affected by a WASH domain, as reviewed in the previous section; and

ii) The severity of health effects in each WASH domain as generally known from the scientific research literature.

The selected domains are:

a) Arsenic contamination of drinking water;
b) Household sanitation facilities; and
c) Handwashing with soap at critical junctures.

Arsenic contamination

Arsenic contamination of drinking water is the most important WASH related health concern in Bangladesh today. Finding cost effective solutions with acceptable benefit-cost ratios is a priority. An intervention to avoid arsenic exposure is provision of deep tubewells. Another intervention is household filtering. In some parts of Bangladesh ponds with sand filter is also an option. Rainwater harvesting for drinking would also solve the problem of arsenic, albeit very little utilized in Bangladesh and likely only a seasonal solution.

Three arsenic mitigation interventions therefore assessed in this paper are:

1) Deep tubewells;
2) Community level pond sand filter; and
3) Community level rainwater harvesting.

Household sanitation facilities

The household sanitation interventions assessed are:

1) Non-shared improved sanitation facility for households currently with a non-shared unimproved facility; and
2) Non-shared improved sanitation facility for households currently sharing a facility with other household(s).

The type of improved sanitation facility is a pour-flush toilet or an improved pit latrine or VIP latrine. These are all common improved sanitation facilities in Bangladesh.

As "only" 1% practice open defecation (OD), interventions to eliminate OD would have relatively small total benefits compared to the two interventions defined above, and is therefore not assessed.

Handwashing with soap

The benefit of handwashing in relation to child health is substantially higher than for adult health. This is because young children are more susceptible to diarrheal infections, have diarrheal infections more frequently, and have higher fatality rate from diarrheal infections than adults (or older children). Handwashing promotion programs are therefore assessed for children and adults separately:

1) Handwashing with soap promotion programs targeting mothers with young children; and
2) Handwashing with soap promotion targeting adults (in addition to mothers with young children).

Benefits of interventions

Improved drinking water quality, sanitation and hygiene can provide multiple health benefits. The health benefits include reduced risk of mortality and disease from arsenic mitigation (Argos et al, 2010; Sohel et al, 2009), reduced risk of diarrhea and other infectious diseases from improved bacteriological water quality, sanitation and hygiene (Pruss-Ustun et al, 2014), reduced risk of parasite infestation from improved sanitation and hygiene (Ziegelbauer et al, 2012), and reduced risk of respiratory infections in children from improved handwashing practices (Rabie and Curtis, 2006). Reduction in repeated diarrheal infections in early childhood can also contribute to improved nutritional status (reduced underweight and stunting), as evidenced by research studies in communities with a wide range of diarrheal infection rates in a diverse group of countries (World Bank, 2008).

Arsenic mitigation

Exposure to arsenic in drinking water has been found to be associated with various health effects, including both mortality and morbidity, and many studies of these health effects have been conducted in Bangladesh.

Studies of mortality from arsenic exposure in populations in Bangladesh include: All-cause and chronic disease mortality (Argos et al, 2010), non-accidental mortality, cancers, cardiovascular disease mortality, and infectious disease mortality (Sohel et al, 2009), heart disease mortality (Chen et al, 2011), lung disease mortality (Argos et al, 2014), mortality in children (Rahman et al, 2013), and stroke mortality (Rahman et al, 2014).

Exposure to arsenic in drinking water is also associated with skin lesions (Argos et al, 2011; Karagas et al, 2015), various forms of cancer, kidney and liver failure, and ulcer (FAO et al, 2010). There is increasing evidence that prenatal arsenic exposure is associated with morbidity and mortality later in life (FAO et al, 2010). Various neurological impairments from arsenic exposure have also been documented in many studies, such as poor cognitive performance, reduced intellectual function, learning deficits, mood disorders, and visual, speech, attention and memory disturbances (Brinkel et al, 2009; Tyler and Allan, 2014).

About 39 million people, or 25% of households in Bangladesh, have arsenic concentrations in drinking water above 10 parts per billion (ppb) or microgram per liter (µg/L) and over 19 million have arsenic above the Bangladeshi standard of 50 ppb (µg/L) according to MICS 2012-13 (BBS/UNICEF, 2014).

Using the results from Sohel et al (2009) and Argos et al (2010) presented in annex 2, it is estimated that roughly 45-63 thousand people die prematurely each year due to arsenic in drinking water in Bangladesh. The average number of deaths is nearly 54 thousand, of which 44% occur among households with arsenic concentrations of 10-50 µg/liter (table 3.1).

The interventions assessed in this paper could mitigate nearly all of these deaths if fully implemented, assuming that 95% of deep tubewells and 100% pond sand filters and rainwater harvesting would comply with the WHO guideline of maximum 10 µg of arsenic per liter of drinking water (UNICEF, 2011). Diarrheal disease incidence, however, may increase somewhat – here assumed to increase by 10% - with substitution from shallow tubewells contaminated with arsenic to pond sand filters and rainwater harvesting as these water sources can become bacteriologically contaminated during handling and storage.

Table 3.1. Annual mortality from arsenic in drinking water in Bangladesh, 2014

Arsenic (µg/liter) (ppb)	Exposed population (million)	Annual deaths based on Sohel et al (2009)	Annual deaths based on Argos et al (2010)	**Annual deaths (average)**
10 - 50	19.7	15,625	32,053	23,839
50 - 150	11.6	14,948	4,995	9,971
> 150	7.9	14,176	25,849	20,013
Total	**39.2**	**44,749**	**62,897**	**53,823**

Source: Estimates by the author.

Improved sanitation and handwashing with soap

About 11,000 deaths from diarrheal disease and typhoid and paratyphoid could be prevented in Bangladesh each year if everyone has basic improved sanitation and practiced regular handwashing with soap. This is estimated from the methodology presented in Pruss-Ustun et al (2014) (annex 1).

Expected household disease reductions from the sanitation and hygiene interventions assessed in this paper are presented in table 3.2. Reductions from (1) and (3) are from Pruss-Ustun et al (2014). Reductions from (2) are assumed to be half of reductions from (1).

If the interventions are fully implemented and adopted, about 40% of the population in Bangladesh would benefit from the sanitation interventions and as many as 80% from the handwashing with soap promotion intervention.

Table 3.2. Reduction in diarrheal disease and mortality from sanitation and hygiene interventions

		Disease reduction
(1)	Non-shared improved sanitation facility for household currently with non-shared unimproved facilities	28%
(2)	Non-shared improved sanitation facility for household currently sharing a facilities with other households	14%*
(3)	Regular handwashing with soap	23%

* Assumed to be half of (1). Source: Based on Pruss-Ustun et al (2014).

Cost of interventions

Arsenic mitigation interventions

Cost of arsenic mitigation interventions is presented in tables 4.1. These costs are adapted and inflation adjusted from UNICEF (2011) in a study of Comilla district in Bangladesh. Each intervention is shared by 10 households. Additionally, it is assumed that households need to use five more minutes per day to fetch drinking water compared to their current source of drinking water supply, in this case shallow tubewells mostly in or near their dwelling.[4]

Table 4.1. Cost of arsenic mitigation interventions, 2014

	Deep tubewell	Pond sand filter	Rainwater harvesting	
Capital cost (BDT per unit)*	67,000	50,000	77,000	Shared among 10 households
Capital cost (BDT per household)*	6,700	5,000	7,700	
Useful life (years)*	20	20	20	
Maintenance and repair (BDT per household year)*	100	700	200	
Program promotion (BDT per household per year)*	800	2,000	2,000	First year
	100	150	150	Per follow-up year
Incremental water access time (minutes/day)	5	5	5	

* Adapted and inflation adjusted from UNICEF (2011). Source: Produced by the author.

[4] 71-75% of households in Bangladesh have water on premises (BBS/UNICEF, 2014; NIPORT et al, 2013).

The largest annualized cost components are capital cost and incremental water access time for deep tubewells and rainwater harvesting. The largest component for pond sand filter is maintenance and repair (table 4.2). The cost of this access time is estimated as 50% of wage rates.

Table 4.2. Annualized cost of arsenic mitigation interventions (BDT per household per year), 2014

	Deep tubewell	Pond sand filter	Rainwater harvesting	Discount rate
Annualized capital cost	437	326	502	3%
	512	382	588	5%
	715	534	822	10%
Annualized program cost	152	281	281	3%
	161	303	303	5%
	185	364	364	10%
Maintenance and repair	100	700	200	
Incremental water access time	473	473	473	

Source: Produced by the author.

The total annualized intervention cost per household per year is on the order of BDT 1,200-1,500 for deep tubewells, BDT 1,800-2,100 for pond sand filter, and BDT 1,500-1,900 for rainwater harvesting systems, using discount rates from 3-10% (table 4.3).

Table 4.3.Total annualized cost of arsenic mitigation interventions (BDT per household per year), 2014

Discount rate	Deep tubewell	Pond sand filter	Rainwater harvesting
3%	1,162	1,780	1,456
5%	1,246	1,858	1,564
10%	1,474	2,070	1,859

Source: Produced by the author.

Sanitation interventions

The cost of on-site household sanitation facilities varies tremendously depending on type, quality and durability of the facilities. In a Community Led Total Sanitation (CLTS) program in Bangladesh very basic latrines were reported to cost as little as BDT 1,200 (US$17.4) per latrine, plus about BDT 500 (US$ 7) in CLTL program cost per household, and BDT 350 (US$ 5) per latrine per year in operating cost.[5] However, these latrines did not always meet WHO/UNICEF's JMP's definition of an improved sanitation facility. More expensive latrines built within the project area cost up to BDT 2,200 (WSP, 2010). In a nationwide total sanitation campaign, latrines have been reported to cost from BDT 350 to BDT 3,500 (Accenture, 2012). More recently, resulting from sanitation marketing is the availability of multiple on-site household sanitation solutions made by local entrepreneurs that range in cost from

[5] These costs were during the study period 2004-2008 of the CLTS program.

BDT 1,600 (US$20) to BDT 20,000 (US$ 250), often available on an installment payment plan of 10-12 months. An example is an improved, twin pit off-set latrine complete with handwashing facilities for BDT 6,500 (WSP, 2013).

A cost of BDT 7,000 per improved household sanitation facility has been applied in this paper for the year 2014. Two household sanitation situations are assessed:

The first situation is a single household that currently has a non-shared unimproved sanitation facility and will upgrade to an improved non-shared facility. The second situations are 3 households (HH) currently sharing 1 facility and 2 of these households will have an improved facility constructed so that each household will have 1 non-shared facility.

In the situation of 3 households currently sharing 1 facility, the intervention cost is 2 times the cost per household. Costs are presented in table 4.4.

Table 4.4. Cost of sanitation interventions, 2014

	From non-shared unimproved to non-shared improved facility (1 HH)	From shared to non-shared improved facility (3 HHs)
Capital cost per household (BDT)	7,000	7,000
Capital cost per intervention (BDT)	7,000	14,000
Useful life (years)	15	15
Operations and maintenance cost (BDT per intervention per year)	350	700
Initial program cost (BDT per intervention)	500	1,000

Source: Produced by the author.

The largest annualized cost component is capital cost followed by operations and maintenance at about half of capital cost (table 4.5).

Table 4.5. Annualized cost of sanitation interventions (BDT per intervention per year), 2014

	From non-shared unimproved to non-shared improved facility (1 HH)	From shared to non-shared improved facility (3 HHs)	Discount rate
Annualized capital cost	586	1,173	3%
	674	1,349	5%
	920	1,841	10%
Annualized program cost	42	84	3%
	48	96	5%
	66	131	10%
Operations and maintenance cost	350	700	

Source: Produced by the author.

The total annualized intervention cost is on the order of BDT 1,000-1,300 per year for a single household and BDT 2,000-2,700 for the situation in which 3 households currently share 1 facility, using discount rates from 3-10% (table 4.6).

Table 4.6.Total annualized cost of sanitation interventions (BDT per intervention per year), 2014

Discount rate	From non-shared unimproved to non-shared improved facility (1 HH)	From shared to non-shared improved facility (3HHs)
3%	978	1,956
5%	1,073	2,145
10%	1,336	2,672

Source: Produced by the author.

Handwashing with soap

Improvement in handwashing practices - i.e., handwashing with soap at critical junctures such as before food preparation, before eating and feeding a child, after going to the toilet, before cleaning a child – involves an increase in use of time, water, and soap and time. All three components have a cost. Time has an opportunity cost, here valued at 50% of wage rates. Water and soap needs to be purchased, or time has to be spent on fetching water.

Unit private costs of handwashing with soap are presented in table 4.7 and annual private and public cost per person in table 4.8. The largest cost components are soap and time consumption. Time consumption is assumed to be 3 minutes per person per day. This implies ½ to 1 minute per hand washing session, including time of walking back and forth to place of handwashing. Water is assumed to cost BDT 25 per m^3. Thus on an annual basis, cost of water for handwashing is 5% of total private cost of BDT 715 per person per year (table 4.8).[6]

Additional cost of improvement in handwashing is a public promotion program. Handwashing promotion programs often targets mothers with children under five years of age as this is the age group most susceptible and vulnerable to diarrheal infections. The cost of a program is assumed to be BDT 500 per person, or the same as per household for improved sanitation. It is further assumed that the improvement in handwashing is fully sustained for 3 years. This is the period of time for the average child targeted by the program to surpass five years of age. Thus annualized promotion cost is BDT 184 with a discount rate of 5%.[7]

[6] The water cost of BDT 25 per m^3 (or BDT 37 per person per year) is equivalent to the time cost of spending 2 minutes on fetching 20 liters of free water.

[7] Annualized promotion cost is BDT 177 with a discount rate of 3% and BDT 201 with a discount rate of 10%. Thus the discount rate has minimal effect on total cost.

The program promotion cost is here allocated to the cost of protecting young children by promoting handwashing with soap to their mothers. However, household members other than the mother of the young child may also improve their handwashing practices and thus benefit from the promotion program at no additional public cost. Thus total annualized cost per person is BDT 899 for children under five years of age and BDT 715 for the population five years and above (table 4.8).

Table 4.7. Quantities and unit private costs of handwashing with soap, 2014

	Unit	Per person	Unit	Value
Increased water use for improved hand washing	Liters/day	4	BDT/m^3	25
Soap consumption	Soaps/month	1	BDT/soap	25
Time used for hand washing	Minutes/day	3	BDT/hour	21

Source: Assumptions by the author.

Table 4.8. Annual cost of handwashing with soap (BDT per person), 2014

	For children under 5 years of age	**Population 5+ years of age**
Increased water use for improved hand washing	37	37
Soap consumption	300	300
Time used for hand washing	379	379
Total private cost	715	715
Annualized program promotion cost	184	0
Total annualized cost	**899**	**715**

Source: Estimates by the author.

Benefit-cost ratios

Valuation of health benefits

The interventions are unlikely to instantaneously provide full benefits for health outcomes that develop over long periods of exposure such as from arsenic exposure. It is therefore assumed that the health benefits of arsenic mitigation are gradually realized over ten years. This means that over a time horizon of 20 years annualized health benefits are 65-75% of full benefits, i.e., of the estimated health benefits presented in section 3.[8]

For infectious diseases associated with sanitation and hygiene full health benefits of interventions are realized in the same year the intervention is implemented.

Avoided deaths and illness from the interventions can be monetized by using various benefit valuation measures. The Copenhagen Consensus Center (CCC) has suggested to apply a value of GDP per capita per avoided "disability adjusted life year" or DALY.

[8] Discount rate is 3 to 10%.

A common alternative approach that attempts to reflect how much people are willing to pay to reduce the risk of death is the use of the so-called value of statistical life (VSL) for valuation of avoided deaths.

A VSL of BDT 4.8 million (US$ 61,672) is estimated for Bangladesh for the year 2014 in this paper (annex 3), equivalent to 50 times GDP per capita. Along with valuation of a day of illness at 50% of wage rates in Bangladesh, this approach results in estimated health benefits for arsenic mitigation and sanitation and hygiene interventions that respectively are 2.1 and 1.2 times larger than when using GDP per capita for a DALY.[9] Health benefits using both approaches are presented in this paper.

Benefits and costs of arsenic mitigation

Benefits and costs of interventions are compared by using their ratio. Thus a benefit-cost ratio (BCR) greater than one indicates that benefits exceed costs. The ratio can be calculated as the present value of benefits over the present value of costs, or as annualized benefits over annualized costs. Discount rates of 3%, 5% and 10% are used in the calculations. BCRs using a discount rate of 5% are presented here, and with all three discount rates in annex 4.

Two health benefit valuation scenarios are presented. Valuation of health benefits using VSL is denoted as "high" and GDP per capita for a DALY as "low".

Annualized benefits per household of the three arsenic exposure mitigation interventions range from about BDT 21,000-46,000 for "high" valuation of health effects and BDT 10,000-21,000 for "low" valuation of health effects. The range reflects arsenic exposure levels from 10-50 µg/liter to > 150 µg/liter (see annex 4).

BCRs of the three interventions are presented in tables 5.1-2. The BCRs are largest for households exposed to arsenic concentrations exceeding 150 µg/liter (150 ppb), but also very substantial for households exposed to arsenic concentrations of 10-50 µg/liter (10-50 ppb), which are as many people as exposed to levels > 50 µg/liter. And BCRs for "high" are about twice as large as for "low".

The BCRs are highest for deep tubewells followed by rainwater harvesting and pond sand filter. On average, across all exposure concentrations (i.e., > 10 µg/liter), the BCRs for deep tubewells are 19 and 9 for "high" and "low" valuation of health benefits, respectively. The average BCR for rainwater harvesting and pond sand filter is 15 and 7 for "high" and "low", respectively. Thus from an economic and health perspective, deep tubewell is the preferred option for the 39 million exposed to arsenic in drinking water above the WHO guideline. It is also the option that generally requires least

[9] The difference is much smaller for sanitation and hygiene interventions than for arsenic mitigation because the number of DALYs per death from infectious diseases is much larger the number of DALYs per death from arsenic.

maintenance, has the lowest risk of bacteriological contamination, and is likely to be the most reliable options in both the dry and rainy season. However, there may be locations where deep tubewells cannot satisfactorily replace shallow tubewells with arsenic, and communities may choose to opt for pond sand filter or rainwater harvesting.

Table 5.1 Benefit-cost ratios of arsenic mitigation interventions, 2014 ("High")

Arsenic exposure (μg/liter)	**Deep tubewell**	**Pond sand filter**	**Rainwater harvesting**
>150	35	25	29
>50	22	15	18
>10	19	13	16

Note: The BCRs in this table reflect a discount rate of 5%. BCRs with a range of discount rates are presented in Annex 4. Source: Estimates by the author.

Table 5.2 Benefit-cost ratios of arsenic mitigation interventions, 2014 ("Low")

Arsenic exposure (μg/liter)	**Deep tubewell**	**Pond sand filter**	**Rainwater harvesting**
>150	17	12	14
>50	10	7	8
>10	9	6	7

Note: The BCRs in this table reflect a discount rate of 5%. BCRs with a range of discount rates are presented in Annex 4. Source: Estimates by the author.

Benefits and costs of sanitation interventions

BCRs of the three sanitation interventions are presented in table 5.3 for two health benefit valuation scenarios. Valuation of health benefits using VSL is denoted as "VSL" and GDP per capita for a DALY as "low". The BCRs range from 1.4 to 2.3. BCRs for "high" are about 10 percent larger as for "low".

The BCRs are highest for the situations with households currently sharing a sanitation facility. This is because these households will benefit from time savings of each getting a non-shared facility.

Annualized benefits range from about BDT 1,500-1,800 for the single household (HH) intervention to BDT 4,500-5,000 for the intervention involving 3 households. Time savings benefits are 45-50% of total benefits for the situations in which households currently share a sanitation facility.

Table 5.3 Benefit-cost ratios of household sanitation interventions, 2014

	"High"	"Low"
From unimproved to improved facility (1 HH)	1.7	1.4
From shared to non-shared improved facility (3 HHs)	2.3	2.1

Note: The BCRs in this table reflect a discount rate of 5%. BCRs with a range of discount rates are presented in annex 4. Source: Estimates by the author.

Benefits and costs of handwashing with soap

BCRs of handwashing with soap for the protection of the health of young children and for the population of age five years and above are presented in table 5.4 for two health benefit valuation scenarios. Valuation of health benefits using VSL is denoted as "highVSL" and GDP per capita for a DALY as "lowDALY". BCRs for "highVSL" are lower than for "lowDALY" for children under five. This is because the high number of DALYs lost per death of a child.

Annualized benefits are BDT 960-1,200 per young children (including the benefit to the mother of improved handwashing), and BDT 130-220 per person aged five years and above. This reflects the substantially higher diarrheal disease burden among young children prior to handwashing intervention, and thus larger benefit of intervention. In view of the intervention cost presented in the previous section, the BCRs are therefore only slightly above 1 for young children (1.05-1.35), and 0.2 – 0.3 for the population of age five years and above.

Table 5.4. Benefit-cost ratios of handwashing with soap, 2014

	Children Under 5 Years			Population Over 5 Years		
Health valuation method	3%	5%	10%	3%	5%	10%
VSL	1.08	1.07	1.05	0.31	0.31	0.31
DALY	1.35	1.34	1.31	0.18	0.18	0.18

Source: Estimates by the author.

Summary and conclusions

As many as 98% of the population in Bangladesh have access to an improved drinking water source. This is a tremendous achievement at Bangladesh's income level. It was, however, discovered that many of the tubewells were contaminated by arsenic, a problem affecting 25% of households with concentrations above the WHO guideline.

Bangladesh has also made huge strides in sanitation. Open defecation has almost been eradicated, down from 34% of the population in 1990. And there has been a substantial increase in improved, non-shared facilities, but also a substantial increase in households sharing facilities. Thus in 2015, 61% of the population had access to improved non-shared sanitation while 28% shared facilities with other households.

The single most effective hygiene practice is regular handwashing with soap. Albeit somewhat higher than regional averages in low- and middle-income countries, 7 studies indicate that only about 18% of the population in Bangladesh practice handwashing with soap (Freeman et al, 2014).

On the basis of this situation, this paper assesses the benefits and costs of arsenic mitigation, improved sanitation and regular handwashing with soap. It finds that as many as 45-63 thousand people die prematurely each year due to arsenic in drinking water in Bangladesh, of which almost all can be avoided by the interventions assessed in this paper. The paper also finds that around 11 thousand deaths can be avoided from improved sanitation and handwashing with soap.

The three arsenic mitigation interventions – deep tubewells, pond sand filter, and rainwater harvesting – are found to provide health benefits that are 6 – 35 times higher than the cost of the interventions, depending on arsenic concentrations and method of valuation of health benefits.

The BCRs are highest for deep tubewells followed by rainwater harvesting and pond sand filter. Thus from an economic and health perspective, deep tubewell is the preferred option. It is also the option that generally requires least maintenance, has the lowest risk of bacteriological contamination, and is likely to be the most reliable options in both the dry and rainy season. However, there may be locations where deep tubewells cannot satisfactorily replace shallow tubewells with arsenic, and communities may choose to opt for pond sand filter or rainwater harvesting.

The two sanitation interventions – improved sanitation for households currently with unimproved facilities and non-shared improved sanitation for households currently sharing a facility with other households – provide benefits that are 1.4 – 2.3 times higher than the costs. These benefits do not include intangible benefits such as status and comfort, which are more difficult to estimate.

And the regular handwashing with soap provides benefits that are 1.05 – 1.35 higher than costs for mothers and young children, but only 1/4th of costs for older children and other adults.

The relatively low benefit-cost ratios of improved sanitation and handwashing with soap mainly reflect two basic realities. Firstly, Bangladesh has achieved substantial reductions in child mortality and diarrheal case fatality rates. This lowers the health benefits of the interventions. Secondly, the valuation of the health benefits is proportional to the country's income level in order to be realistic about affordability. The monetized benefits are therefore relatively low, as GDP per capita in Bangladesh was about US$ 1,330 in 2014.

The main conclusion of the assessment in this paper is the very high benefits relative to costs of combatting exposure to arsenic in drinking water. This is not only the case for households exposed to concentration levels above the Bangladeshi standard of 50 ppb, but also for households exposed to concentrations as low as the WHO guideline of 10 ppb. The BCRs are highest for deep tubewells which from an economic and health perspective is the preferred option wherever they suitably can be implemented.

References

Accenture. 2012. Bangladesh Market Assessment – Sector Mapping. Global Alliance for Clean Cookstoves.

Argos, M., Kalra, T., Rathouz, P., Chen, Y., et al. 2010. Arsenic exposure from drinking water, and all-cause and chronic-disease mortalities in Bangladesh (HEALS): a prospective cohort study. *Lancet,* 376: 252-58.

Argos, M., Kalra, T., Pierce, B., Chen, Y., et al. 2011. A prospective study of arsenic exposure from drinking water and incidence of skin lesions in Bangladesh. *Am J Epidemiol,* 174(2): 185-94.

Argos, M., Parvez, F., Rahman, M., et al. 2014. Arsenic and skin lesion status in relation to malignant and non-malignant lung disease mortality in Bangladeshi adults. *Epidemiology,* 25(4): 536-43.

BBS/UNICEF. 2014. Bangladesh Multiple Indicator Cluster Survey 2012-13. Final Report. Bangladesh Bureau of Statistics (BBS) and UNICEF Bangladesh. Dhaka, Bangladesh.

BBS/UNICEF. 2010. Bangladesh Multiple Indicator Cluster Survey 2009. Final Report. Bangladesh Bureau of Statistics (BBS) and UNICEF Bangladesh. Dhaka, Bangladesh.

BBS/UNICEF. 2007. Bangladesh Multiple Indicator Cluster Survey 2006. Final Report. Bangladesh Bureau of Statistics (BBS) and UNICEF Bangladesh. Dhaka, Bangladesh.

Black, R., Allen, L., Bhutta, Z., et al. 2008. Maternal and child undernutrition: global and regional exposures and health consequences. *Lancet,* 371: 243-60.

Brinkel, J., Khan, M.H. and Kraemer, A. 2009. A systematic review of arsenic exposure and its social and mental health effects with special reference to Bangladesh. *Int. J. Eviron. Res. Public Health,* 6: 1609-19.

Cairncross, S., Hunt, C., Boisson, S., et al. 2010. Water, sanitation and hygiene for preventing diarrhoea. *Int J. Epidemiology,* 39: i193-i205.

Chen, Y., Graziano, J., Parvez, F., Liu, M., et al. 2011. Arsenic exposure from drinking water and mortality from cardiovascular disease in Bangladesh: a prospective cohort study. *British Medical Journal*, 342:d2431.

Curtis, V., and S. Cairncross. 2003. Effect of Washing Hands with Soap on Diarrhoea Risk in the Community: A Systematic Review. *The Lancet Infectious Diseases* 3:275-81.

Ejemot, RI., Ehiri, JE., Meremikwu, MM., and Critchley, JA. 2009. Handwashing for preventing diarrhea (Review). *The Cochrane Library,* Issue 3.

FAO, UNICEF, WHO and WSP. 2010. Towards an arsenic safe environment in Bangladesh. A joint publication by the Food and Agriculture Organization, UNICEF, World Health Organization and the Water and Sanitation Programme.

Fewtrell, L., A. Prüss-Üstün, R. Bos, F. Gore, and J. Bartram. 2007. Water, Sanitation and Hygiene: Quantifying the Health Impact at National and Local Levels in Countries with Incomplete Water

Supply and Sanitation Coverage. *Environmental Burden of Disease Series* 15. Geneva: World Health Organization.

Fewtrell, L., R.B. Kaufmann, D. Kay, W. Enanoria, L. Haller, and J.M. Colford. 2005. Water, Sanitation and Hygiene Interventions to Reduce Diarrhea in Less Developed countries: a systematic review and meta-analysis. *The Lancet Infectious Diseases* 5:42-52.

Fewtrell, L., Kaufmann, R., and Pruss-Ustun, A. 2003. Lead: assessing the environmental burden of disease at national and local levels. *Environmental Burden of Disease Series, No.2.* WHO, Geneva.

Fishman, M.S., L.E. Caulfield, M. De Onis, M. Blossner, A.A. Hyder, L. Mullany, and R.E. Black. 2004. Childhood and Maternal Underweight. In Ezzati, M., A.D. Lopez, A. Rodgers, and C.J.L. Murray (Eds): *Comparative Quantification of Health Risks – Global and Regional Burden of Disease Attributable to Selected Major Risk Factors*. Vol. 1. Geneva: World Health Organization.

Freeman, M., Stocks, M., Cumming, O., et al. 2014. Hygiene and health: Systematic review of handwasing practices worldwide and update of health effects. *Trop Med Int Health,* 19: 906-16.

Gakidou, E., Oza, S., Fuertes, CV., et al. 2007. Improving child survival through environmental and nutritional interventions. *Journal of the American Medical Association*, 298(16): 1876-87.

Karagas, M., Gossai, A., Pierce, B., and Ahsan, H. 2015. Drinking water arsenic contamination, skin lesions, and malignancies: A systematic review of the global evidence. *Curr Envir Hlth Rpt*, 2: 52-68.

Larsen, B., 2007. Cost of environmental health risk in children under five years of age: Accounting for malnutrition in Ghana and Pakistan. Background report prepared for the World Bank. Environment Department, World Bank.

Lim, S.S., Vos, T., Flaxman, A.D., Danaei, G., et al. 2012. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet,* 380: 2224-60.

Lindhjem, H., Narvud, S., Braathen, N.A., and Biausque, V. 2011. Valuing mortality risk reductions from environmental, transport, and health policies: A global meta-analysis of stated preference studies. *Risk Analysis,* 31(9): 1381-1407.

Navrud, S. and Lindhjem, H. 2010. Meta-analysis of stated preference VSL studies: Further model sensitivity and benefit transfer issues. Prepared for the Environment Directorate, OECD.

NIPORT, Mitra Assoc., and ICF Int. 2013. Bangladesh Demographic and Health Survey 2011. Dhaka, Bangladesh and Calverton, Maryland, USA.

NIPORT, Mitra Assoc., and Macro Int. 2009. Bangladesh Demographic and Health Survey 2007. Dhaka, Bangladesh and Calverton, Maryland, USA.

Pruss-Ustun, A., Bartram, J., Clasen, T., Colford, J., et al 2014. Burden of disease from inadequate water, sanitation and hygiene in low- and middle-income settings: a retrospective analysis of data from 145 countries. *Trop Med Int Health,* 19: 894-905.

Pruss-Ustun, A., Kay, D., Fewtrell, L., and Bartram, J., 2004. Unsafe water, sanitation and hygiene. In: Ezzati, M. et al. (eds): Comparative quantification of health risks: global and regional burden of disease attributable to selected major risk factors. World Health Organization. Geneva.

Pruss, A., Kay, D., Fewtrell, L., and Bartram, J.,2002. Estimating the Burden of Disease from Water, Sanitation and Hygiene at the Global Level. *Environmental Health Perspectives*, 110(5):537-42.

Rabie, T. and Curtis, V. 2006. Handwashing and risk of respiratory infections: a quantitative systematic review. *Tropical Medicine and International Health*, 11(3): 258-67.

Rahman, M., Sohel, N., Yunus, M., Chowdhury, M.E., et al. 2014. A prospective cohort study of stroke mortality and arsenic in drinking water in Bangladeshi adults. *BMC Public Health,* 14:174.

Rahman, M., Sohel, N., Yunus, M., Chowdhury, M.E., et al. 2013. Increased childhood mortality and arsenic in drinking water in Matlab, Bangladesh: A population-based cohort study. *PLOS ONE,* 8(1): e55014.

Sohel, N., Persson, LA., Rahman, M., Streatfield, PK., Yunus, M., Ekström, EC., Vahter, M. 2009. Arsenic in drinking water and adult mortality: a population-based cohort study in rural Bangladesh. *Epidemiology*, 20(6):824-30.

Tyler, C., and Allan, A. 2014. The effects of arsenic exposure on neurological and cognitive dysfunction in human and rodent studies: A review. *Curr Envir Health Rpt,* 1: 132-47.

UNICEF. 2011. Making economic sense for arsenic mitigation: A case study of Comilla District, Bangladesh.

Waddington, H., Snilstveit, B., White, H., and Fewtrell, L. 2009. Water, sanitation and hygiene interventions to combat childhood diarrhoea in developing countries. Synthetic Review 001. International Initiative for Impact Evaluation (3ie).

WHO/UNICEF. 2015. Bangladesh: Estimates on the use of water sources and sanitation facilities. Joint Monitoring Programme for Water Supply and Sanitation (JMP). Update June 2015. www.wssinfo.org

WHO. 2009. Estimated deaths and DALYs attributable to selected environmental risk factors, by WHO member states, 2004. World Health Organization. *Downloadable at:*

http://www.who.int/quantifying_ehimpacts/national/countryprofile/intro/en/index.html

WHO. 2004. Comparative quantification of health risks: Global and regional burden of disease attributable to selected major risk factors. World Health Organization. Geneva, Switzerland.

World Bank. 2015. World Development Indicators. World Bank. Washington DC. USA.

World Bank. 2008. Environmental health and child survival: Epidemiology, economics, experiences. Washington, DC: World Bank.

WSP. 2013. Making sanitation marketing work: The Bangladesh story. Water and Sanitation Program, World Bank.

WSP. 2010. Financing on-site sanitation for the poor: A six country comparative review and analysis. Water and Sanitation Program, World Bank.

Ziegelbauer, K., Speich, B., Mausezahl, D., Bos, R., Keiser, J., and Utzinger, J. 2012. Effect of sanitation and soil-transmitted helminth infection: Systematic review and meta-analysis. *PLOS Medicine,* 9(1): e1001162.

Annex 1. Health effects from water, sanitation and hygiene

Inadequate water, sanitation and hygiene (WASH) is directly and indirectly affecting population health. Directly, poor WASH causes diarrheal infections and other health effects which in turn lead to mortality especially in young children. Indirectly, poor WASH contributes to poor nutritional status in young children through the effect of diarrheal infections (World Bank, 2008; Fewtrell et al, 2007; Larsen, 2007).[10] Poor nutritional status in turn increases the risk of child mortality from disease (Fishman et al., 2004; Black et al, 2008). Child underweight is the nutritional indicator most commonly used in assessing the risk of mortality from poor nutritional status (Fishman et al, 2004).

Direct effect

Pruss-Ustun et al (2014), based on a global review, presents a methodology for estimating the diarrheal disease burden from inadequate WASH, or that can be expected to be prevented from improved WASH. For drinking water, the preventable disease burden is estimated in relation to piped water supply to dwelling or yard combined with safe point-of-use treatment and drinking water storage. For sanitation, a distinction is only made between unimproved and improved sanitation facilities as studies of health risks of other sanitation dimensions are insufficient. For hygiene, the focus is on handwashing with soap. The relative risks of disease from unimproved sanitation and lack of adequate handwashing with soap are presented in table A1.1.

Table A1.1. Relative risk of diarrheal disease and mortality from sanitation and hygiene

	Relative risk of diarrheal disease (RR)
Unimproved sanitation (vs. improved sanitation)	1.39
Lack of adequate handwashing with soap	1.30

Source: Based on Pruss-Ustun et al (2014).

The attributable fraction (AF) of diarrheal disease and mortality from unimproved sanitation or lack of adequate handwashing with soap is calculated as follows:

$$AF = \frac{\sum_{i=1}^{n} P_i (RR_i - 1)}{\sum_{i=1}^{n} P_i (RR_i - 1) + 1} \qquad \text{(A1.1)}$$

[10] Repeated infections, and especially diarrheal infections, have been found to significantly impair weight gains in young children. Studies documenting and quantifying this effect have been conducted in communities with a wide range of infection loads in a diverse group of countries. World Bank (2008) provides a review of these studies.

where P_i is the population share with unimproved and improved sanitation, or population share with inadequate and inadequate handwashing with soap, and RR_i is the corresponding relative risks in table A1.1[11]

The joint attributable fraction (AF^J) of disease burden from unimproved sanitation and inadequate handwashing with soap, or preventable disease burden from provision of improved sanitation and adequate handwashing with soap can be approximated as follows:

$$AF^J = 1 - \prod_{k=1}^{n}(1 - AF^k) \quad \text{(A1.2)}$$

where AF^k is the attributable fraction associated with sanitation and handwashing with soap. It should be noted, however, that the joint AF formula as applied here hinges on two key assumptions (Gakidou et al, 2007). First, exposures to the risk factors are uncorrelated and second, that the hazardous effects of one risk factor are not mediated through any of the other risk factors. The formula is nevertheless applied here, as in Pruss-Ustun et al (2014), in the absence of a more suitable approach.

Indirect effect

Estimating the indirect mortality effects of diarrhea from WASH is here undertaken in two stages. First, the fraction of under-five child mortality attributable to child underweight is estimated. This follows the methodology in Black et al (2008). Second, a fraction of under-five child mortality from underweight is attributed to diarrheal infections from WASH in early childhood using the approach in Fewtrell et al (2007).

An alternative approach to estimating the fraction of mortality attributable to diarrheal infections from WASH is the methodology developed in Larsen (2007) and World Bank (2008). This, however, requires estimation of counterfactual prevalence rates of child underweight (prevalence of underweight in the absence of diarrheal infections) from original survey data of child nutritional status. As the original survey data are often not readily available, the approach in Fewtrell et al is here used instead. The approach in Fewtrell et al gives a somewhat lower estimate of indirect mortality from WASH than the Larsen and World Bank methodology.

Estimates of increased risk of cause-specific mortality in children under five years of age with mild, moderate and severe underweight is presented in table A1.2 based on Black et al (2008).

[11] RR=1 for improved sanitation and adequate handwashing with soap.

Table A1.2. Relative risk of mortality from severe, moderate and mild underweight in children under five

	Severe	Moderate	Mild	None
Acute lower respiratory infections (ALRI)	6.4	1.3	1.2	1.0
Diarrhea	9.5	3.4	2.1	1.0
Measles	6.4	2.3	1.3	1.0
Malaria	1.6	1.2	0.8	1.0

Source: Black et al (2008). ALRI is acute lower respiratory infections. Relative risks are in relation to underweight according to the WHO Child Growth Standards.

These relative risk ratios are applied to prevalence rates of child underweight to estimate attributable fractions (AF_j) of mortality by cause, *j*, from child underweight as follows:

$$AF_j = \frac{\sum_{i=1}^{n} P_i (RR_{ji} - 1)}{\sum_{i=1}^{n} P_i (RR_{ji} - 1) + 1} \qquad \text{(A1.3)}$$

where RR_{ji} is relative risk of mortality from cause, *j*, for children in each of the underweight categories, *i*, in table A1.2; and P_i is the underweight prevalence rate.

Annual cases of mortality from child underweight (by cause, "j", in table A1.2) are estimated as follows:

$$M_j = C * U5MR * AF_j \beta_j \qquad \text{(A1.4)}$$

where C is annual live child births in unit of thousands, U5MR is the under-five child mortality rate (per 1,000 live births), and β_j is the fraction of under-five mortality by cause "j".

Annual under-five child mortality from diarrheal infections in early childhood (W) is then estimated as follows:

$$W = \sum_{j=1}^{j=m} \gamma_j M_j \qquad \text{(A1.5)}$$

where γ_j is the fraction of child underweight mortality (M_j) attributed to diarrheal infections in early childhood. A value $\gamma_j = 0.5$ for ALRI, measles, malaria and "other infectious diseases" is applied here based on Fewtrell et al (2007). This is then multiplied by the fraction of diarrheal disease attributed to water, sanitation and hygiene using the methodology in Pruss-Ustun et al (2014), i.e., 0.56 for Bangladesh, to calculate estimated mortality from WASH. The additional indirect effect through child underweight on diarrheal mortality is estimated using a joint attributable fraction formula in Gakidou et al (2007).

Annex 2. Mortality from arsenic in drinking water

Argos et al (2010) assessed the association between arsenic exposure and all-cause mortality among adults of age 18+ years, and Sohel et al (2009) assessed the association between arsenic exposure and all-cause non-accidental mortality among people of age 15+ years. Argos et al used the prospective cohort Health Effects of Arsenic Longitudinal Study (HEALS) data from Araihazar in Bangladesh. Nearly 12,000 population based participants were recruited during October 2000 to May 2002 with an average follow-up of 6.5-6.6 years. Sohel et al studied a population of 115,903 persons in Matlab in Bangladesh from 1991 to 2000.

Estimated hazard ratios from the two studies for all-cause and non-accidental all-cause mortality are presented in table A2.1 in relation to arsenic concentrations in the participants' drinking water.

Table A2.1. Hazard ratios for all-cause and non-accidental all-cause mortality associated with arsenic in drinking water

Arsenic (µg/liter)	Hazard ratio (95% CI)	
	All-cause mortality	Non-accidental all-cause mortality
≤ 10	1.00	1.00
10 - 50	1.34 (0.99-1.82)	1.16 (1.06–1.26)
50 - 150	1.09 (0.81-1.47)	1.26 (1.18–1.36)
> 150	1.68 (1.26-2.23)	1.36 (1.27–1.47)

Note; CI=Confidence Interval. Source: Argos et al (2010) and Sohel et al (2009).

Argos et al estimate the attributable fraction (AF) of all-cause mortality as follows:

$$AF = 1 - \sum_{i=1}^{n} P_i / HR_i \qquad \text{(A2.1)}$$

where P_i is the proportion of all deaths that are within the *i*th arsenic exposure category and HR_i is the hazard ratio in arsenic exposure category *i=1,….4* in table A2.1. Annual cases of mortality (M) from arsenic in drinking water can then be estimated as follows:

$$M = AF * POP * CDR/1000 \qquad \text{(A2.2)}$$

where *POP* is the total population and *CDR* is the crude death rate (per 1,000) among the population.

Annex 3. Valuation of health benefits

Two valuation measures are considered for estimating the benefit of avoided illness is in this paper: i) a day of disease is valued as 50% of average labor income per day; or ii) a year lost to disease (YLD) is valued at GDP per capita as suggested by the Copenhagen Consensus Center (CCC).

Two valuation measures are considered for estimating the benefit of an avoided death in this paper: i) the value of statistical life (VSL); or ii) a year of life lost (YLL) to premature mortality is valued at GDP per capita as suggested by CCC.

A VSL for Bangladesh is estimated based on Navrud and Lindhjem (2010). Navrud and Lindhjem conducted a meta-analysis of VSL studies for OECD based exclusively on stated preference studies which arguably are of greater relevance for valuation of mortality risk from environmental factors than hedonic wage studies. These stated preference studies are from a database of more than 1,000 VSL estimates from multiple studies in over 30 countries, including in developing countries. Navrud and Lindhjem provide an empirically estimated benefit-transfer (BT) function from these stated preference studies that can be applied to estimate VSL in any country or region. A modified BT function with income elasticity of one is applied here:[12]

$$\ln VSL = 0.22 + 1.0\ln(gdp) - 0.445\ln(r) \qquad \text{(A3.1)}$$

where *VSL* is expressed in purchasing power parity (PPP) adjusted dollars; *gdp* is GDP per capita in PPP adjusted dollars; and *r* is the change in risk of mortality.[13] The VSL is then converted to a country's currency by multiplying by the PPP rate as reported in World Bank (2015), which is the ratio "GDP in local currency / PPP adjusted GDP in dollars".

Applying the BT function also involves specifying change in mortality risk (r). The mortality risk from environmental factors depends on the environmental factor at hand. Most stated preference studies of VSL use a mortality risk in the range of 1/10,000 to 5/10,000 per year. A mid-point risk of 2.5/10,000 per year is applied in this paper.

The VSL estimated for Bangladesh for the year 2014 by this methodology is BDT 4.79 million, or about 50 times GDP per capita that year (table A3.1).

Table A3.1 Economic data and VSL for Bangladesh, 2014

GDP per capita	BDT 95,864	Bangladesh Bureau of Statistics
Average monthly wage	BDT 7,307	International Labour Organization
Value of statistical life (VSL)	BDT 4,787,591	Calculated from equation A3.1

[12] A later version of their paper (Lindhjem et al, 2011) reports income elasticities in the range of 0.77 – 0.88 for a screened sample of VSL studies.

[13] This BT function implies that the income elasticity is 1.0, meaning that VSL varies across countries in proportion to their PPP adjusted GDP per capita level.

Annex 4. Benefit-cost ratios

Benefits, costs, and benefit-cost ratios (BCRs) are presented with valuation of health benefits using VSL for mortality ("High") and DALY equal to GDP per capita ("Low").

Arsenic mitigation interventions:

Table A4.1 Benefits and costs of deep tubewells, 2014 (BDT/household/year) ("High")

	3% discount rate			5% discount rate			10% discount rate		
Arsenic exposure (µg/L)	Benefit	Cost	**BCR**	Benefit	Cost	**BCR**	Benefit	Cost	**BCR**
>150	45,953	1,162	**40**	44,162	1,246	**35**	39,803	1,474	**27**
>50	27,988	1,162	**24**	26,897	1,246	**22**	24,242	1,474	**16**
10-50	22,072	1,162	**19**	21,212	1,246	**17**	19,118	1,474	**13**

Source: Estimates by author.

Table A4.2 Benefits and costs of pond sand filters, 2014 (BDT/household/year) ("High")

	3% discount rate			5% discount rate			10% discount rate		
Arsenic exposure (µg/L)	Benefit	Cost	**BCR**	Benefit	Cost	**BCR**	Benefit	Cost	**BCR**
>150	47,849	1,780	27	45,963	1,858	25	41,374	2,070	20
>50	28,937	1,780	16	27,789	1,858	15	24,994	2,070	12
10-50	22,711	1,780	13	21,805	1,858	12	19,601	2,070	9

Source: Estimates by author.

Table A4.3 Benefits and costs of rainwater harvesting, 2014 (BDT/household/year) ("High")

	3% discount rate			5% discount rate			10% discount rate		
Arsenic exposure (µg/L)	Benefit	Cost	**BCR**	Benefit	Cost	**BCR**	Benefit	Cost	**BCR**
>150	47,849	1,456	33	45,963	1,564	29	41,374	1,859	22
>50	28,937	1,456	20	27,789	1,564	18	24,994	1,859	13
10-50	22,711	1,456	16	21,805	1,564	14	19,601	1,859	11

Source: Estimates by author.

Table A4.4 Benefits and costs of deep tubewells, 2014 (BDT/household/year) ("Low")

	3% discount rate			5% discount rate			10% discount rate		
Arsenic exposure (µg/L)	Benefit	Cost	**BCR**	Benefit	Cost	**BCR**	Benefit	Cost	**BCR**
>150	21,736	1,162	19	20,889	1,246	17	18,827	1,474	13
>50	13,238	1,162	11	12,722	1,246	10	11,466	1,474	8
10-50	10,440	1,162	9	10,033	1,246	8	9,043	1,474	6

Source: Estimates by author.

Table A4.5 Benefits and costs of pond sand filters, 2014 (BDT/household/year) ("Low")

	3% discount rate			5% discount rate			10% discount rate		
Arsenic exposure (µg/L)	Benefit	Cost	**BCR**	Benefit	Cost	**BCR**	Benefit	Cost	**BCR**
>150	22,448	1,780	13	21,556	1,858	12	19,385	2,070	9
>50	13,503	1,780	8	12,960	1,858	7	11,638	2,070	6
10-50	10,558	1,780	6	10,129	1,858	5	9,087	2,070	4

Source: Estimates by author.

Table A4.6 Benefits and costs of rainwater harvesting, 2014 (BDT/household/year) ("Low")

	3% discount rate			5% discount rate			10% discount rate		
Arsenic exposure (µg/L)	Benefit	Cost	**BCR**	Benefit	Cost	**BCR**	Benefit	Cost	**BCR**
>150	22,448	1,456	15	21,556	1,564	14	19,385	1,859	10
>50	13,503	1,456	9	12,960	1,564	8	11,638	1,859	6
10-50	10,558	1,456	7	10,129	1,564	6	9,087	1,859	5

Source: Estimates by author.

Sanitation interventions:

Table A4.7 Benefits and costs of household sanitation, 2014 (BDT/intervention/year) ("High")

Intervention	3% discount rate			5% discount rate			10% discount rate		
	Benefit	Cost	**BCR**	Benefit	Cost	**BCR**	Benefit	Cost	BCR
From non-shared unimproved to non-shared improved facility	1,821	978	**1.9**	1,821	1,073	**1.7**	1,821	1,336	**1.4**
From shared to non-shared improved facility (3 HHs)	4,997	1,956	**2.6**	4,997	2,145	2.3	4,997	2,672	**1.9**

Note: HH=household. Source: Estimates by author.

Table A4.8 Benefits and costs of household sanitation, 2014 (BDT/intervention/year) ("Low")

Intervention	3% discount rate			5% discount rate			10% discount rate		
	Benefit	Cost	**BCR**	Benefit	Cost	**BCR**	Benefit	Cost	BCR
From non-shared unimproved to non-shared improved facility	1,503	978	**1.5**	1,503	1,073	**1.4**	1,503	1,336	**1.1**
From shared to non-shared improved facility (3 HHs)	4,532	1,956	**2.3**	4,532	2,145	**2.1**	4,532	2,672	**1.7**

Note: HH=household. Source: Estimates by author.

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